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Editorial Team

The *Journal* is published by The Telecommunications Association (TelSoc), a not-for-profit society registered as an incorporated association. It is the Australian telecommunication industry's oldest learned society. The *Journal* has been published (with various titles) since 1935.

Editorial

The Digital Economy and Cyber Security

Leith H. Campbell
Managing Editor

Abstract: This editorial comes in three parts: some remarks on developing a cyber security architecture for the digital economy; a note on changes to the *Journal*'s editorial team; and a brief introduction to the papers in this issue.

Keywords: Digital economy, Cyber security, Editorial

The Digital Economy and Cyber Security

As I write this editorial, Australia is reeling from the revelation of a security breach at Optus, one of the country's leading telcos. A great deal of personal identity information on Optus customers may have been stolen. About 40% of Australia's population may have been affected in some way and about 10% of the population may have had data used for personal identification (such as passport numbers and driver's licence details) compromised. The full ramifications of the data breach are yet to be made publicly available. Meanwhile, a rather unseemly "debate" about who to blame continues.

This incident brings into stark relief the ubiquity of online services as the basis of a modern economy. Data breaches like this should not occur – but they do occur, both because of human error and because of new technologies or operations that open up unforeseen opportunities for malicious actors. The digital economy makes personal identity data particularly valuable for those who wish to take over others' accounts. Unfortunately, the expansion of the digital economy also expands the opportunities for illegal exploitation. We publish a paper on one such example in this issue (Mauladi, Jaya & Esquivias, 2022).

Personal identity information was being kept by Optus because Australian law requires that the identity of prepaid SIM-card users be verified (ACMA, 2022). This is a common requirement in many countries. It has benefits for law enforcement and to restrict illegal activity via mobile services, but it causes databases of identity information to be kept by telcos

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and other service providers. This, then, creates a potential vulnerability that can be exploited, as in the current incident.

In the general Internet and Web, in contrast to mobile services, identity is a weak concept. It is easy to acquire an email address and build an identity online that bears little relationship with one's real-world identity. This feature can provide benefits for some people. It can allow one to segment one's online activities between different hobbies or businesses, for example; or it can help to isolate unwanted messages from advertisers or social-media platforms. It does, of course, also open up opportunities for fraud.

Trust in identity is important in many instances. Customers need to be sure that they are dealing with legitimate businesses. A business needs to know that a customer can be held liable to pay for delivered goods or services. But, in the real world, there is a large sphere of activity where privacy and anonymity can be maintained and are often expected. Online, however, it is hard to maintain true anonymity – made harder by the dominance of multinational companies, like Google and Facebook, that have built vast businesses on constructing detailed profiles of all users who interact with them. Initiatives that may have led to enhanced privacy and anonymity online, such as Bitcoin, seem largely to have failed.

Now that the digital economy and digital society are so pervasive, governments must take the lead in defining an online identity architecture that is fit for purpose and does not require personal identity data to remain in the hands of private companies where it may be vulnerable to theft, while also maintaining privacy wherever possible.

There are no current off-the-shelf solutions available, but there is progress in some countries. Estonia is recognized as an "e-state" ('e-Estonia', 2022) but its architecture is probably not acceptable in other jurisdictions with a different democratic history. The Indian government has been developing India Stack ("National plumbing for the Internet Age") for more than a decade. It aims "to unlock the economic primitives of identity, data, and payments at population scale" ('India Stack', 2022) and it appears to be succeeding. In the Netherlands, there are a number of proof-of-concept projects on "Self-sovereign identity" ('Self-sovereign identity', 2022), which aims to give a user "control over which personal and other data is shared and with whom". The Australian government has made a start – for example, IDMatch (Australian Government, 2022), which provides for online verification of official documents – but much more is needed. It will require trials in a variety of countries before an acceptable architecture has been discovered – and it will be a challenge in many jurisdictions where governments are not very "cyber aware".

In addition, there will be a need to regulate data *operations* to ensure that data is maintained safely and accurately. We have seen the rise of detailed and far-reaching "health and safety"

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regulation for real-world safety: we need something similar and as pervasive for digital identities and private data. Again, there is a start – see, for example, ACMA (2020) – but much more is needed.

Incidents like the Optus data breach show us that something better is required. It is now time for governments and regulators to step up and provide a "health and safety" framework for the digital society.

New Section Editor

It is a pleasure to announce that Dr Frank den Hartog from the University of New South Wales (UNSW) Canberra has recently taken up the role of Section Editor for Telecommunications. He brings a long history of research in telecommunications, both for industry and academia, to this position. We welcome submissions to the section on all aspects of Telecommunications, including technology, operations and planning.

Dr Michael de Percy, who has been a Section Editor for a number of years, now takes up the role of Section Editor for Public Policy. His new position will strengthen our focus on policy issues and, we hope, lead to a continuing stream of submissions in this area.

In This Issue

Continuing our series of outputs from TelSoc's Broadband Futures Forums, we publish in the Public Policy section a summary of progress in *Regional Connectivity and Shared Infrastructure in NSW and New Zealand* from a Forum held in April 2022.

In the Digital Economy section, we have five papers. Two papers are from Indonesia: *Exploring the Link Between Cashless Society and Cybercrime in Indonesia*; and *Supporting Logistics Management to Anticipate Covid 19 Using the "Retail Direct Order" Concept*. Three papers examine the existing literature to discern themes and to identify gaps: *Technology Acceptance Model (TAM): A Bibliometric Analysis from Inception*; *Digital Marketing Strategies Driven by Wellbeing in Virtual Communities*; and *Mapping Top Strategic E-commerce Technologies in the Digital Marketing Literature*.

In the Telecommunications section, we publish two papers. *Denial-of-Sleep Attack Detection in NB-IoT Using Deep Learning* describes a solution for an issue with IoT devices. *Latency Analysis for Mobile Cellular Network uRLLC Services* examines ultra-reliable, low latency services in future 5G networks.

In the Biography section, we publish an obituary of Rollo Brett, who had been an influential head of the PMG Research Laboratories and had held a number of other senior positions in Telecom Australia.

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As always, we encourage you to consider submitting articles to the *Journal* and we welcome comments and suggestions on which topics or special issues would be of interest.

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The Broadband Futures Forum

Regional Connectivity and Shared Infrastructure in NSW and New Zealand

Peter Adams
Director, NSW Regional Digital Connectivity Program

Steve Inglis
Crown Infrastructure Partners

John Proctor
CEO, Rural Connectivity Group

Abstract: On 13 April 2022, TelSoc hosted the thirteenth Broadband Futures Forum, held online, to describe the initiatives in New South Wales, Australia, and New Zealand for greater regional availability of broadband access and the implementation of shared infrastructure in regional areas. There were three speakers: one speaker from New South Wales on the trials and plans in that State; and two speakers from New Zealand on the government actions and commercial response to provide broadband services in otherwise unserved areas. Discussion after the presentations probed details of each initiative and expanded comparisons between the two countries' approaches.

Keywords: Broadband, regional connectivity, shared infrastructure

Introduction

The Broadband Futures Project (Holmes & Campbell, 2019) has been organizing a series of public forums under the title Broadband Futures to encourage debate, and potentially to build consensus, about the future of Australia's National Broadband Network (NBN) and a National Broadband Strategy for Australia (Holmes *et al.*, 2020). The forums are hosted by TelSoc (the Telecommunications Association Inc., publisher of this *Journal*) and have been held regularly since July 2019.[i] The thirteenth in the series, held on 13 April 2022, was entitled "Regional Connectivity and Shared Infrastructure: NSW and New Zealand" and provided an overview of new initiatives in New South Wales (Australia) and New Zealand on the expansion of regional broadband access and the shared infrastructure that supports it.

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The remainder of this paper summarizes the content of the Forum.

The NBN Futures Forum

The Forum was conducted online via Zoom, with at least 32 participants online. Dr Murray Milner from the TelSoc Broadband Futures Group chaired the Forum.

He noted the timeliness of the Forum. The Australian Government had just published its response to the Regional Telecommunications Review conducted in 2021. Recommendation 10 of that review had proposed that government give preference in funding to mobile towers and other infrastructure that provided shared network access. In response, the Government had said that it would seek a neutral-host solution for funding under the Connecting Rural Australia initiative and would draw lessons from international experience, including comparisons with New Zealand.

NSW Regional Digital Connectivity Program

Peter Adams began by noting that the NSW Regional Digital Connectivity program is based on a 20-year economic vision for regional New South Wales (NSW), last updated in February 2021 (NSW Government, 2021). The vision gave special mention to digital infrastructure, to lift productivity and growth, and to technology-enabled primary industries. He indicated that the emphasis in telecommunications provision was in rural and remote underserved areas of the State. The Regional Digital Connectivity Program has funding of AUD 400 million, as part of a larger program to invest in transformational and economically productive infrastructure, plus other ongoing initiatives. The two main budget items are:

- $300M for mobile coverage, to improve mobile connectivity where people live and work. Peter Adams noted that this funding is additional to the Commonwealth support for overcoming mobile blackspots.
- $100M for a “Gig State” initiative to bring metro-level Internet service and pricing to regional NSW.

Because the funding for additional mobile coverage is comparable to the Commonwealth support, it was decided to use the first $50M to undertake some trials with industry to gather data for a full business case for the remaining funds. There are four trials to begin later in 2022 and run for about four months: on MORAN (Multi-Operator Radio Access Network (RAN)); on MOCN (Multi-Operator Core Network); on Open RAN; and on domestic roaming. The aim will be to develop a suite of commercial and technical frameworks suitable for the variety of rural, regional, and remote circumstances in NSW. Where possible, there will be alignment with support for emergency services communications.

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The "Gig State" initiative is primarily about Internet access and backhaul. There are 131,000 premises in NSW whose only option for Internet access is via satellite. Providing alternatives for these premises through Fixed Wireless Access (FWA) or, potentially, a more modern LEO service is a priority. The total funding will not be sufficient for all these services: if they each could have been connected for $5,000 or less, they would likely have been connected to FWA by the National Broadband Network. The total cost of improved connectivity would therefore be above $650M and probably much more. There had also been an initial challenge in that the funding had been profiled as a capital investment by NSW Treasury. This has since been changed to operational expenditure, meaning that direct grants programs can be run.

There are two initiatives currently underway. One is to move premises west of Cobar onto FWA. The other is a trial in a hilly and rocky area near Queanbeyan to explore cost-effective distributed designs.

The NSW Government had made a submission to the Commonwealth's Regional Telecommunications Review 2021. The NSW Government's recommendations were clustered in three areas: the need for sharing of infrastructure co-funded by government; the availability of radio spectrum for States or Territories; and the need for industry to flatten their backhaul and business Internet pricing.

The industry is now moving in a direction that is compatible with what the governments are trying to achieve. The sale of mobile towers by Optus and Telstra means that there are tower operators who can service the industry as a whole. The Commonwealth is trialling a "neutral host" mobile delivery model with industry. Open RAN technologies are being developed. These all support a sharing model for government-funded infrastructure.

After the announcement of the Regional Digital Connectivity program, there have been some beneficial responses by the telecommunications industry:

- NBN Business Fibre Zones are being established. They deliver metropolitan prices for fibre access in regional areas.
- Backhaul prices have dropped significantly. There are areas in which prices are now 15–20% of what they were one or two years ago.
- Nine regional data centres are being built in NSW and a further nine have been announced.

The Stage 1 trials for the Mobile Coverage Program are based on prioritising competition and collaboration over single-operator coverage outcomes and seek to address any perceived barriers to participation by the private sector. Stage 1 will identify appropriate technical solutions, delivery models and commercial arrangements: these will be identified and signed off by the industry partners participating in the trials. The following $250M main round will

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then use the learnings from Stage 1 to deliver transformative models for mobile coverage in rural and regional NSW.

In addition to the programs described above, there is also a "Farms of the Future" program that is designed to accelerate the adoption of agricultural technologies by NSW farm businesses. The program has five pilot regions targeting NSW's highest grossing agricultural sectors. There are three core streams: connectivity to improve backhaul in pilot regions; education and capacity building to improve understanding of the benefits of ag-tech; and grants to subsidise the cost of devices to stimulate uptake.

The NSW Government will continue to cooperate with the Commonwealth Government on regional connectivity programs and the Mobile Blackspots Program. In addition, the NSW program is responding to short-term coverage needs: for example, it is improving mobile coverage on the Snowy Mountains Highway for safety reasons in the light of increased construction traffic on the road.

Rural Coverage in New Zealand using Shared Cellular sites

Steve Inglis and John Proctor presented this section of the Forum.

The New Zealand Government had set an aspirational goal that, by 2025, 99% of New Zealanders should be able to access broadband at peak speeds of at least 50 Mbps and the remaining 1% should be able to access at least 10 Mbps. To date, about 86% of premises have fibre access and, of these, 68% are taking broadband service at 1 Gbps or greater.

The Government has now embarked on a Rural Broadband Initiative, phase 2, (RBI2) since 2016 to provide high-speed broadband access to the greatest number of rural end-users within the available funding; and to do so by providing similar high-speed broadband access across all regions of rural New Zealand. Eligible end-users are those with terrestrial access to only 20 Mbps peak rate, or less, and who are not in the footprint of fibre, VDSL or 4G wireless broadband. Service providers to be supported under RBI2 must commit to being able to provide an HD video stream and two other less onerous applications in parallel without significant buffering.

There is also a Mobile Black Spots Fund (MBSF) to improve availability of mobile services along State Highways and at key tourist destinations. Unlike the Australian program, the Fund does not currently support the provision of mobile services to communities in general. Eligible locations must otherwise have no mobile service. The Fund supports a minimum level of voice, text and data service. All new towers have 4G radios. However, where there is a need for health and safety coverage (e.g., long stretches of highway or remote track ends), an overlay of 3G is added to maximise the number of compatible devices that can access emergency services.

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Segments of State Highways were ranked in priority by traffic volume, distance to existing coverage, and the frequency of emergencies. Tourism destinations were ranked by visitor numbers.

For RBI2 and MBSF together, a budget of NZ$150M was provided from a telecommunications industry levy. The Government had requested information from local Councils in 2015 and had compiled a long list of possible candidate areas for support.

Crown Infrastructure Partners undertook a detailed data analysis exercise, including coverage data from mobile service providers, to compile the final list of initiatives to be supported. A request for proposals was issued in October 2016, with responses due by February 2017 (somewhat delayed by a large earthquake). After an evaluation of commercial, technical and geospatial aspects had been completed, contracts for service provision were announced in August 2017.

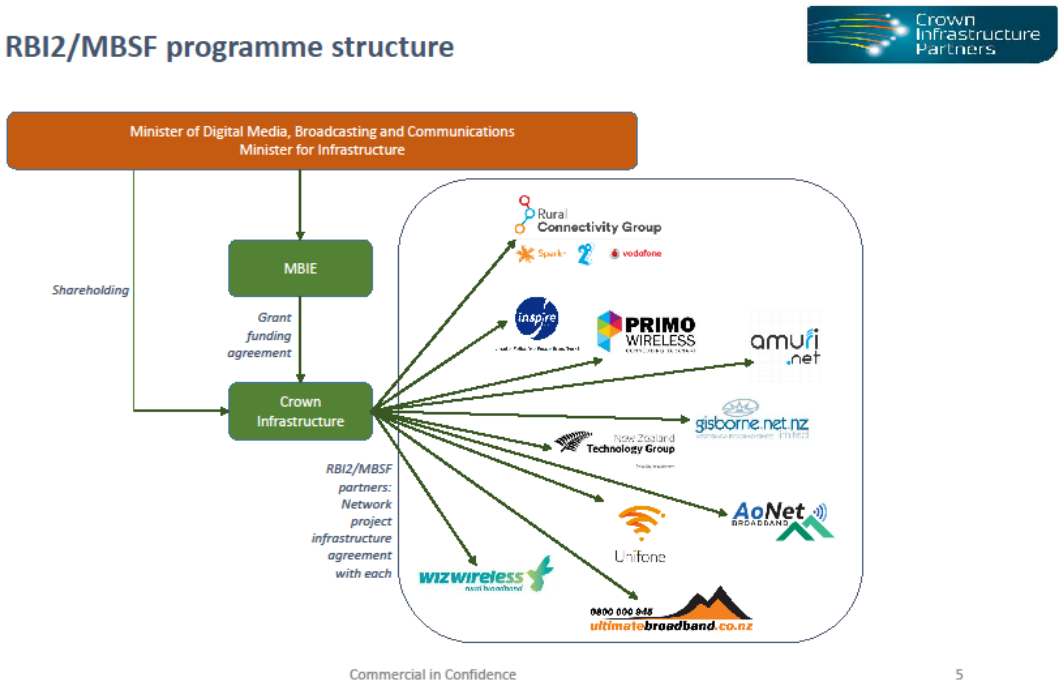

Figure 1. RBI2/MBSF broad program structure (Source: Crown Infrastructure Partners)

Figure 1 shows the general management structure of the two programs. The structure has broadly remained stable over several changes of government. Of the partner organizations shown in Figure 1, most are WISPs – Wireless Internet Service Providers. The WISPs are generally small organizations but are highly agile and adaptive to their local environment. They provide very cost-effective solutions in all corners of the country.

To respond to RBI2, the Mobile Network Operators, Spark, Vodafone and 2degrees, set up a joint venture (which required Commerce Commission clearance) called Rural Connectivity Group (RCG). RCG was appointed by the government to deliver the RBI2 and MBSF programs.

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It secures land and builds, operates and maintains a 4G broadband and mobile network, together with a 3G overlay for mobile blackspots. RCG is not a service retailer: it delivers connectivity for retailers to use.

In addition to the NZ$150M from the government, RCG was given NZ$75M in capital from the three Mobile Network Operators and the spectrum needed for the network. The operations costs are fully funded by the Operators. An expansion program is funded by Crown Infrastructure Partners on a tower-by-tower basis. RCG is a cost-conscious, lean organization of approximately 50 people that encourages technology innovation.

The aim is to have about 500 cell sites operational by December 2023. Currently, there are 330 cell sites and 68 tourist destinations covered. Each cell site supports services from Spark, Vodafone and 2degrees, as well as providing co-location capacity for at least one WISP. The current network covers 27,650 households and 742 km of State Highways. The targets are for 34,000 rural homes and businesses with broadband coverage of at least 20 Mbps, 1,000 km of mobile coverage over 32 State Highways, and coverage for 100 tourist hotspots. The main service uses 4G wireless broadband, with 3G mobile coverage for roads and tourist locations without service from any operator. A recent highlight has been a brand-new network on the Chatham Islands, where there had previously been no communications network at all.

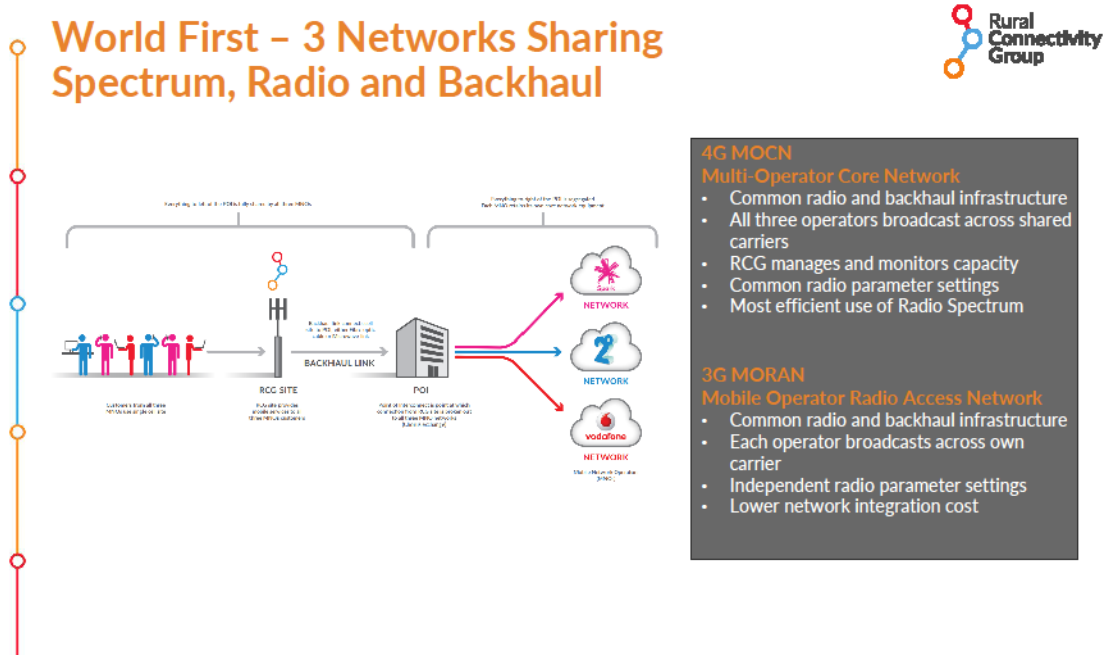

Figure 2. 4G Multi-Operator Core Network configuration (Source: Rural Connectivity Group)

Figure 2 shows the 4G Multi-Operator Core Network (MOCN) architecture used by RCG. This has been an early implementation of 4G MOCN with three operators. It provides for the most efficient use of radio spectrum. In addition, RCG supports 3G Mobile Operator Radio Access

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Network (MORAN) configurations, which permit independent operation of the radio networks without spectrum sharing.

RCG has found that rural communities really welcome mobile coverage, in addition to the broadband service provided via RBI2. RCG's activities are restricted to areas where it is "non-economic for any one operator", but the model could be beneficial in other areas as well.

There have been many challenges in rolling out a network in rural and remote areas. A key consideration is powering: a large site typically needs 1.5-2 MW, for which off-grid power solutions are large and expensive. Backhaul transmission of sufficient quality, e.g., via satellite, is also expensive. There are many issues with access to sites, especially due to the New Zealand weather and topography.

The main program, which was planned in 2014, has been adapted to respond to the dynamic environment of the actual rollout. Rural Connectivity Group and Crown Infrastructure Partners have worked well together to modify the program. The expansion program of new sites provides great flexibility, but the required site-by-site business case development is somewhat inefficient.

There have been technical challenges. The MOCN technology is new, so the rollout has faced novel configurations, like MOCN over satellite links. RCG has worked with its suppliers to develop solutions. In addition, the Mobile Network Operators and the WISPs have different standards for performance and cost that need to be harmonized.

A balance between commercial and government requirements has been needed. The Operators may, for example, favour connecting as many homes as possible, while Crown Infrastructure Partners may have other priorities to cover emergency-services sites.

Rural Connectivity Group, as a consortium of Mobile Network Operators, is privy to highly confidential data from its partners on business plans and projected demand and has had to develop strong procedures to keep this material confidential. It also has restrictions on its operations from the Commerce Commission to protect normal competition in other areas.

As a result of its experience, RCG would recommend:

- The use of MOCN technology for efficient use of spectrum;
- An independent structure for a joint venture but with an essential relationship with its Mobile Network Operators and effective control of confidential data;
- A careful consideration of where the joint venture should operate (e.g., rural only);
- A plan that is outcomes based, rather than just on achieved rollout, such as numbers of sites activated;
- Building relationships with WISPs, including using them for backhaul.

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Questions and Discussion

Question: What targets have been set for the active-sharing trials in NSW?

Peter Adams indicated that the trials were testing the commercial arrangements with operators and achieving best value for money for NSW taxpayers. They were not assessed on "money out the door", although there would always be an expectation on the public service to spend allocated funds to deliver the program's objectives.

Question: Have you observed a movement of people to regional areas and, if so, how have your plans changed in response?

John Proctor said that RCG had seen a movement of people to rural areas, bringing expectations of urban-style telecommunications in terms of service and connectivity, and sometimes price. The requirements for rural people, he suggested, are now the same as for urban dwellers.

Steve Inglis indicated that the population pressure is now on urban fringes where there are new housing developments but fibre access is not yet available. Users who cannot get service at all or whose service has degraded substantially due to increased demand have been identified. Crown Infrastructure Partners has started a new program for rural capacity upgrades, to offload traffic from mobile towers to fixed networks or WISPs, or to add extra capacity to the towers. New towers do fill up quickly, so a mechanism to manage broadband capacity is needed.

Peter Adams agreed that the urban fringes, such as the trial area near Queanbeyan, provided the greatest challenges for connectivity. He described a "willingness to pay" survey conducted for the NSW government, which had shown that city residents had a greater willingness to pay than others for improved coverage in regional areas: city residents prefer to avoid going in and out of coverage when travelling, whereas it is a "fact of daily life" for regional residents.

Question: Please explain the complementary nature of the service provided by the Mobile Operators and the WISPs.

Steve Inglis described the WISPs as a cost-effective means of providing coverage at the edges of networks. They primarily use Wi-Fi technology in unlicensed spectrum, but they do not support mobile service. In more populated areas, they would have capacity constraints due to interference.

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Question: Have the major mobile operators in Australia been open to engaging with the active-sharing trials in NSW?

Peter Adams was cautious in his response, because commercial negotiations were ongoing. He indicated that they had looked at the New Zealand experience and would like to get to an arrangement, as in New Zealand, that was industry-led. The market composition and dynamics in Australia are different, however. He suggested that, as with many other industries, the incumbents would prefer to keep on doing what they are doing. Telstra and TPG, nevertheless, have recently announced a mutual sharing agreement (subject to regulatory approval).

Question: What power solutions are being used in New Zealand?

John Proctor answered that RCG is using local mains power wherever possible. He explained that a tower site is always a compromise between the RF design, the power supply, backhaul costs, and other considerations. Long power lead-ins can be expensive. On the other hand, the installation costs for off-grid power at a large site could be around NZ$250K.

Steve Inglis noted that diesel generators are used in some cases in the South Island on roads between mountains where solar and wind assets are limited.

In answer to a subsidiary question, John Proctor said that their battery-backup is specified for 8-11 hours of operation. He remarked that RCG's experience was that failures were more often due to backhaul problems, not power backup.

Question: Is there any reason that the New Zealand Rural Connectivity Group model would not work in Australia?

Peter Adams suggested that there were no barriers to adopting this model in Australia, but his current trial will highlight any issues. He reiterated that the market is changing, while commercial issues currently dominate.

In answer to a later question, Peter Adams noted that the issue of continuous corridor coverage is important. For example, new government-funded shared coverage along a road corridor, but then existing single-operator coverage in the towns along the way and at each end would not make sense. The restriction in New Zealand of only using the Rural Connectivity Group model where there is no coverage at all would not work well in Australia.

Question: Is the mobile coverage data in New Zealand now of better quality than it was at the start of the programs?

Steve Inglis considered that it was. Among the evidence is fewer complaints from WISPs that they are being overbuilt. There is greater confidence in the data providers. The large Mobile Network Operators have always provided accurate data but they each measure their signal

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strengths slightly differently: this data has had to be "normalised" for the 20 Mbps profile. Crown Infrastructure Partners has also used public sources, initially from Land Information NZ and now also from Core Logic (which provides building outlines as well as land parcel boundaries).

Question: What are the timelines for trials in NSW?

Peter Adams answered that the active-sharing program would kick off on 27 April 2022 and run for just under four months, with milestones along the way. The tender process to build the trial sharing solutions developed would open in Q4 this year (2022).

Question: How do you manage the changes in coverage and capacity over time?

Steve Inglis indicated that Crown Infrastructure Partners' capacity contracts included monthly reporting on traffic levels, so it is possible to detect and act on hotspots. Upgrades are to provide for the next five years at a minimum. He noted that there has been a shift to working from home during the pandemic; he wondered if there would be a move back to office working, relieving some of the pressure on capacity in the urban fringes.

John Proctor suggested that the capacity problems facing his organization were with backhaul, not spectrum. There needs to be greater emphasis on backhaul issues.

Peter Adams said that his program was anticipating where growth would occur, as well as identifying high-value areas and providing coverage along highways. The program design is informed by and is consistent with other NSW government strategies.

Conclusion

This was the thirteenth of a planned series of forums related to the future of the NBN and a broadband strategy for Australia. Its aim was to describe and compare the approaches adopted in New Zealand and Australia for extending broadband access to rural and remote businesses and residents.

In New Zealand there has been a clear plan to "mop up" the remaining areas without broadband coverage and to provide a minimum standard of 20 Mbps downstream. There has been an active and engaged public-service organization to plan and manage the rollout to unserved areas. As a result, the Mobile Network Operators have responded with a joint venture, which conforms to competition law and other requirements, that can plan, implement and manage the required new mobile networks, in conjunction with Wireless ISPs. The deployments have used the new technology standard MOCN to use spectrum efficiently and to support competitive service provision.

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In Australia, telecommunications is largely a Commonwealth issue. The Commonwealth government has rolled out a National Broadband Network (NBN) for fixed broadband access and three major Mobile Network Operators have competitively deployed 4G and 5G mobile broadband. The Commonwealth is continuing to support a Mobile Blackspots program to improve mobile coverage.

Unserved and underserved areas remain. The Forum focussed on one State program to explore and implement commercial and technical solutions to extend broadband coverage to rural areas where it has proved uneconomic to deploy mobile services or where the NBN solution is perceived to be inadequate. While the industry has been moving towards greater sharing of facilities and costs, there has not yet been a cooperative response, unlike in New Zealand, to find shared solutions to network deployments in otherwise uneconomic areas. The State of NSW is supporting, through trials and funding, new competitive and technical models for broadband provision in priority areas, including along unserved highways. While the New Zealand experience is instructive, it is not seen as directly applicable in Australia, due to differences in market conditions and the geography of existing deployments.

The New Zealand model of a continuing series of plans by the government to stimulate and support the deployment of broadband across the country has proved successful. In Australia, with its greater geographical extent and its variety of interests by Federal and State governments, the technical solutions for underserved areas are still being explored and, importantly, the commercial arrangements that will balance competition requirements with economic deployments are yet to fully emerge.

Acknowledgement

The summary of the discussion and the commentary in the Conclusion were written by Leith Campbell.

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Endnote

[i] The first forum was held in July 2019 (Campbell & Milner, 2019), the second in October 2019 (Campbell, 2019), the third in February 2020 (Campbell, 2020a), the fourth in August 2020 (Campbell, Smith & Brooks, 2020), the fifth in November 2020 (Campbell, 2020b), the sixth in March 2021 (Campbell, 2021a), the seventh in May 2021 (Campbell, 2021b), the eighth in

August 2021 (Pritchard-Kelly & Costa, 2022), the ninth also in August 2021 (Campbell & Mithen, 2021), the tenth in October 2021 (Waters & Koch, 2022), the eleventh (on 5G trends and developments) in November 2021, and the twelfth (on the Australian Broadband Advisory Council's eHealth report) in March 2022.

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Denial-of-Sleep Attack Detection in NB-IoT Using Deep Learning

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Abstract: With increasing Internet-of-Things (IoT) protocols and connectivity, a growing number of attacks are emerging in the associated networks. This work presents approaches using deep learning (DL) to detect attacks in an IoT environment, particularly in narrowband Internet-of-Things (NB-IoT). By virtue of its low cost, low complexity and limited energy, an NB-IoT device will not likely permit cutting-edge security mechanisms, leaving it vulnerable to, for example, denial-of-sleep (DoSl) attacks. For performance analysis, a NB-IoT network was simulated, using ns-3, to generate a novel dataset to represent an implementation of DoSl attacks. After preprocessing, the dataset was presented to a collection of machine learning (ML) models to evaluate their performance. The considered DL recurrent neural network (RNN) models have proven capable of reliably classifying traffic, with very high accuracy, into either a DoSl attack or a normal record. The performance of a long short-term memory (LSTM) classifier has provided accuracies up to 98.99%, with a detection time of 2.54 x 10^{-5} second/record, surpassing performance of a gated recurrent unit (GRU). RNN DL models have superior performance in terms of accuracy of detecting DoSl attacks in NB-IoT networks, when compared with other ML algorithms, including support vector machine, Gaussian naïve-Bayes, and logistic regression.

Keywords: Deep learning, denial-of-sleep attack (DoSl), Internet-of-Things (IoT), NB-IoT, recurrent neural network (RNN).

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Introduction

The evolution and materialization of the Internet of Things (IoT) lead to the concurrent deployment of numerous battery-powered and energy-harvesting user equipment (UE) types to achieve the functions of sensing and actuation in target application domains that include smart cities, precision agriculture, telemedicine, and industrial automation. The number of IoT devices could surpass 70 billion in 2025, with 70% of the deployed devices being in the low-power and low-cost categories. It is apparent that communications for these low-power devices is mostly by means of wireless technologies. It is believed that wireless low-power and low-cost technologies will have their eminence in connecting billions of deployed IoT devices.

Low power wide area networks (LPWAN) have affected a contemporary direction in the IoT ecosystem through furnishing cost-effective connectivity to distributed low-power devices over a relatively broad geographical area (few tens of kilometres), while maintaining a battery life of up to ten years. LPWAN technologies are readily appropriate for the special requirements of machine-to-machine (M2M) and IoT systems. Despite the fact that these technologies are predominantly at the initial stages of commercial implementations, nevertheless they seem to be up-and-coming. A generic LPWAN network configuration consists of an LPWAN sensing or actuation device, a gateway, and a distant application server on the Internet.

Narrowband Internet-of-Things (NB-IoT) is a relatively new cellular LPWAN technology that has been proposed in the 3rd generation partnership project (3GPP) Release 13 for providing wide-area coverage within the field of IoT (Popli, Jha & Jain, 2018). It possesses the previously described advantages of LPWAN networks, in addition to the special feature of flexible wide coverage, using a small frequency bandwidth of as little as approximately 180 kHz on existing cellular technologies (Wang *et al.*, 2017; Tahat *et al.*, 2020). They have vital superiority for nationwide integration with sustained seamless coverage of high capacity.

However, IoT systems in general are confronted with risks and vulnerabilities that are proportionate to the broad scope of IoT applications in multiple vertical industries. They may endure assaults and attacks against physical interfaces or remote communications, in addition to traditional attacks that can be launched against user interfaces, accounts, authentication, and internal communications. Among the various types of attacks that NB-IoT networks can be exposed to are denial-of-service and denial-of-sleep (DoSl) attacks, which are of vital importance, as they not only decrease the performance and efficiency of networks, but they will also shorten the expected overall lifetime of deployed UEs. The expected lifetime of a UE is assumed to be at least 10 years in worst case scenarios, according to requirements of the 3GPP (TR-45.820, 2015).

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By virtue of its low-cost, low-complexity and limited energy, an NB-IoT device design will not likely permit cutting-edge and impeccable security mechanisms (Chen *et al.*, 2017; TR-45.820, 2015). Hence, this drawback could likely simplify the process of security vulnerability exploitation. Considering the massive numbers of NB-IoT terminals or UEs, any minor vulnerability is potentially capable of inducing critical repercussions to network security. If we envisage a network deployment scheme with NB-IoT terminals which are using a live cellular core network, the device equipment has the capability to infect elements of the mobile core network, including the home subscriber server, the mobility management entity, and supplementary UEs, so as to affect communications of mobile subscribers, resulting in refusal of UE access to the network.

Within this framework, a crucial dilemma is that of denial-of-sleep (DoSl) attacks, as they permanently or transiently dispossess battery-powered or energy-constrained NB-IoT UEs of commencing sleep or energy-saving modes, consequently depleting their stored charge. Alternatively, a viable DoSl attack leads to an extended outage of the compromised NB-IoT UEs. Furthermore, to restore operation of these battery-drained UEs, the tedious task of replacing their batteries needs to be conducted, especially if a battery-powered device is installed at an unattainable setting. Despite the fact that, over the past few years, researchers have proposed ample protection methods against DoSl attacks, the majority of current IoT protocols, including NB-IoT, are not equipped at all with mechanisms to defend against DoSl attacks. Nevertheless, while admitting that there exist abundant DoSl defences, powerful and efficient defences against particular types of DoSl attacks, and for specific connectivity technologies, such as the NB-IoT standard, still need to be developed.

In this paper, we present a deep learning (DL) based approach to defend against DoSl in a NB-IoT network to prevent and protect against the described issues and ramifications. This is accomplished through detecting malicious traffic packets related to an DoSl attack in a model NB-IoT network. To this end, a dataset was generated and subsequently analyzed to train a collection of designated machine learning (ML) algorithms for this goal, including RNN models. This is accomplished by the construction and simulation of an NB-IoT network to be attacked by the *HELLO flood* DoSl attack. The generated traffic was extracted, visualized and pre-processed. All network simulation codes were implemented on the network simulator (ns-3) software suite and written using the C++ programming language. The ML RNN models were implemented using Python on the Google Colaboratory (Colab) platform (Google Colaboratory (Colab), 2021; Bisong, 2019) for training and testing of all samples of the dataset to obtain reliable, consistent, and accurate results for verification. Based on our investigations, results and observations of many experiments, our presented models yielded outstanding performance and accuracy within our investigative framework of the NB-IoT technology.

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The contributions of our work are as follows:

- We analyzed the performance of various DL models in terms of DoSl attacks detection accuracy in NB-IoT wireless access networks.
- We provided a simulation model that can be used to generate and extract a novel dataset for DoSl attacks in an NB-IoT network architecture.
- We showed through extensive simulations within the scope of our study and using the constructed simulation model that:
    1. RNN DL models are capable of successfully and reliably classifying traffic data into either a DoSl attack or a normal record with very high accuracies and that the performance of an LSTM classifier outperforms the performance of GRU by several orders of magnitude. However, an interesting finding was that, on a preprocessed version of traffic data, accuracies of both LSTM and GRU classifiers improved to 99.1% and 98.6%, respectively, making the performance roughly the same, which may justify the use of GRU instead of LSTM due to its higher performance-cost ratio and higher performance efficiency in terms of less memory usage and higher training speed.
    2. RNN DL models outperform some traditional ML models (support vector machine, Gaussian naïve-Bayes, and logistic regression) in terms of the accuracy of DoSl attacks' detection in NB-IoT wireless access networks.

The rest of the paper is organized as follows. Section II discusses relevant foundation, background and associated literature. We present in Section III our methodology and implementation, including system architecture. Simulation results are presented and discussed in Section IV. Finally, we draw conclusions in Section V.

Relevant Background

This section provides a review and discusses relevant background of the main components and underlying principles of the framework that constitutes this work.

Narrowband Internet of Things

Countless applications of the NB-IoT technology make such a network an attractive target for attackers to invade. Physical and logical channels for NB-IoT are constructed based on the LTE technology, but with some corresponding NB-IoT-specific variations and improvements (Wang *et al.*, 2017). For instance, in the group of *Downlink* channels, modifications include the definition of the Narrowband primary synchronization signal (NPSS), the Narrowband

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secondary synchronization channel (NSSS), the Narrowband physical broadcast channel (NPBCH), the Narrowband reference signal (NRS), and Narrowband physical downlink shared channel (NPDSCH). In the group of *Uplink* channels, there are the Narrowband physical random access channel (NPRACH) and Narrowband physical uplink shared channel (NPUSCH). These two channels are used most frequently in communications. Unlike LTE physical channels, these channels are multiplexed.

The NB-IoT technology is a centralized system and its standard was firstly started within the LTE network architecture. The evolved node B (eNB) controls downlink as well as uplink scheduling to ensure resource coordination between UEs. The NB-IoT uplink communication is initiated when any user equipment (UE) device requests a transmission to an eNB using the random access procedure (NB-IoT RA) (Martiradonna, Piro & Boggia, 2019), as shown in Figure 1. Different uplink physical channels are used during transmission, including NPRACH and NPUSCH. The eNB receives a transmission request (Random Access Preamble) and sends a scheduling grant (Random Access Response) indicating time and frequency allocation to the device. Downlink communication starts after the device completes sending its identity and other important information about its transmission. Different downlink physical channels are used, including the NPBCH, the NPDCCH, the NPDSCH, the NPSS, and the Narrowband reference signal (NRS) (Miao *et al.*, 2017).

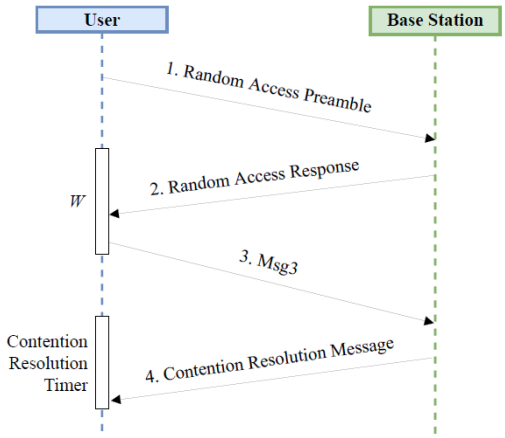

Figure 1. NB-IoT UE RA sequence diagram (Martiradonna, Piro & Boggia, 2019).

NB-IoT is a new fast-growing wireless cellular technology standard, first standardized in Release 13 of the 3GPP (Chen *et al.*, 2017; TR-45.820, 2015). NB-IoT has high energy efficiency and minimum power consumption that enables a battery life of more than 10 years. It supports a massive number of new connections, using a very small part of the available spectrum — as little as approximately 180 kHz — increasing capacity, while it is capable of an extended reach to underground and closed hard-to-reach spaces, providing deep indoor coverage (Chen *et al.*, 2017). NB-IoT can support a wide range of applications, which makes it such a promising technology that enables it to develop and expand several markets and organizations with

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increased efficiency (Xu & Darwazeh, 2018; Fattah, 2018). Nevertheless, in an NB-IoT network, all sensors' data are sent to the server through their nearest connected serving base station (eNB). The server, in turn, processes and retransmits the data. Normal traffic UE's data in a typical application is exchanged between server and the serving base station of the connected UE. However, attackers can communicate with other UEs and their coupled sensors in their base station's coverage area and attack them.

Denial-of-Sleep attacks

The main purpose of UEs and their associated sensors in current NB-IoT networks is the collection of data, where UEs or nodes are configured to go into sleep mode when their scheduled tasks are accomplished to increase lifetime of their batteries. As a consequence of several data collections by NB-IoT services, data disclosure risk exists during transfer on-network, and during data processing by various network elements. Data packets exchanged between various components throughout sessions, that are established between UEs and eNB base stations, could be captured and monitored using hijacking tools employed in the network data communication domain. In that case, the communication is seized, allowing attackers to evaluate security vulnerabilities within captured communication messages after extraction of data. The compromised NB-IoT UEs may induce a signalling storm due to shared mobile telecommunication networks with massive numbers of UEs and mobile telecommunications subscribers.

It is possible to forge or tamper with the core network signalling of a NB-IoT system; or it may be replay-attacked due to the lack of a mechanism for mutual authentication of network elements. Moreover, the interface between NB-IoT core network and the Internet could be impaired due to multiple attacks from the Internet.

The DoSl attack is a type of denial-of-service attack that can prevent UEs from going into sleep mode and saving their energy. This will decrease the battery's lifetime of the UE. These attacks will send more messages in order to keep the UEs awake and deplete their stored energy, until totally consumed, by being kept in this state, even when there is no actual traffic, causing the node to die (Kaur & Ataullah, 2014). In addition, due to the fact that, when bandwidth is fully occupied by DoSl attack traffic, a communications jamming effect will be inflicted upon normal data packets that are being exchanged, further indirectly inducing additional duty, such as that of listening or retransmissions, and hence more power dissipation (Brun *et al.*, 2018).

Different types of DoSl attacks could be applied considering the various classes of networks (Mahalakshmi & Subathra, 2014; Niu *et al.*, 2012; Yuan *et al.*, 2019). For instance, different

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types of *sleep-deprivation* attacks aim at maximizing the power consumption of UEs, which, in turn, reduces their lifespan. An attacker initiates an interaction with the target node, dragging out the interactions as long as possible, depriving the node from entering into sleep mode, dissipating much needed power that could be conserved. The *HELLO flood* attack relies on the fact that many routing protocols in a wireless sensor network require network nodes to announce themselves by broadcasting 'hello' packets. A *HELLO flood* attack occurs when a network is weighed down with packets trying to initiate connections; consequently, it can no longer respond to the requests.

This work investigates protection and flexible usage for NB-IoT networks, wherein the DoSl *HELLO flood* attack is implemented and deployed on the proposed design of a NB-IoT network. Machine learning is utilized for the detection of a DoSl attack.

Machine Learning

The process of choosing the most suitable ML algorithm involves several elements (Al-Rashdan & Tahat, 2020), which can influence our decision, since we will not be able to identify a single approach that will be most effective for all scenarios. ML algorithms are capable of discovering patterns and replicating them in a systematic way. ML algorithms are broadly categorized using learning methods, such as supervised learning, unsupervised learning, and reinforcement learning. A collection of supervised ML algorithms is employed and investigated. This is because the aim is to recognize a DoSl attack relying on previously collected training data. Their performance was evaluated and compared in detection of a DoSl attack in a simulated NB-IoT network topology and associated environment variables. We present below a brief introduction to the underlying approach and principles of operation for each of the employed ML methods and algorithms, including deep learning techniques, used for classification tasks in this paper. (Aggarwal *et al.*, 2018; Al-Rashdan & Tahat, 2020; Tahat *et al.*, 2021).

1) Support Vector Machine

Support Vector Machine (SVM) is used in regression and classification problems. In this algorithm, each data item will be plotted as a point in the n-dimensional space with the value of each feature being the value of a particular coordinate. Then, the classification will be performed by finding the hyperplane that differentiates the two classes very well (Burges, 1998).

2) Logistic Regression

Logistic regression (LR) (Le Cessie & Van Houwelingen, 1992) is used in solving regression and binary classification issues with one or more attributes to predict the target. It analyses the

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relationship between attribute variables and response variables (normal and abnormal traffic) using the Bernoulli distribution and probability.

3) Gaussian Naïve-Bayes

Gaussian Naïve-Bayes (John & Langley, 2013) is used for binary classification issues based on using Bayes Theorem while incorporating the assumption that each pair of features is independent.

4) Recurrent Neural Networks

A recurrent neural network (RNN) is a type of deep learning neural network, subdivided into long short-term memory (LSTM) and gated recurrent unit (GRU), which will be discussed in greater detail subsequently.

Deep Learning

Attaining high accuracy and large success rates in a wide range of applications in various fields requires using deep learning ML techniques and algorithms in conjunction with big data analysis. Deep learning (DL) is a subcategory of ML that performs the machine-learning tasks, relying on its own learnt experience without explicit programming, thereby extracting valuable patterns from the involved dataset. Hence, DL can break the limitations of other ML methods on extracting well-represented features. It allows for composing multiple sequences from that input. It uses and processes the previous input by sending feedback signals to compute the output.

RNNs are different from other neural network types, since RNNs have memory elements as part of their architecture. Hence, RNN DL neural networks have attracted significant attention for applications involving sequential tasks (Tang *et al.*, 2019). Working with an RNN implies that the dataset incorporates sequential information necessary to solve the presented issue or problem (Tang *et al.*, 2019).

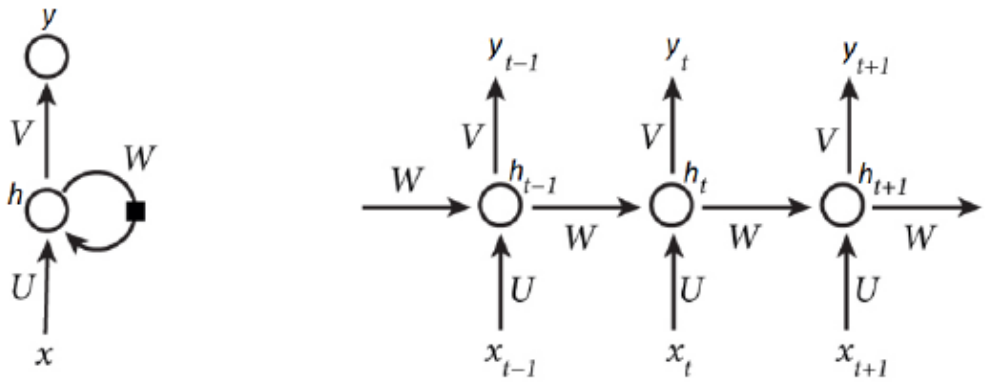

Figure 2. Architecture of a Recurrent Neural Network (Wei & Nguyen, 2019).

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As shown in Figure 2, a basic RNN consists of three basic layers with feedback that serves as memory, where the first layer is input, the second layer is the hidden layer, and the output layer is a third layer. In RNNs, neural sequence connections between units are formed as a directed cycle. The hidden states in RNNs are computed using a function that takes sequence inputs, $x = (x_1,.., x_T)x = (x_1,.., x_T)$, and uses them with internal memory to exhibit temporal behaviour. It also incorporates a sequence of hidden layers, $h = (h_1,.., h_T)h = (h_1,.., h_T)$, to generate an output vector, $y = (y_1, \dots, y_T)y = (y_1, \dots, y_T)$, at time T,T, which is the last step in time in the sequence (Wei & Nguyen, 2019). RNN is computed based on the previous hidden state $h_{t-1}h_{t-1}$ with input at the current step x_tx_t to calculate the current hidden step h_t, h_t,using (1):

$$h_t = g(Ux_t + Wh_{t-1})h_t = g(Ux_t + Wh_{t-1}) \quad (1)$$

RNN has processing layers to learn the representations of data with many levels of abstractions since it builds many hidden layers with multiple simple features to represent a developed concept. In addition, it has a several hidden layers that repeat the learning process many times, which makes DL much more powerful. In brief, DL is a subset of ML that uses artificial neural networks having three or more layers with nonlinear processing units to perform enhanced learning from large volumes of data (Al-Rashdan & Tahat, 2020; Chaabane *et al.*, 2020). To this end, in our investigation, DL proved to be very advantageous in the detection of DoSl attacks on NB-IoT networks.

Recurrent neural networks (RNNs) and convolutional neural networks (CNNs) are DL neural networks. CNN is a multi-layered neural network with a unique design to extract complex specific data features in each layer by deriving the most important information from the input data (Muhammad *et al.*, 2018). On the other hand, the RNN-type DL neural network receives an input sequence and generates the output, where U and W are the weight matrices of the network, and $g(f)$ is the nonlinear activation function, such as a *sigmoid*. As a final stage to find y, the previous outputs are re-formed by using another activation function V, such as *softmax*, in order to implement and represent a linear output in the final layer. The RNN DL neural networks are further subdivided into two architectures: the long short-term memory (LSTM) and the gated recurrent unit (GRU), that are briefly introduced below.

1) Long Short-Term Memory

Linear long short-term memory (LSTM) is an RNN-specific architecture capable of learning long-term dependencies and remembering the information for prolonged periods of time as a default. This LSTM architecture is organized in a chain structure and has additional interactions per module (or cell), where each cell has three gates. These gates are input gate (i_ti_t), which determines the ratio of the input when calculating the cell state, the forget gate (f_tf_t), which decides on passing on or forgetting the previous memory h_{t-1}, and the output

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gate (o_t), which decides if it should pass the output of the memory's cell or not. In addition, there is a cell activation vector (c_t). All of these parameters can be calculated using (2)-(6), respectively (Wei & Nguyen, 2019; Kim *et al.*, 2016; Li *et al.*, 2018; Zadeh *et al.*, 2010).

$$i_t = \sigma(U_i x_t + W_i h_{t-1} + V_i c_{t-1}) i_t = \sigma(U_i x_t + W_i h_{t-1} + V_i c_{t-1}) \quad (2)$$

$$f_t = \sigma\big(U_f x_t + W_f h_{t-1} + V_f c_{t-1}\big) f_t = \sigma\big(U_f x_t + W_f h_{t-1} + V_f c_{t-1}\big) \quad (3)$$

$$c_t = f_t c_{t-1} + i_t tanh(U_c x_t + W_c h_{t-1}) c_t = f_t c_{t-1} + i_t tanh(U_c x_t + W_c h_{t-1}) \quad (4)$$

$$o_t = \sigma(U_o x_t + W_o h_{t-1} + V_o c_t) o_t = \sigma(U_o x_t + W_o h_{t-1} + V_o c_t) \quad (5)$$

$$h_t = o_t tanh(c_t) h_t = o_t tanh(c_t) \quad (6)$$

where σ is the logistic *sigmoid* function (7), and U, W, and V are the weight matrices of the peephole connections. The second phase is to use forget gate (f_t), which takes the c_t and decides what parts to keep and to forget. This process of identifying and excluding data is decided by the logistic sigmoid function formulated by (7), which takes the output of the last LSTM unit (h_{t-1}) at time $t-1$ and the current input (x_t) at time t. Additionally, the sigmoid function determines which part from the old output should be eliminated.

$$\sigma(s) = \frac{1}{(1+e^{-s})} \quad (7)$$

The third phase takes the c_{t-1} coming from the forget gate, and the h_{t-1} coming from the first gate, and simply combines them. In the final step, the output value (h_t) is based on the output cell state (o_t) but in a filtered version.

2) Gated Recurrent Unit

The gated recurrent unit (GRU) is a newer generation of RNN. The special architecture of GRU uses fewer gates than LSTM; therefore, training time of GRU is shorter than training time in LSTM. In addition, GRU has fewer parameters than LSTM, as it lacks an output gate, and has only a reset gate and update gate. LSTM and GRU and their different properties will be used in this paper to detect DoSl attacks in the NB-IoT access technology.

Related work

Many studies in recent years (Tang *et al.*, 2019) have proposed the use of GRU, SVM, Naïve-Bayes and LSTM (Wei & Nguyen, 2019) in intrusion detection systems, where GRU has achieved the best accuracy when applying these methods on different datasets, such as the NSL-KDD dataset. In this work, these models will be applied and investigated on a simulated NB-IoT network using the presented NB-IoT characteristics, that are based on those of LTE built-in designs in OPNET and the LTE-Sim tool (Miao *et al.*, 2017; Martiradonna *et al.*, 2018).

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Consequently, we have generated a new dataset specific to NB-IoT access technology network to perform our investigation by applying the presented models to our dataset. In other recent works, NB-IoT systems have been simulated in Hassoubah, Solaiman & Abdullah (2015) using network simulator-3 (ns-3) based on the srsLTE file. They used the random access procedure in their configurations, where their technique aimed to improve average access delay (time interval). They explained in detail how random access works, provided explanations of LTE and NB-IoT channels with their setup parameters, and, in addition, how they extracted channel codes using ns-3 LTE-Helper.

Multiple models have been put forward to detect and mitigate DoSl attacks. Hassoubah, Solaiman & Abdullah (2015) discuss three models to detect attacks, such as absorbing Markov chain (AMC), secure wake-up scheme and isolation table intrusion detection system (ITIDS). A study in Saeedi (2019) presented methods for distributed denial-of-service (DDoS) attack detection in NB-IoT network, where ML algorithms were then applied to return one working memory instead of a pair of long-term and short-term memories. GRU cells have two input features, input vector Xt and previous output vector $h(t\text{-}1)$. GRU has gates that perform logical operations in addition to nonlinear transformations, in order to calculate the output of each gate. Equations (8)-(11) describe relationships between input and output (Wang, Liao & Chang, 2018).

$$r(t) = \sigma_g(W_r x(t) + U_r h(t-1) + b_r) \tag{8}$$

$$z(t) = \sigma_g(W_z x(t) + U_z h(t-1) + b_z) \tag{9}$$

$$h(t) = \big(1 - z(t)\big) \circ h(t-1) + z(t) \circ h(t) \tag{10}$$

$$h(t) = \sigma_h\big(W_h x(t) + U_h(r(t) \circ h(t-1) + b_h)\big) \tag{11}$$

where $z(t)$ is called the update gate vector, $r(t)$ is called the reset gate vector, W and U are defined to be parameter matrices and vectors. In addition, $h(t)$ is set to be an activation function, σ_g is the sigmoid function, and σ_h is the hyperbolic tangent. The element-wise product is used to distinguish between DDoS packets and normal packets. Hasan *et al.* (2019) have presented in their study the application of preprocessing and cleaning stages on a downloaded IoT dataset from the Kaggel website, so that it can be used for intrusion detection system design through applying various ML algorithms, including random forest, SVM and logistic regression. A genetic algorithm-based approach has been presented in Gunasekaran & Periakaruppan (2017) for DoSl attack detection in a wireless sensor net environment.

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Methodology and Implementation

A NB-IoT network was designed and simulated using the ns-3 network simulation tool. The cellular network parameters were configured to use the NB-IoT on a 5G network using this simulator. The set-up network was then attacked by a *HELLO flood* DoSl attack in order to derive a dataset for investigation, including training and testing, where the dataset would be applied to the implemented DL modules.

Network set-up

The attacker of the *HELLO Flood* attack in this experimental framework is assumed to be located within the area covered by the base station serving the NB-IoT network. It will launch an attack against other UEs (e.g., sensors) in the same network, when communicating through the serving base station. The attack traffic direction is depicted in Figure 3. Our DoSl attack detection module is placed in NB-IoT base station, so as to scan received traffic and classify whether it is normal/attack traffic to perform the detection.

As described previously, all UEs with different IP addresses send their data to the server through their nearest connected base station. However, the attacker broadcasts the flood of *HELLO* messages to the sensors served by the same network through its base station. Meanwhile, the designed NB-IoT network topology consists of one server in the network and three base stations, where each base station has up to 10 connected sensors or UEs. Three attackers (i.e., UEs that initiate an attack) are implemented in this network (one attack in each base-station service area). The NB-IoT network testbed architecture is depicted in Figure 4. This NB-IoT network was simulated based on values that are listed in Table 1.

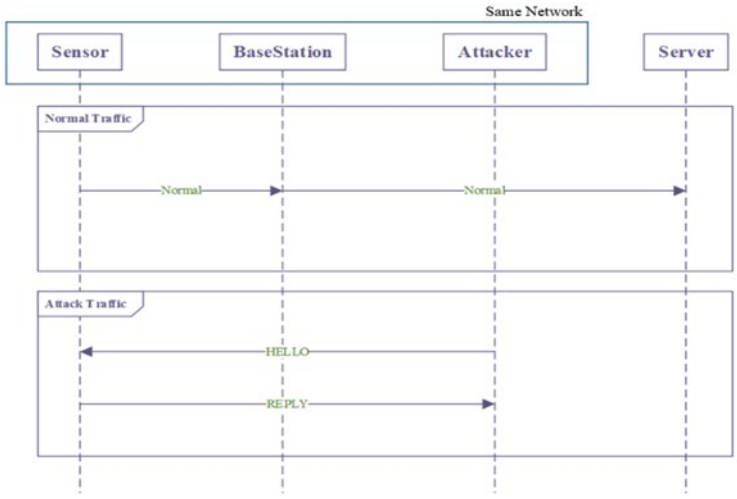

Figure 3. The attacker acts as a Man-in-the-Middle and exchanges HELLO message/reply with UEs. The server and UEs exchange normal messages through the base station.

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Table 1. NB-IoT network simulation parameters.

Parameter	Value
Number of base stations (eNB)	3
UE nodes (sensors)	10 nodes per cell
Distance between UE nodes	300 m
Distance between nodes and base station	500 m-1000 m
Tx Power	500 mW
Rx Power	80 mW
Network access procedure	Random Access

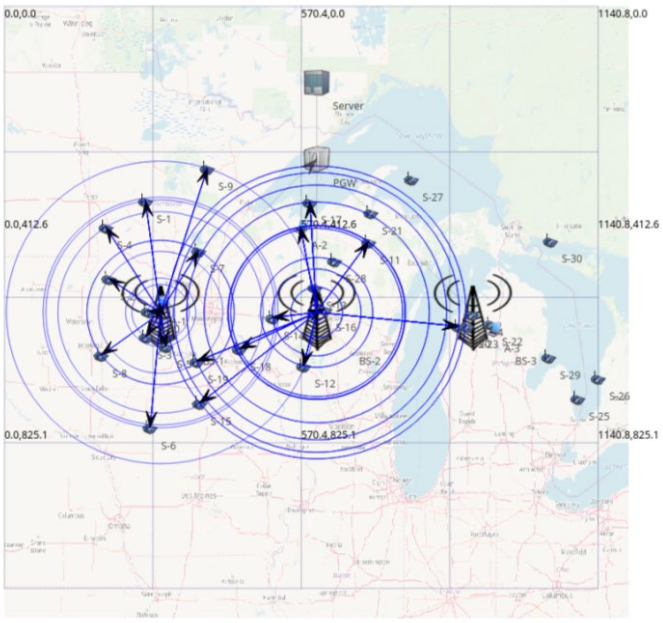

Figure 4. Designed NB-IoT network testbed for considered topology.

Dataset generation

After simulating the NB-IoT network topology, the *HELLO flood* attack was implemented and applied as a DoSl attack among the UEs. In order to improve battery autonomy, the NB-IoT standard includes Power Saving Mode (PSM) parameter configurations, which allow the device to enter into a deep sleep mode ranging from seconds to days. In this sleep mode, the network is no longer connected to the device, where the use of sleep mode is a matter of choice over power consumption and device reachability (Ehsan & Khan, 2012). However, attackers send a flood of packets in order to get the sensor out of this sleep mode. Sensors are configured to be in sleep mode. When they receive the *HELLO* message request, they will wake up and reply with *HELLO*-REPLY messages, consuming power each time they wake up and reply with *HELLO*-REPLY.

A *HELLO flood* DoSl attack can be induced by a node (the attacker), which broadcasts a *HELLO* packet with a very high power in order to attack a large number of nodes in the NB-IoT network in the same coverage area. These nodes are then convinced that the attacker node is their own trusted neighbour, so that the nodes will respond to the *HELLO* messages and waste their

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energy. Consequently, the network is left in a state of confusion (El Soussi *et al.*, 2018). Whenever the attacker starts the *HELLO Flood* DoSl attack, sensors are not able to enter into sleep mode because they have received a large number of HELLO messages. As a result of this communication, the energy of the UE will be consumed rapidly and eventually the sensors will die due to drained batteries.

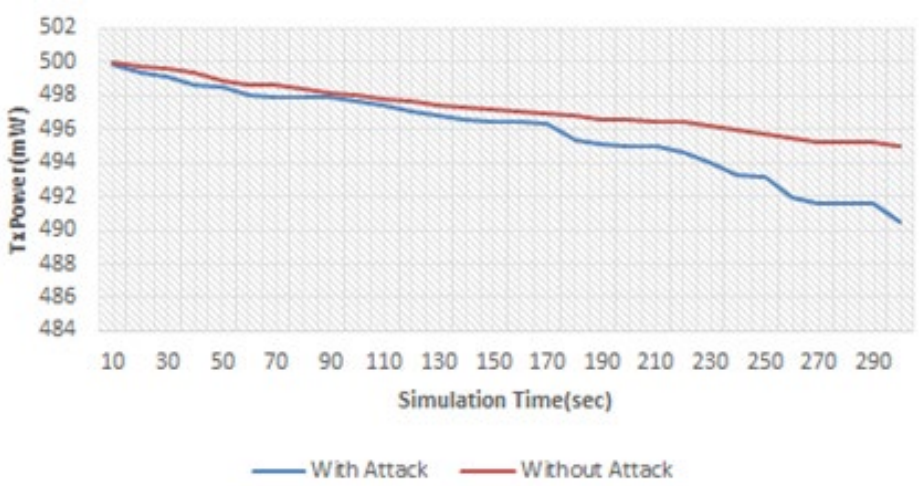

Figure 5. Power dissipation comparison on the node with/without applying DoSl attack on Tx Power.

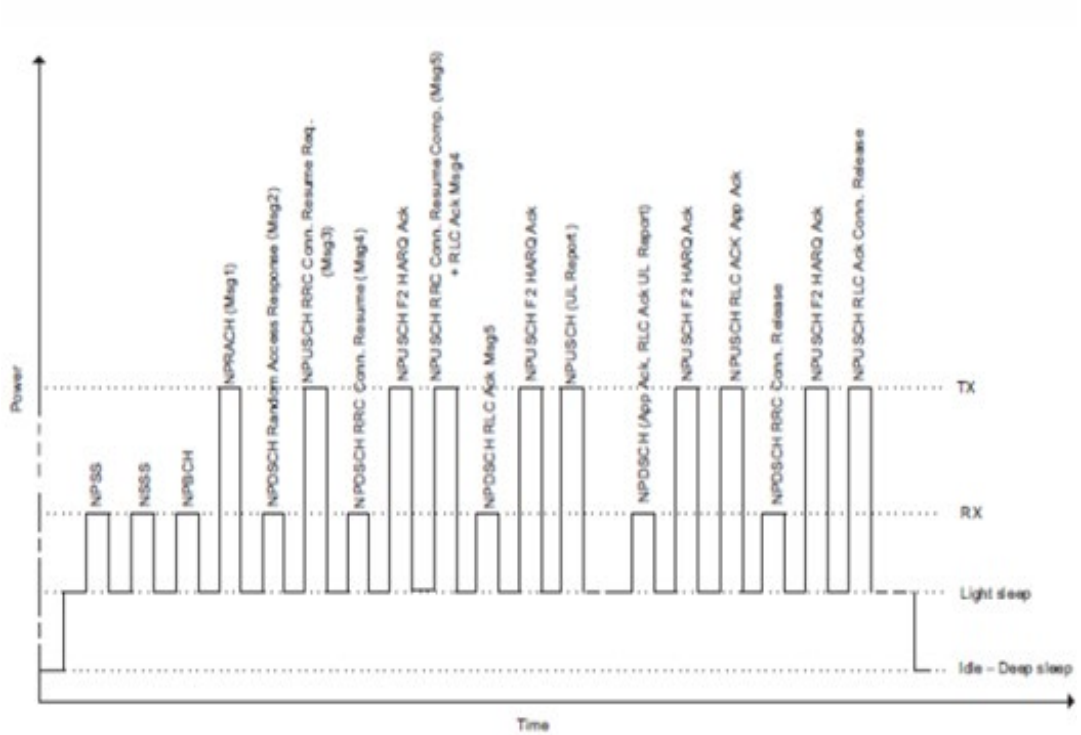

Figure 6. NB-IoT device power consumption in different modes (Liberg *et al.*, 2017).

A plot comparing power dissipation between a normal node and a DoSl attacked node during transmission (Tx) is depicted in Figure 5. The power dissipation reached up to 10 mW in 280 s, when transmitting packets of HELLO-REPLYs, where the power dissipation reached up to 3 mW in 280 s, when receiving packets of HELLO-REQUESTs for the same attack criteria. This dissipation of power demonstrates that Tx channels in NB-IoT consume more power than

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receive (Rx) channels, when the node tries to reply with a HELLO-REPLY message. Using transmission channels discussed before, including NBRACH and NPUSCH transmission channels, power consumption during different states of a NB-IoT device is shown in Figure 6 (Liberg *et al.*, 2017).

The ns-3 simulation was run for five continuous days of the designed NB-IoT network with the implementation of the *HELLO flood* DoSl attack on the network, in order to generate and export our dataset for investigation, analysis and performance evaluation.

Preprocessing of the dataset

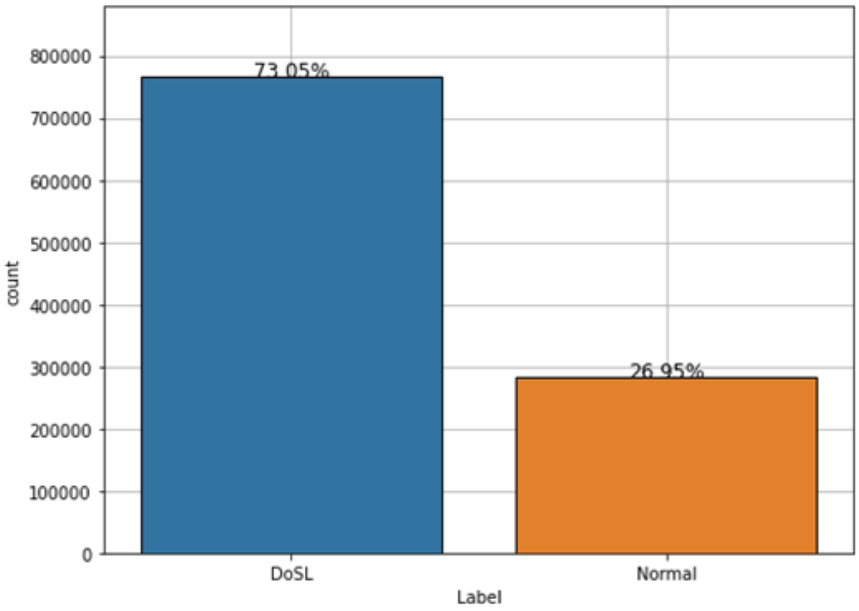

Figure 7. Bar chart representation for the distribution of target labels in dataset.

This DoSl attack detection dilemma can be treated as a binary classification problem. Therefore, when generating the dataset, it was designed to have two labels, namely: *Normal* or *Attack* labels. The distribution of *Normal* and *Attack* packets in the whole dataset is depicted in Figure 7.

The blue bar shows the packet rate of the *Attack* packets in the generated dataset, which is 73.05%. The orange bar shows the packet rate of *Normal* packets, which is 26.95% in the dataset that was generated from the DoSl-attacked NB-IoT network topology, as was discussed before. The dataset will be preprocessed in order to be more suited for presentation to each of the collection of investigated ML models. The next two steps will be performed in order to select which features in the generated dataset have more relevance in better detecting the *HELLO flood* DoSl attack.

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1) Multi-Correlated Features

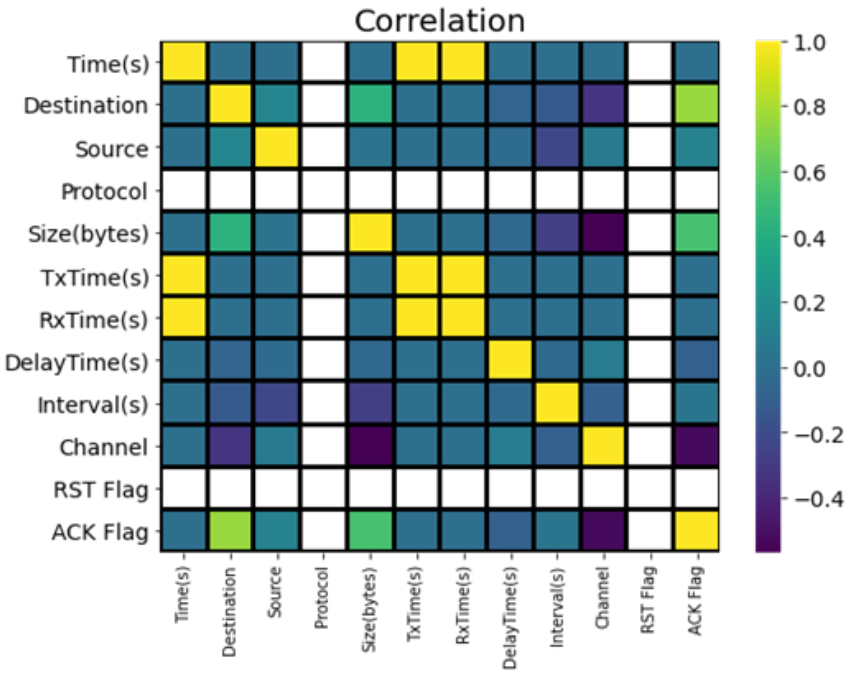

Figure 8. Heat map for Pearson correlation values between features in the extracted NB-IoT DoSl dataset.

Multi-Collinearity means that there are many features in the dataset that are highly correlated with each other, so they are monotonically increasing or monotonically decreasing together. In order to find the correlation, the Pearson correlation coefficient was used to extract the main features that are least correlated to each other. The linear correlation between two variables x and y could be measured by using (12), as in Wang, Liao & Chang (2018):

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \acute{x})(y_i - \acute{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \acute{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \acute{y})^2}} \quad (12)$$

where $\acute{x}$ is the mean value of x, $\acute{y}$ is the mean value of y, and r_{xy} is the Pearson coefficient between x and y. The results of applying (12), for the correlation matrix between each pair of features, are illustrated in Figure 8.

2) Constant Features

Constant features increase the redundancy in the dataset, which affects the detection accuracy. For this reason, they should be removed. In order to remove these features, the standard deviation has been calculated for each feature column in the dataset (Sharafaldin, Lashkari & Ghorbani, 2018).

3) Normalization

A scaling method will be applied in order to obtain the appropriate ranges of the feature values. For further applications of the dataset in DL models, it is required to perform normalization in order to make the samples more comparable. We mapped the original data range (X) into

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another data scaled range by taking the minimum value (X_{min}) and the maximum value (X_{max}) and replacing them with the chosen new scaled range ($X_{Normalized}$). Then, we computed the normalized values of the samples using (13) (Yin *et al.*, 2017).

$$X_{Normalized} = \frac{(X - X_{min})}{(X_{max} - X_{min})} \quad (13)$$

Our dataset has then been divided into training, validating and testing ranges of samples, as demonstrated in Table 2, in order to investigate, analyze and evaluate performance in detection accuracy of our collection of considered ML models through computation of evaluation metrics for these models.

Table 2. Number of records used in paper.

Kind of record	Number of records	Used percentage
Training Records	734,002	70%
Validation Records	157,286	15%
Testing Records	157,286	15%

Numerical Results and Discussion

The machine learning RNN models were implemented using Python on the cloud-based environment, Google Colaboratory (Colab) platform (Google Colaboratory (Colab), 2021; Bisong, 2019), for training and testing of all samples to obtain reliable, consistent, and accurate results for verification. During the implementation of LSTM and GRU classifiers, a number of parameters were tuned so as to get the final design of the DoSl attack detection system given in Table 3. There are test values of the hyper-parameters that were based on ones adapted from Tang *et al.* (2019), Wei & Nguyen (2019), and Wang, Liao & Chang (2018), to start-off with. Nevertheless, the final retained values selected for the classifiers' design parameters were those that yielded best achieved accuracy.

Table 3. Design Parameters of LSTM and GRU classifiers.

Parameter	Tested values	Best chosen values
Batch-Size	32, 64, 128	128
Hidden Layers	1, 2, 3	3
Optimizers	Adam, SGD.	Adam
Activation Functions	Tanh, Sigmoid, ReLU	ReLU, Sigmoid
Epochs	100	100

In order to evaluate the adopted ML models' effectiveness in attack detection, some evaluation metrics have been computed, such as loss function, confusion matrix parameters (Saeedi, 2019; Yin *et al.*, 2017), error matrix, receiver operating characteristic (ROC) curve, area under curve (ROC-AUC), precision, recall and $F_{1-score}$,to figure out the performance of the adopted LSTM and GRU models.

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Initially, the ML classifiers, including DL models, were tested on the original dataset (without preprocessing) to establish a performance baseline for comparison with the performance results achieved in application and testing with the preprocessed dataset.

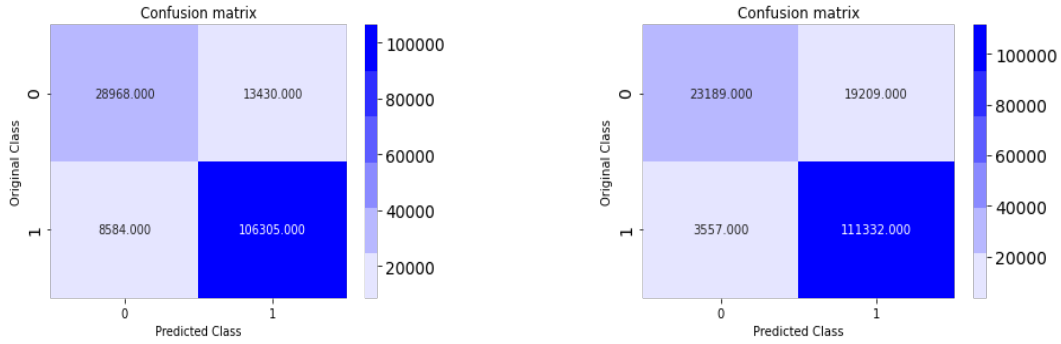
1) Original Non-Preprocessed Dataset Performance Evaluation Results

This original raw dataset has been fed into RNN models before preprocessing, in order to verify that the applied preprocessing steps have indeed enhanced their corresponding performance. As depicted in Table 4, the LSTM model has achieved 87%, 0.8042, 0.8878, 0.9252 and 0.9061, in terms of accuracy, ROC-AUC, precision, recall and $F_{1-score}$, respectively. The GRU has achieved 85.52%, 0.7579, 0.8528, 0.9690 and 0.9072, in terms of accuracy, ROC-AUC, precision, recall and $F_{1-score}$, respectively.

Table 4. Performance comparison in terms of accuracy, AUC, precision, recall, and F1-Score between LSTM, GRU, SVM, Logistic Regression and Gaussian Naïve-Bayes when applied on original dataset.

Model used on the original dataset	Accuracy	ROC-AUC	Precision	Recall	F1-Score
LSTM	0.87	0.80	0.89	0.93	0.91
GRU	0.86	0.76	0.85	0.97	0.91
Linear SVM	0.85	0.75	0.85	0.97	0.90
Gaussian Naïve-Bayes	0.78	0.71	0.85	0.85	0.85
Logistic Regression	0.85	0.76	0.86	0.95	0.90

The confusion matrices for both the LSTM and GRU models are illustrated in Figure 9, and the ROCs in Figure 10. In addition to the considered DL RNN models, performance metric values obtained for other traditional ML algorithms are presented in Table 4.



(a) (b)

Figure 9. Confusion matrix for RNN models with original dataset: (a) LSTM; (b) GRU.

2) LSTM and GRU Performance Evaluation Results – The Preprocessed Dataset

The performance of LSTM and GRU models was compared after training the models for 100 epochs and evaluating the accuracy and confusion matrix parameters. As illustrated in Figure 11(a), the LSTM model has predicted successfully 113,881 true DoSl attack packets (labelled with class label 1), and predicted successfully 41,833 true normal packets (labelled with class 0 label),

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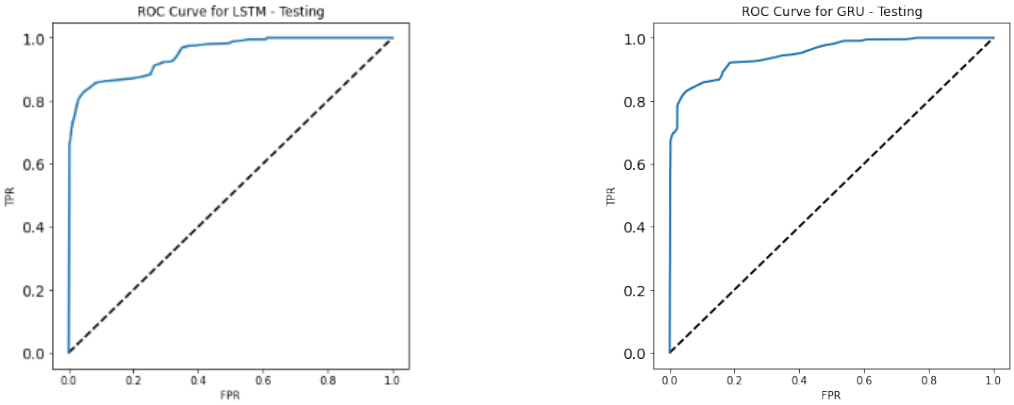
while it unsuccessfully predicted 1,008 attack packets and 565 normal packets, out of 157,286 total testing samples.



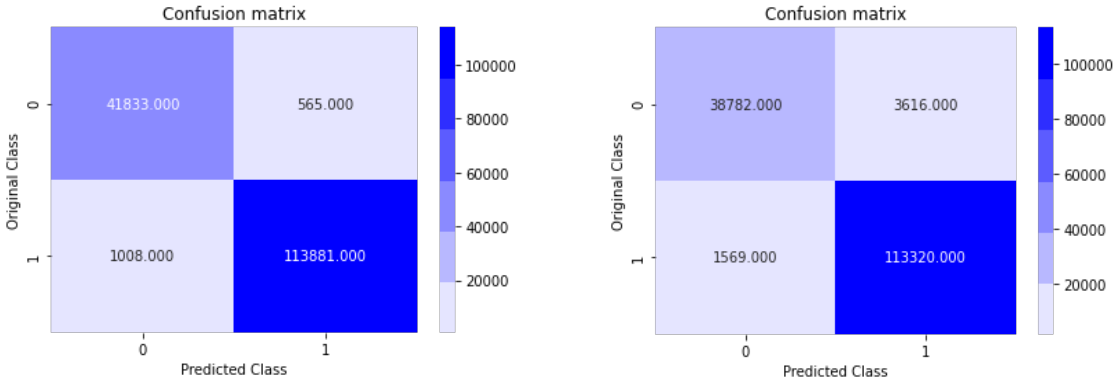
(a) (b)

Figure 10. ROC for (a) LSTM (b) GRU models when applied on original dataset.

The GRU model has successfully detected 113,320 DoSl attack packets and missed detection of 1,569 packets, while it has successfully predicted 38,782 normal records, as shown in the confusion matrix of Figure 11(b). While it has incorrectly predicted 3,616 packets out of 157,286 total testing samples. It is evident from the previous results that both RNN models have effectively learnt how to classify DoSl attack and normal packets in the preprocessed dataset. To support our observations, however, we evaluated other previously presented performance metrics. The loss function (LF) and accuracy plots versus epoch number for each of the LSTM and GRU models are illustrated in Figure 12 when training and validating the dataset when presented with the pre-processed dataset. The LF for both models is computed by the mean squared error (MSE) using (14):

$$LF = MSE = \frac{1}{n}\sum_{i=1}^{n}\left(Y_i - \hat{Y}_i\right)^2 \quad (14)$$

where Y_i is target and $\hat{Y}_{i_i}$ is output.



(a) (b)

Figure 11. Confusion matrix for RNN models with preprocessed dataset: (a) LSTM (b) GRU.

Applying testing samples after concluding the training phase, the accuracy reached up 98.99% with a detection time of 2.54×10^{-5} second/record at the 100th iteration for the LSTM model,

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as shown in Figure 12(a). The GRU model has begun with a low value of accuracy, then it has improved along epochs until it has achieved an accuracy of 96.70%, with $1.90e^{-5}$ seconds/record detection time, as shown in Figure 12(b).

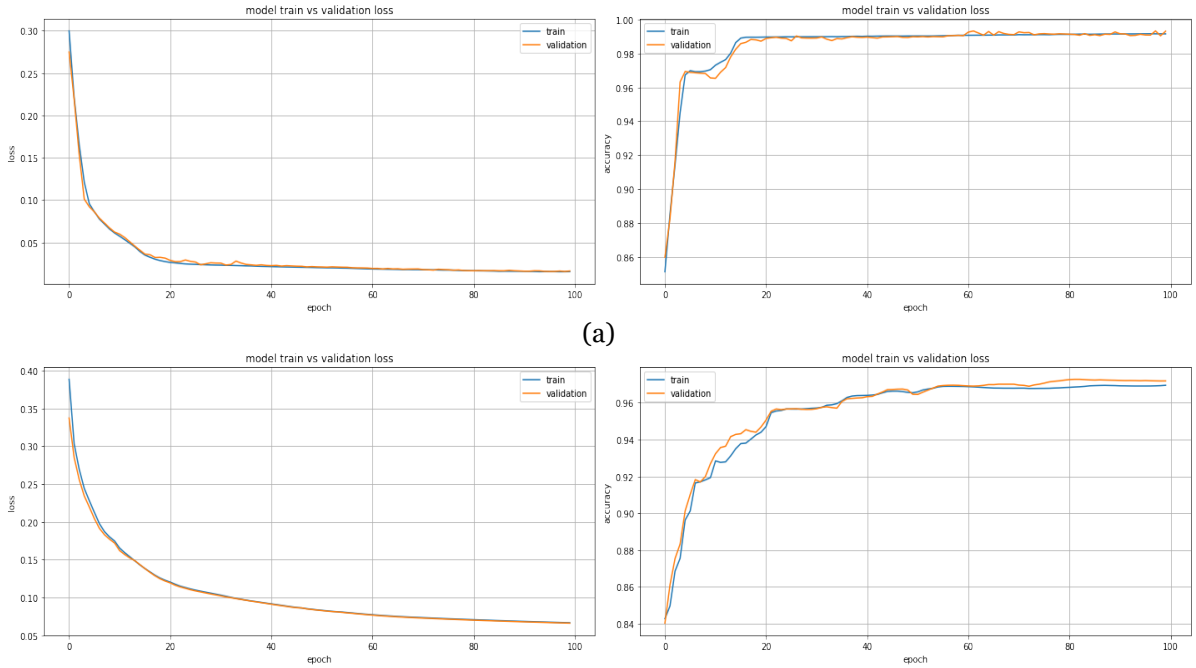

Figure 12. Plots of loss function and accuracy for training and validation range of dataset along epochs for (a) LSTM and (b) GRU models with preprocessed dataset.

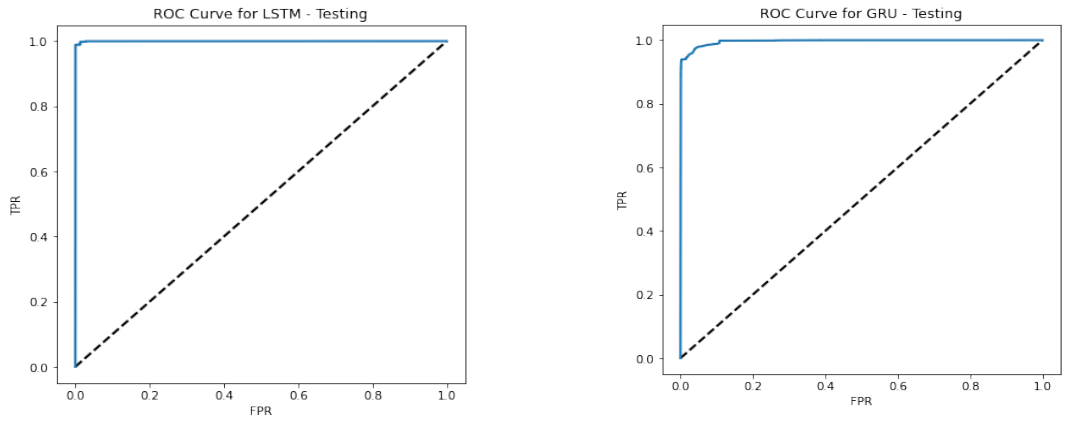

Figure 13. ROC-AUC for (a) LSTM and (b) GRU models when applied on preprocessed dataset.

The AUC is considered to be a powerful indicator of classifying performance of binary predictive models. As AUC reaches 1, the predictive performance of the model is considered optimal. The ROC-AUC for the LSTM and the GRU models are plotted in Figures 13(a) and 13(b), respectively, where it reached up to 0.9889 for LSTM and 0.9505 for the GRU. Also, the precision, recall, and $F_{1-score}$ performance metrics have been calculated for both models, where the LSTM model attained the respective values of 0.9950, 0.9912 and 0.9931, while the GRU model achieved 0.9690, 0.9863, and 0.9776 in terms of precision, recall, and $F_{1-score}$, respectively, as detailed in Table 5.

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Table 5. Performance Metrics Results Summary for RNN Models and Traditional ML Algorithms.

Model Type	Accuracy	ROC-AUC	Precision	Recall	F1-Score	Detection time (seconds/ record)
Original dataset/LSTM	87.00%	0.8042	0.8878,	0.9252	0.9061	4.45×10^{-5}
Original dataset/GRU	85.52%	0.7579	0.8528	0.9690	0.9072	3.81×10^{-5}
LSTM	98.99%	0.9889	0.9950	0.9912	0.9931	2.54×10^{-5}
GRU	96.70%	0.9505	0.9690	0.9863	0.9776	1.90×10^{-5}
Linear SVM	85.10%	0.7549	0.8538	0.9682	0.9047	3.18×10^{-5}
Gaussian Naïve-Bayes	78.46%	0.7123	0.8514	0.8546	0.8472	1.27×10^{-5}
Logistic Regression	85.35%	0.7601	0.8572	0.9528	0.8991	1.27×10^{-5}

Achieved performance of the RNN models has also been compared to other traditional ML classification algorithms, including support vector machine (SVM), Gaussian naïve-Bayes (GNB), and logistic regression (LR). The SVM classifier model achieved an accuracy up to 85% with a DoSl attack detection response time of 3.18×10^{-5} seconds/record, when training 734,002 and testing 157,286 samples. The GNB and LR classifier models detected the DoSl attack by 78% and 85% in terms of accuracy, respectively. Their DoSl attack detection time response was 1.27×10^{-5} seconds/record for each model. The remaining considered performance parameters, including confusion matrix, precision, recall, and $F_{1-score}$, are also presented in Table 5. It is evident that, while DL RNN models have superior performance in terms of accuracy of detecting DoSl attacks, when compared with other well-known traditional ML algorithms, including SVM, GNB, and LR, within the framework of our investigation and analysis, the LSTM was the better performer than the GRU of the two RNN models.

Conclusion

The NB-IoT wireless connectivity technology within the broad domain of IoT facilitates expedited deployment, due to the special feature of flexible wide coverage, using a small frequency bandwidth on existing cellular technologies, with a nationwide or even global introduction, and integration with sustained seamless coverage of high capacity. Along with that, security challenges become more critical and worth investigating. In this paper, *HELLO flood* DoSl attack is investigated within the framework of a model NB-IoT network, where a novel dataset of 1,048,576 records has been generated for this purpose, utilizing the ns-3 network simulation suite. Our investigation revealed that DL RNN models, including LSTM and GRU, are very advantageous in the detection of DoSl attacks on NB-IoT networks.

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Also, when compared with other well-known traditional ML algorithms, including SVM, GNB, and LR, within the framework of our investigation and analysis, it was clear that DL RNN models have the superior performance in terms of accuracy in detecting DoSl attacks. Moreover, the LSTM model was a better performer than the GRU model among the two RNN DL models, where it has achieved a high detection rate up to 99% against the considered DoSl attacks. These results verify the feasibility of the proposed DL RNN models in enhancing network security of the numerous vertical industries that employ NB-IoT networks.

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Latency Analysis for Mobile Cellular Network uRLLC Services

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Abstract: The fifth generation (5G) mobile network technologies include ultra-Reliable Low Latency Communications (uRLLC) capability. To fully exploit uRLLC, distributed Multi- access Edge Computing (MEC) is being developed and introduced at the network edge with an architecture that supports applications and services. Some of the MEC applications will benefit from uRLLC, including virtual reality, augmented reality, education, health, online gaming, automatic manufacturing and Vehicle-to-everything. However, unique challenges and opportunities exist for 5G cellular networks and MEC due to a range of factors, including end-user device mobility and the implementation of the network Control Plane (CP) and User Plane (UP). In this regard, there is a need to optimize protocols and network architecture. This paper investigates latency and related network elements in the next generation mobile cellular network. We also analyze the 5G network latency in the CP and UP. Finally, the paper identifies protocol optimization considerations for MEC integration with 5G to achieve low end-to-end latency.

Keywords: Ultra-reliable Low Latency Communications, Multi-access Edge Computing, End-to-End Latency, User Plane, Control Plane

Introduction

The evolution of mobile telecommunications and the development of information technology provides new horizons for the introduction of the Internet of Things (IoT), person-to-person and machine-to-machine communications. The innovative applications that are supported by the fifth generation (5G) mobile networks include remote surgery, smart cities, online gaming, virtual reality, augmented reality and autonomous vehicular networks. Specifications,

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architectures and standards are required for the new technologies, e.g., heterogeneous connections, high-throughput, ultra-reliability and ultra-low latency communications. The International Telecommunication Union (ITU), working with industry bodies, has introduced three areas of focus for 5G technology development, including enhanced Mobile Broadband (eMBB), massive Machine Type Communication (mMTC) and ultra-Reliable Low Latency Communications (uRLLC). With the introduction of 5G, significant improvements will be achieved for throughput, reduced latency, mobility, connectivity, density and energy efficiency.

For the 5G uRLLC scenario, the end-to-end (E2E) latency should be reduced to 1-10 ms (1 ms for user plane delay, 10 ms for control plane delay), which is 20% of that achieved for 4G. The 5G technology improvements are a big step forward; however, there is a need for compute and storage offloading at the network edge to ensure that the 5G improvements can be fully realized. Multi-access Edge Computing (MEC) is being developed and introduced at the network edge to fulfill this role. The European Telecommunications Standards Institute (ETSI) has made a significant contribution to the development of MEC and continues to provide guidance on specifications and architectures for MEC. MEC servers will be deployed at the edge of the 5G network to provide a facility for computation and data offloading and to reduce the current reliance on the Cloud with its associated high latency (Li, Wang & Zhang, 2020). MEC services, including Radio Network Information Service (RNIS), Location Service (LS) and Traffic Management (TM), can be used to make intelligent network-related decisions for effective service continuity and mobility.

To fulfil the potential of MEC with 5G, researchers have been rethinking network architectures and protocols. Changes to the core network architecture are a primary symbol of the evolution of the network. The mobile core network has evolved to become separated, virtualized and software-based. The Control and User Plane Separation (CUPS) architecture was introduced in 4G EPC nodes. In the 5G Core (5GC) architecture, the control and user plane separation has further evolved. Network slicing was introduced into the 5GC architecture. A network can be virtualized into multiple network slices. Each slice has its application scenario, network capability and quality assurance, and different slices are isolated from each other.

Network Function Virtualization (NFV) is being implemented in the core network to enhance communication network flexibility. NFV can be used to decouple hardware and software. Network functions can be rapidly and dynamically created and migrated utilizing modern software practices. Software Defined Networking (SDN) is a paradigm being introduced that separates the network control and forwarding planes, and the centralized control plane provides the 5G network with visibility, flexibility and dynamic deployment capability. However, the deployment of the SDN controllers in 5G networks can increase latency. The

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further separation between the Control Plane (CP) and User Plane (UP) components increases the number of network components involved, and the messages exchanged among them. Complex CP exchange increases the latency and overhead. Therefore, optimizing the network protocols and architecture is a current research focus that aims to significantly reduce latency in this scenario (Parvez *et al.*, 2018; Mohammadkhan, Ramakrishnan & Jain, 2020).

In this paper, the network latency and a selected latency-sensitive application (mobile online gaming) are analyzed in different domains. The latency is analyzed in the CP and UP. To emphasize the importance of optimized system architecture and protocols, selected CP protocols, e.g., User Equipment (UE) Registration and Handover procedures, are analyzed. The latency is analyzed in a real mobile network to identify the need for an optimized network architecture and protocols. Finally, the considerations for an MEC handover protocol are provided. The main contributions of this article are summarized as follows:

- We elaborated on the recent advances in lowering latency in the CP and UP planes across different domains.
- We emphasized the importance of an optimized network architecture and protocols to enhance service mobility and continuity.
- We analyzed the latency in the CP and UP in a real cellular network and identified the need for an optimized 5GC architecture.
- We identified CP latency as an ongoing challenge.
- We discuss the potential approaches for an optimized handover protocol based on the integration of 5G and MEC.

The rest of the paper is organized as follows. A review of related works is presented in the Current Research section. The Latency Definition and Use Cases section provides a review of the latency in different domains. The CP and UP Latency Analysis section comprehensively analyzes the latency in the CP and UP, the latency caused by mobility, and indicates the importance of the necessity of optimized CP protocols and network architecture. In the System Architecture and Protocol Consideration section, we identify considerations for an optimized handover protocol. The paper is concluded in a Conclusion section.

Current Research

MEC and 5G significantly benefit uRLLC applications. Recently, researchers have investigated how the integration of MEC and 5G affects latency and have explored the use cases. Shukla *et al.* (2021) discussed the recent latency reduction technologies, including Fog computing, machine learning and conventional techniques, in the cloud and IoT across computation. Parvez *et al.* (2018) presented a detailed latency survey by considering the different domains in 5G, including Radio Access Network (RAN), core network and caching. In the RAN domain,

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the emerging technologies were studied, e.g., short frame, new waveform design, modulation and coding scheme, to facilitate low latency. SDN, NFV and MEC deployments with 5GC were also investigated to identify how latency was affected. Distributed and centralized caching, e.g., cache placement and content delivery methods, were presented for latency minimization in the caching domain.

As a typical uRLLC application, mobile online gaming has been investigated to explore the challenges of the architecture. In Premsankar, Di Francesco & Taleb (2018), Premsankar, Di Francesco & Taleb evaluated the MEC performance for mobile gaming, and the results showed that MEC deployment effectively reduced the latency for mobile gaming. Kasenides & Paspallis (2020) compared the performance of the different game services in terms of latency, and the study showed that Infrastructure as a Service (IaaS) implementations outperformed Platform as a Service (PaaS) implementations. Huedo *et al.* (2021) proposed a distributed edge cloud platform, where an online gaming application was deployed across seventeen locations. The results showed that the latency achieved from the experiment was below 10 ms.

The recent changes to the 5G network architecture significantly improved network and service performance. One of the goals of the 5G technologies is to reduce network latency to meet the demands of the new specification for uRLLC services. Guimaraes *et al.* (2020) proposed an SDN-NFV based architecture in Wi-Fi networks by using the SDN and NFV orchestration functionalities. The proposed architecture significantly improved mobility management and reduced latency. Tomaszewski, Kukliński & Kołakowski (2020) proposed the three variants of the integration of MEC into 5GC architecture based on the consideration of service mobility and continuity. Khaturia *et al.* (2021) proposed a novel 5G architecture by separating UE control from network control to improve the flexibility of the 5G network architecture. Abdulghaffar *et al.* (2021) proposed an SDN-based 5GC network architecture to enhance the flexibility of network management. The results indicated that the proposed architecture reduced the latency by from 18% to 62% when compared with the previously proposed architecture.

Articles that respond to optimization of the CP protocols related to latency, including access and handover procedures, were reviewed. Mohammadkhan *et al.* (2016) proposed a simplified software-based architecture and a simplified control protocol for the mobile network by reducing the number of control messages to achieve lower latency. Gaur *et al.* (2018) proposed an efficient vertical handover based on containerization in IoT networks by considering criteria such as latency, reliability, and power consumption. The proposed method enhanced data precision for latency and reliability. Tan *et al.* (2018) identified that the signalling operation contributes a large portion of the latency and proposed a cross-layer design to reduce latency in the signalling operation. Zhou *et al.* (2021) proposed a handoff algorithm by

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considering the combined signalling and computational load. The result indicated that the proposed algorithm could significantly reduce the latency.

Latency Definition and Use Cases

Latency in the Next Generation Cellular Network

E2E latency across multiple networks is a focus for the next generation cellular networks. The latency of the E2E service delivery includes both processing delay and network delay. The processing latency is the computational latency (router, switch, VMs). The network latency is the sum of the transmission delay and the propagation delay over the link between two network entities. The transmission delay is the time for a forwarding device to receive or to send a packet (Martini *et al.*, 2015). In the 3rd Generation Partnership Project (3GPP), latency in a 5G network can be divided into CP latency and UP latency. In order to send or receive packets, the UE must be in the active mode following the idle mode. In the idle mode, the UE is in the Radio Resource Control (RRC) disconnected state The UE is in the RRC connected state in the active mode. The delay that happens in this process is defined as the typical CP latency. A signalling process is performed between the radio and the core network. Therefore, the CP latency in 5G networks is the time consumed by the signalling message exchange in the CP. In the next generation mobile network (NGMN) white paper (Hattachi & Erfanian, 2015), the UP latency is the time consumed to transfer and receive a data packet from the UE to the destination node at the 5G network interface between layer 2 and layer 3. In 3GPP TS 22.261 (G.Group.A, 2021), the E2E latency is the time consumed to transfer a given piece of information successfully from a source to a destination, which is measured at the communication interfaces. E2E latency is not only in the 5G network but also is in other networks outside of 5G networks. The latency definition is also considered in One-way delay (OWD) and Round -trip time (RTT). OWD is the time taken to transfer a packet from the source to the destination. RTT is the time taken by a packet that is transferred from the source to the destination and for a response from the source to be received at the destination. Overall, the network latency can be defined as a packet transferred over multiple networks or application nodes such as RAN, core, transport and data centre, along with the one-way or round-trip time (Kurian, 2018). Figure 1 depicts the typical route for the E2E delay of a packet transmission.

There are several approaches that might be explored for latency reduction in the RAN, including frame/packet structure, symbol detection, waveform/multiple access, mmWave, location-aware communication, and improved modulation. The backhaul latency occurs between the gNodeB and the core network over copper wires, optical fibres or microwave. The latency in the core network is the transmission and processing, which is a combination of

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delays associated with the network entities and control signalling. The transport latency is the transmission and signalling delay between the core network and end-points considering transport layer delays and signalling (Parvez *et al.*, 2018).

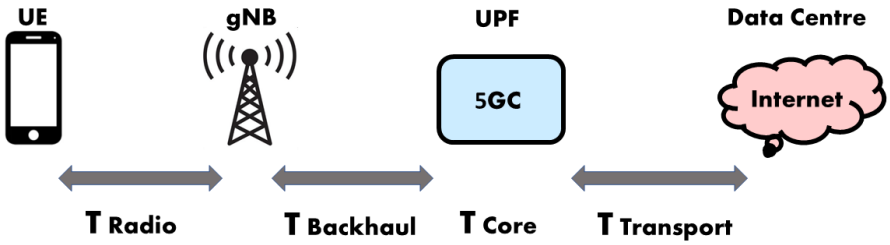

Figure 1. Latency contribution in packet transmission E2E delay

Latency-sensitive Application: Mobile Online Gaming

Mobile online gaming is likely to become one of the most popular 5G uRLLC applications. However, the user experience will degrade when the network latency is more than 30-50 ms. Ideally, 1 ms RTT is recommended for mobile online gaming, e.g., human interactive applications with high-quality visualization. An architecture for mobile online gaming is provided in Figure 2.

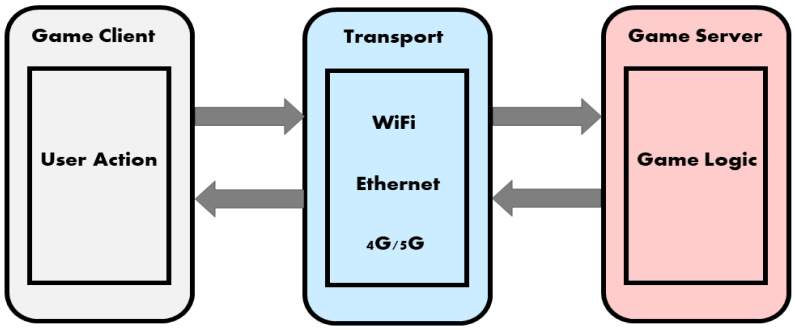

Figure 2. Mobile Online Gaming Architecture

Mobile online gaming has three key elements: the gaming client, the transport network and the gaming server. The players connect and use the gaming client, while the gaming server's role is to provide game logic management. The transport network provides the communications path between the gaming server and the gaming client and includes the mobile telecommunication network. The latency caused by the game operation can be divided into three parts: processing delay, playout delay and network delay. The time consumed for the gaming server to receive gaming client commands, to process and update the game state and respond is called the processing delay. Playout delay is the time consumed for a gaming client to receive, decode and render a frame on the screen. The network delay is the time required for a round of data to be exchanged between the gaming client and the gaming server (Peñaherrera-Pulla *et al.*, 2021; Sreenibha Reddy & Zaahid, 2018).

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Network latency is the essential network performance metric for mobile online gaming. The gaming server location and distance to the gaming clients will significantly affect the network latency. Network congestion will also affect latency. The decision on where to locate gaming servers is an essential consideration, affecting network architecture and energy utilization. The deployment of multiple gaming servers complicates the protocol and data exchange among the network components, thereby increasing latency. Therefore, the latency should be analyzed from different network domains and planes, combined with user behaviour, to achieve optimized protocols and network architecture for latency minimization (Peñaherrera-Pulla *et al.*, 2021; Sreenibha Reddy & Zaahid, 2018).

Control Plane and User Plane Latency Analysis

CP and UP Protocol Stacks

In 4G networks, the CP and UP are not completely separated, and some of the signalling messages and user data flow through the Serving Gateway (SGW) and Packet Data Network Gateway (PGW). Such a centralized system structure reduces network control and maintenance but limits backflows. In particular, the CP should focus on signal processing, while the UP should forward data. Thus, a fully decoupled CP and UP design should increase efficiency. Even though the CUPS was introduced in 4G, it is in 5G networks that CUPS has been fully implemented. CUPS in 5G allows network operators to separate the CP and UP, where the CP can be managed centrally. As we can see from Figure 3 and Figure 4, the 5G CP protocol stack is shown including UE, 5G-Access Network (AN), Mobility Management Function (AMF) and Session Management Function (SMF) in 5GC, and the UP protocol stack for UE, 5G-AN and User Plane Function (UPF) in 5GC. The data flows are transmitted through each sublayer of the UP. The signalling is exchanged between the CP sublayers. In 3GPP TS 23.501, the protocol stacks among 5G system elements are described, including the UE, the 5G-AN, the 5GC and 5G network functions. In Figure 3, the CP protocol stacks between the UE and the SMF via interfaces N2 and N11 over the multiple protocol layers are described, including NG Application Protocol (NG-AP), Stream Control Transmission Protocol (SCTP), 5G-AN Protocol layer, Non-Access-Stratum (NAS)—Mobility Management (MM) and NAS-Session Management (SM). AMF is the most important 5GC CP entity, which mainly supports registration, authentication and mobility management. The SMF is a session establishment, modification and release functional entity of the 5GC. In the CP, SMF is involved in SM parts of NAS message (G.Group.A, 2020). NGAP protocol is responsible for the application layer signalling protocol. SCTP protocol in the transport layer is over the Internet Protocol (IP) layer to guarantee the transport and application layer of the signalling messages. The IP layer provides the transmission of the signalling Protocol Data Unit (PDUs) (E.Group, 2019). The

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NAS protocol on N1 includes a NAS-MM and a NAS-SM. NAS-MM is responsible for registration, authentication, mobility management of NAS signalling and supports the UP activation and deactivation. NAS-SM is responsible for the PDU session management and is transparently transferred to the AMF. The 5G-AN protocol layer is a set of protocols related to the 5G access network.

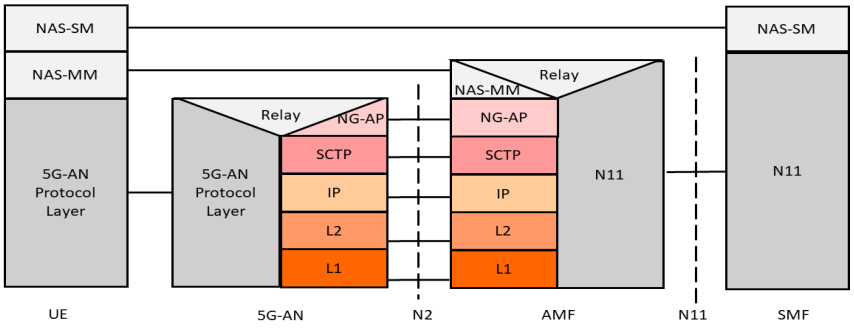

Figure 3. 5G Control Plane Protocol Stack [(G.Group.A, 2020)]

In the UP protocol stack, Figure 4 illustrates the UP transport for a PDU session from UE to UPF over UP protocol layers, including the PDU layer, GPRS Tunnelling Protocol for the User plane (GTP-U), 5G-AN and User Datagram Protocol (UDP)/IP via N3, N9 and N6 interfaces. UPF is a primary UP entity responsible for packet routing and forwarding. The PDU layer transmits PDU between the UE and the Data Network (DN) over the same PDU session. The GTP-U protocol layer provides user data tunnelling, the encapsulation of a PDU session, and a QoS flow definition. UDP is a transport layer protocol and supports unreliable datagram transmission between applications. IP is a network layer protocol and is responsible for a datagram service delivered between applications. TCP and UDP are the key network protocols used to transport traffic [(G.Group.A, 2020)].

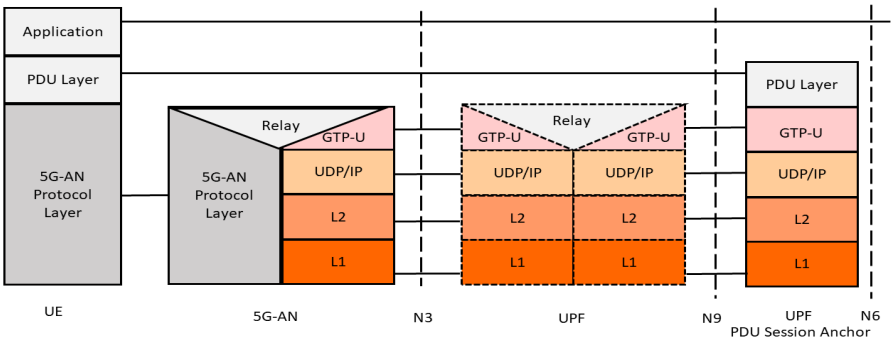

Figure 4. 5G User Plane Protocol Stack [(G.Group.A, 2020)]

Separation of the CP and UP enables flexible network operation and deployment and enhances the independent scaling of the network architecture, such as flexibly adding UP nodes without affecting the CP nodes, enabling SDN and NFV in the CP more efficiently, and providing a relatively independent evolution for the functions in the CP and UP.

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Control Plane Protocol Analysis

Due to the CP and UP separation and a set of distributed network components based on SDN and NFV, the cellular network has evolved into a new network architecture. However, this also increases the number of network components and the number of control messages exchanged, which significantly increases the protocol overhead and latency (especially in the CP). The CP latency is the key factor affecting E2E latency. Meanwhile, data packets in UP often wait for the CP functions to occur. Therefore, optimizing the CP latency will significantly reduce the E2E latency and improve user experience. We discuss and analyze selected 5G CP protocols (UE Registration and Handover) in the following sections.

Initial UE Registration Procedure

The initial UE registration procedure is a typical CP procedure. During an initial registration procedure, a user wants to make a connection with the cellular network to enable authentication, mobility tracking and service reachability. This event is quite similar in 4G and 5G protocols. It is called the initial attach procedure in 4G and the initial registration procedure in 5G.

The initial registration procedure in 5G is described in Figure 5 (E.Group, 2018). The UE first sends an RRC Connection Request to the gNB-Distributed Unit (gNB-DU). Once gNB-DU receives this message, the F1 Application Protocol (F1AP) Initial UL RRC Message Transfer message for UE will be transferred to gNB-Centralized Unit (gNB-CU) with Cell RNTI (C-RNTI) allocated by the gNB-DU. Then, gNB-CU will allocate a gNB-CU UE F1AP ID for the UE and creates an RRC Connection Setup message for the UE, which will be encapsulated in the F1AP DL RRC Message Transfer message. The gNB-DU sends the RRC connection Setup to the UE, then the UE sends back the RRC connection Setup Complete to the gNB-DU. Once gNB-CU has received the UL RRC message Transfer, it will trigger an Initial UE message to AMF. From steps 8 to 18, the UE Context, RRC security and reconfiguration will be set up and completed. After UE sends the RRC Connection Reconfiguration Complete message to the gNB-DU, gNB-DU completes encapsulation and sends it to the gNB-CU. The Initial UE Context Setup Response message will be sent to the AMF. Initial UE registration is then complete.

The function of the F1AP is to provide the signalling service between a gNB-CU and a gNB-DU. C-RNTI is responsible for identifying and scheduling RRC connection to a particular UE. In Jin, Zhong & Zhou (2016), an optimized access procedure was proposed for 4G networks by saving UE context information in the eNodeB in the idle state and sinking the control function of the radio bearer from the MME to the eNodeB and configuring the radio bearer to

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reduce signalling overhead and CP latency. The proposed access procedure also can meet the low latency requirements of the 5G network.

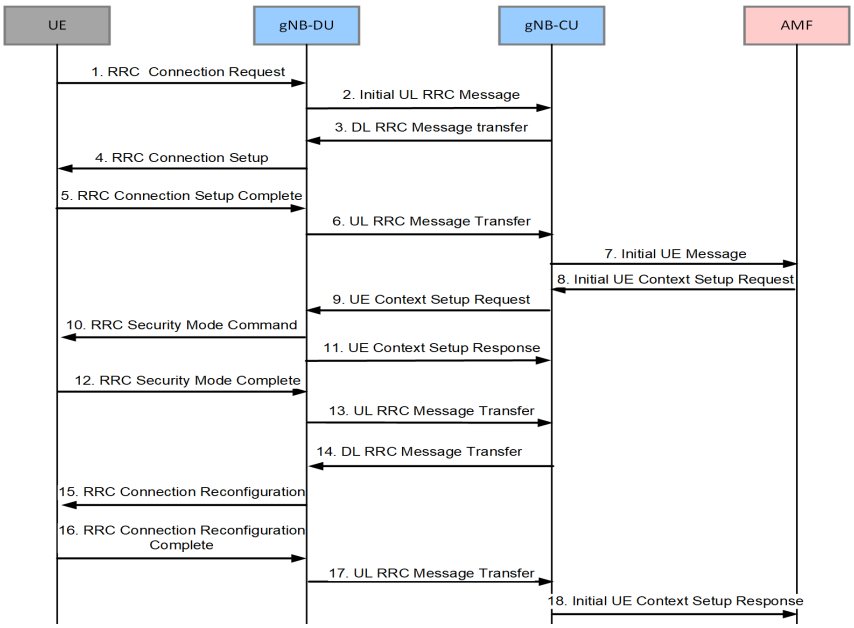

Figure 5. UE Initial Registration Procedure in 5G (E.Group, 2018).

Handover Procedure

When a UE moves across the network, handover happens from the serving base station to an adjacent base station. Handover is a significant cause of mobility latency. In order to reduce mobility latency, handover is optimized. There are two handover mechanisms, including hard handover and soft handover. A hard handover is a break-before-make approach, while a soft handover is a make-before-break approach. In 4G networks, 3GPP specifications include hard handover. A common strategy is X2 interface handover in 4G, in which the handover procedure occurs between eNodeBs and the signalling load towards the core network is reduced. On the other hand, in terms of S1 handovers, a reduced core network interaction was performed — this improved 4G network handover. The 5G uRLLC demands that handover latency be very close to zero. 5G handover includes Xn and N2 handover, and the differences between 4G handover (X2, S1) and 5G Handover (Xn, N2) are subtle. 5G Xn handover and 4G X2 handover are both hard handovers, where UE releases the connection to the source gNodeB before the connection to the target gNodeB is established. Here, before the UE starts to communicate with the target gNodeB, the uplink and downlink transmissions are finalized in the source gNodeB. This handover mechanism causes an interruption in communication between the network and the UE.

In order to optimize the mobility management procedure, reducing the handover interruption time between 5G cells is critical. To overcome this, a Dual Active Protocol Stack (DAPS) handover has been proposed by the 3GPP. DAPS handover maintains the source gNodeB

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connection after reception of the RRC message for handover and releases the source gNodeB after successful random access to the target gNodeB (G.Group.B, 2021).

Research into the optimization of the handover procedure has occurred. Gimenez *et al.* (2017) proposed a data forwarding mechanism with the handover (make-before-break) procedure by analyzing handover time, UE and e-NodeB processing times and interface latency. The result indicated that the proposed data forwarding can reduce the interruption time by 18% and make-before-break handover is much more suitable for future latency-sensitive applications. Jain, Lopez-Aguilera & Demirkol (2018) proposed a new handover signalling method based on enhanced SDN and evaluated this method in 4G and 5G scenarios. The proposed mechanism effectively reduced latency and processing costs compared to the 3GPP handover specifications. Peltonen, Sasse & Basin (2021) presented a comprehensive analysis for 5G handover protocols and indicated that a formal and comprehensive analysis is essential for designing the reliability and security protocols and network architecture.

User Plane Protocol Analysis

In a cellular network, the UP latency is the time taken to transmit a packet/message on the application layer over the radio protocol layer 2 and layer 3 in between the uplink and downlink. For uRLLC applications, UP latency requirements are 0.5 ms for UL and 0.5 ms for DL. Improved reliability also needs to be associated with lowering latency. For the next generation cellular technologies, the UP latency should be much lower than the current target (G.Group.B, 2020). Evangelista, Kaddoum & Sattar (2021) formulated a mathematical model to analyse the latency and reliability performance of mmWave massive MIMO uRLLC applications by using the reactive and K-repetition Hybrid Automatic Repeat Request (HARQ) protocol. The result indicated that mmWave massive MIMO decreased the failure probability, but there is no significant improvement in reliability with a certain number of antennas. Thus, mmWave massive MIMO alone could not guarantee that the performance requirement is met for uRLLC applications.

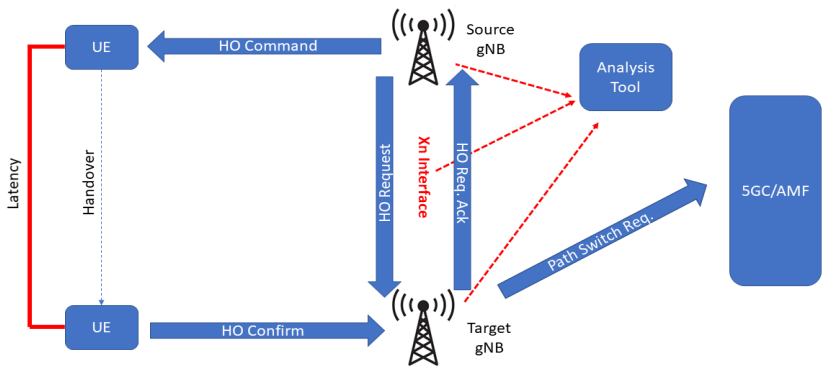

Figure 6. Xn Handover Signal Analysis and Monitoring Framework

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Evaluation

In order to verify the latency among the network components, we conducted two empirical studies of the latency in the CP and UP over a national Chinese service provider 5G network. We collected and analyzed the latency from the two typical control signalling procedures (UE initial registration and Xn handover procedures). The signalling messages were captured from the gNodeB and filtered and analyzed utilizing a standard signalling message statistical and analytical tool. The data analyzed corresponds to 5G cells under good air interface conditions. The handover signal analysis and monitoring framework is specified in Figure 6.

Table 1. Latency in Control Plane for UE Access Procedure

Latency may belong to	Latency	Start	Signal Message	End
UE+RAN	0 ms	UE	RRC Connection Request	gNB-DU
RAN	0 ms	gNB-DU	Initial UL RRC message	gNB-CU
RAN	0 ms	gNB-CU	DL RRC message transfer	gNB-DU
UE+RAN	0 ms	gNB-DU	RRC Connection Setup	UE
RAN	31 ms	gNB-DU	UL RRC Message Transfer	gNB-CU
RAN+CORE	31 ms	gNB-CU	Initial UE message	AMF
RAN+CORE	36 ms	AMF	Initial UE Context Setup request	gNB-CU
RAN	36 ms	gNB-CU	UE Context Setup Request	gNB-DU
UE+RAN	1 ms	gNB-DU	RRC Security Mode Command	UE
RAN	1 ms	gNB-DU	UE Context Setup Response	gNB-CU
UE+RAN	5 ms	UE	RRC Security Mode Complete	gNB-DU
RAN	5 ms	gNB-DU	UL RRC Message Transfer	gNB-CU
RAN	4 ms	gNB-CU	DL RRC message transfer	gNB-DU
UE+RAN	4 ms	gNB-DU	RRC Connection Reconfiguration	UE
UE+RAN	11 ms	UE	RRC Connection Reconfiguration Complete	gNB-DU
RAN	11 ms	gNB-DU	UL RRC Message Transfer	gNB-CU
RAN+CORE	0 ms	gNB-CU	Initial UE Context Setup response	AMF

Table 2. Latency in Control Plane for Xn Handover

Latency may belong to	Latency	Start	Message	End
RAN	152 ms	S-gNB	Handover Request	T-gNB
RAN	9 ms	T-gNB	Handover Request Ack	S-gNB
UE+RAN	0 ms	T-gNB	RRC Connection Reconfiguration	UE
RAN	2 ms	S-gNB	SN Status Transfer	T-gNB
UE+RAN	34 ms	UE	RRC Connection Complete	T-gNB
RAN+CORE	0 ms	T-gNB	Path Switch Request	AMF
RAN+CORE	62 ms	AMF	Path Switch Request Ack	T-gNB
RAN+CORE	0 ms	T-gNB	UE Context Release Request	AMF
RAN+CORE	0 ms	AMF	UE Context Release Command	T-gNB
RAN+CORE	2 ms	T-gNB	UE Context Release Complete	AMF
UE+RAN	0 ms	T-gNB	RRC Release	UE

Tables 1 and 2 indicate the median processing time consumed for each signal message; more than 20 samples have been analyzed. The latency belonging to different network components

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in the CP is shown in Table 1 and Table 2. As we can see from Table 1 and Table 2, CP latency is more than the 5G CP target of 10 ms when the core network latency is around 31 ms-36 ms. In addition, the CP latency caused by the Xn handover procedure during the handover preparation phase is high, around 150 ms, which is much higher than the 10 ms we expected. Therefore, optimizing the 5GC architecture and CP latency is an ongoing challenge.

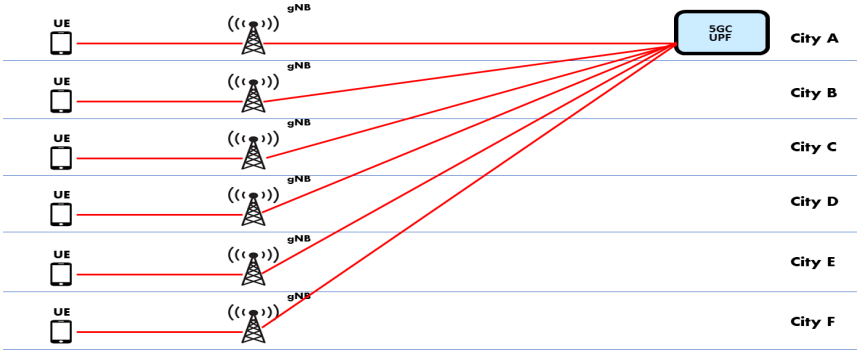

Figure 7. Ping Test Route

Table 3. Latency in User Plane

City	Latency between UE to gNB	Latency in gNB	Latency between gNB to UPF
City A	5 ms	3 ms	1-2 ms
City B	5 ms	3 ms	4-5 ms, 30 ms occurs
City C	5 ms	3 ms	4-5 ms, 30 ms occurs
City D	5 ms	3 ms	4-5 ms, 30 ms occurs
City E	5 ms	3 ms	3-4 ms, 30 ms occurs
City F	5 ms	3 ms	3-4 ms, 30 ms occurs

We also conducted a set of UP ping tests to analyze and verify the UP latency. We chose two cells per city to conduct multiple ping tests from UE to gNodeB, from gNodeB to core network UPF in the 5G network. The UPF of each city was deployed in city A. Figure 7 depicts the ping test route, and Table 3 shows the ping results. The UP median latency between UE and gNodeB in each city was almost the same, due to each pair of the UE and gNodeB being located in the same city. The UP median latency between gNodeB and UPF in city A is also stable for the same reason. For the rest of the cities, the latency is not stable, and 30ms latency occurs as their UPFs are located in city A, away from their gNodeB. Therefore, the backhaul distance and network deployment significantly affect performance and latency. Since the UP procedures need to be triggered and paused until the CP procedures are completed, complex CP protocols will directly affect the UP performance. Thus, cooperation and association with UP protocols also need to be considered when we optimize CP protocols.

System Architecture and Protocol Consideration

Examining the current protocols and latency in the CP and UP, there are many exchanged messages among the network elements, particularly for the evolved core network. A significant

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portion of this traffic is from the distributed network architecture in UP and complex CP protocols such as the handover procedure. Thus, it is essential to optimize the network architecture and lower the CP overheads. In the following section, we analyze the need for network optimization and propose a series of optimization considerations.

5GC and MEC Integration Architecture

The cellular core network is the brain of the telecommunication network and is mainly responsible for user and data control, management and distribution. The functions of each core element are different. To improve core network performance, changes to the core network architecture have occurred, from the separation of CP and UP, to the UP functions linking with the MEC nodes. The network elements on the UP can benefit from services offered by MEC nodes. The MEC technology enables applications by deploying capability to the edge of the network. A distributed architecture migrates the computing, storage and processing tasks close to the UE, thus significantly reducing transmission and processing latency. The new core network enabling technologies, e.g., SDN and NFV, have been proposed to provide hardware and software flexibility to ensure that service mobility and continuity occur.

Challenges related to the 5GC network and MEC include orchestration and management of the network and computation resources, which requires changes in the network architecture. Tomaszewski, Kukliński & Kołakowski (2020) proposed three variants of the integration of MEC into 5G slicing architectures, focusing on the integration of 5GC and MEC solutions. MEC APIs and 5GC CP capabilities from the Network Exposure Function (NEF) will extend the amount of communication information available for MEC and 5G tight integration to ensure smooth interaction and low latency. Fan & Huo (2021) provided an evolutionary perspective for low latency in cellular networks in two important aspects, including network architecture (RAN, core network, and bearer network) and physical layer air interface technologies (packet size, frame structure, modulation scheme, coding scheme, minimum transmission interval). A series of challenges in the network architecture are discussed, such as the trade-off between cost, maintenance and performance, standardized protocol and technologies, resource management and active cooperation. In addition, another challenge is CP scalability whilst balancing CP load to meet 5G latency requirements.

5G and MEC Handover

As one of the most critical procedures of the cellular network, handover can significantly impact the latency in CP and UP and the network performance. Mohammadkhan, Ramakrishnan & Jain (2020) proposed an optimized handover protocol based on a new CleanG system architecture to lower the latency, in which the control component duplicates

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the downstream packet for the source and target eNodeBs, while a sequence number will be added into the packets. Such packet duplication only takes a short period for handover actions. To optimize CP protocols, the authors eliminated synchronization and acknowledgement messages among the different core components. In addition, they used Generic Routing Encapsulation (GRE) tunnels instead of the GTP tunnels to eliminate the GTP tunnelling overheads. The authors use a series of measures to design the CP protocols, in which the protocols are designed for the specific scenarios to reduce the unnecessary messages in the standard scenarios by using a shared data structure and merging and reordering the messages to reduce exchanged messages among the core components, reassigning the tasks to the network components to reduce the unnecessary acknowledgement messages. Furthermore, besides optimizing the 5G system CP protocols, standardization of protocols is essential when considering the integration of MEC and 5G.

The integration of MEC and 5G is considered to be an effective solution to meet the requirement for uRLLC applications. Latency occurs between the MEC server and the cellular network UE; integrating with MEC services that are migrated to the edge network by deploying applications close to UE and enabling service migration between MEC hosts during the UE mobility procedures, which improve the computation and storage capacity and reduce the latency. Existing 5G mobility management procedures that do not consider the computational and processing load of MEC servers, are not suitable for real-time execution and integration with the standard protocol stack, which can affect the performance of the 5G MEC applications and increase the latency. Specifically, handover progress occurs between the base stations and MEC servers. The different MEC servers may have varying capabilities and loads, which will affect the user application performance. The current handover decisions only focus on signal strength using Signal-to-Interference-plus-Noise Ratio (SINR) and Reference Signal Received Quality (RSRQ), without concern for the state of neighbour MEC servers. However, the MEC server capacity and load can significantly affect the handover procedures and the latency.

Most importantly, in 5G networks, cell sizes in some parts of the network are small (<500 m), which causes more frequent handovers. Therefore, the challenges related to handovers are increasing (Zhou *et al.*, 2021). In Zhou *et al.* (2021), the authors proposed the Comp-Ho handoff algorithm, which jointly optimized signal strength in base stations and computational load in MEC servers. The base station will trigger a handover and reassign the communication and computation processes to another base station and MEC server when signal strength degrades to threshold values or the current MEC server does not have enough capacity and becomes overloaded. A balance is taken into consideration. Although this algorithm significantly reduced the latency caused by MEC congestion, developing an algorithm with the

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predictive capability to predict mobility where the resources can be pre-allocated before handover occurs is becoming very popular.

According to the analysis, we proposed optimization considerations for 5G and MEC integration. We identified an optimization consideration for handover procedures before and during the handover preparation pause, since the latency before handover request is quite high from our evaluation described earlier. We scale the MECs to deal with the UE directly by using the RNIS of the MEC, which will decrease the signal message overheads between the MECs and base stations over Xn links. The user context will start to prepare the migration from the source MEC when the source MEC receives a response from the UE, to see if it can reduce the latency before the handover request. Based on the optimized handover procedure and information sharing, the user context migration time between MECs may also reduce. Figure 8 depicts the proposed optimization considerations. Future work includes verifying the considerations by using a 5GC simulation, e.g., free5GC, to deploy 5GC into a Kubernetes environment, which orchestrates the MEC and 5GC network elements as containers.

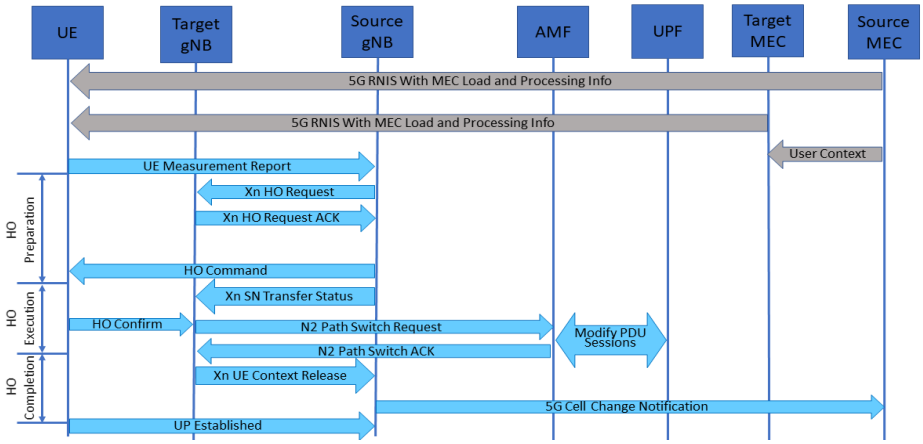

Figure 8. Optimization Considerations

Conclusion

This paper analyses CP and UP latency. A series of considerations for optimizing the CP protocol handover is proposed based on integrating 5G and MEC architectures. To achieve ultra-low latency, we can provide the following conclusions in the changes of network architecture: 1. core UP components keep moving towards the network edge; 2. network components continue to be virtualized on the Cloud platform; and 3. the integration of sliced 5GC and MEC is occurring based on Capital Expenditure (CAPEX) and Operating Expenditure (OPEX) considerations.

We can present the following conclusions for the optimization of CP protocols: 1. unnecessary exchanged messages in CP increased due to the evolution of the network, and security challenges persist; 2. the messages can be reordered depending on the network element

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responsibilities; and 3. the CP protocol can be optimized, related to the different service requirements based on the association with the UP.

DAPS handover has been developed with the goal of reducing the UP latency to near 0 ms when a handover occurs, but complex CP protocols and network traffic during the mobility management procedure remain a challenge. The communication control protocols contribute to the significant latency. There is increasing use of SDN and NFV and the separation of CP and UP to provide scalability and flow distribution flexibility. However, adding an SDN controller to the network can be another latency source. Thus, there is a trade-off between the scalability of controllers and latency. Mobility management in a core network based on SDN can potentially introduce delays due to the complex CP exchange. Although uRLLC applications over 5G networks integrated with MEC can significantly improve application performance, the geographically distributed architecture and vast volumes of data further increase network complexity. Therefore, a challenge remains to optimize the CP exchange and the current network architecture to meet the demand for ultra-low latency.

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Exploring the Link Between Cashless Society and Cybercrime in Indonesia

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Abstract: This study examines whether the rise in cybercrime activity in Indonesia is associated with the perceived benefits, convenience, and risk of a cashless society. In doing so, we apply Structural Equation Modelling (SEM) to a total sample of 200 Indonesian respondents who have been victims of cyber fraud. The results indicate that the high cybercrime rate, including phishing, distributed denial-of-service (DDoS), and social engineering, is positively associated with the perceived benefits and risks of transacting online. The rise in cases of DDoS can particularly be linked to consumers' increasing perceptions of convenience in undertaking cashless transactions. The findings suggest that more stringent cyber law enforcement needs to be implemented. Digital technologies will continue to improve, and more consumers will do transactions digitally. With increasing volumes of cashless transactions, the risk of cyber attacks will likely increase. Stakeholders need to strengthen data privacy and provide a secure environment for customers. International cooperation should be promoted through the establishment of virtual world law as economic activities and cybercrime risks now become borderless.

Keywords: cybercrime, fraud, cashless society, fintech, digital economy

Introduction

Developments in science and technology have brought tremendous benefits to civilization. Jobs that previously required considerable physical strength are increasingly replaced by automated systems (Dwivedi *et al.*, 2021;Malesev & Cherry, 2021;Trinugroho *et al.*, 2017). Similarly, new technologies are applied to business activities to enhance the consumer experience (Wohllebe *et al.*, 2021). Rapid incorporation of technologies in new business

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models is likely to encourage the use of digital means by consumers and businesses (Tee & Ong, 2016). However, as more consumers embrace digital transactions, the risk of exposure to cybercrime may also increase. Criminal activities target Internet users through hacking, cracking, and cyber terrorism. Not surprisingly, cybercrime rates have increased substantially in the last decade (Kemp, Miró-Llinares & Moneva, 2020).

Fraud cases are increasingly reported worldwide (Ajayi, 2016;Hidayati *et al.*, 2021;Nawang, 2017), with victims reaching millions of Internet users (Hill & Marion, 2016). In the United Kingdom, a third of the total crimes (nearly 3.8 million in 2019) are related to online activities, according to the Crime Survey of England and Wales (Office for National Statistics, 2022). In the United States, cybercrime increased by almost 69% in 2019, with losses equivalent to US$4.2 billion, a figure three times larger than that for 2018 (Economist, 2021). Cybercrime has expanded in both advanced and developing countries (Ajayi, 2016; Lubis & Handayani, 2022; Nawang, 2017). In Indonesia, the number of cases is the second highest globally, after Japan. Akamai International (2013), a security threat report, showed that Indonesia ranked first in the list of countries at risk of increased cyber-attack. Internet users in Indonesia reached more than 202 million in 2021, equivalent to nearly 73% of the population (http://www.datareportal.com). Still, awareness among business people and the general public about the risk of cybercrimes remains low.

Based on the traffic anomaly data reported by the National Cyber and Crypto Agency (Indonesia), throughout 2020, Indonesia experienced more than 495 million cyber anomalies, which is a 41% increase from 2019 (BSSN, 2020), with trojans becoming the most frequent cyber threat. From the same report, nearly 2,550 cases of email phishing were detected, 79,439 accounts experienced data breaches, and 9,749 sites experienced web defacement. Educational-related resources saw the largest number of cases in Indonesia in 2020, likely due to remote schooling due to the COVID19 pandemic. Meanwhile, from January to July 2021, traffic anomalies/cyber threats reached 741.4 million, with the most frequent being malware, distributed denial-of-service (DDoS), and trojans. Increasingly, cyber attackers demand ransom and cause data leaks.

In Indonesia, most cybercrime cases are data hacking, often caused by Internet users' ignorance and carelessness (Lubis & Handayani, 2022). According to data from the Indonesian National Police (POLRI), from April 2020 to July 2021, at least 937 cases of cybercrime were reported, with the highest involving provocative/hate content (473 cases), fraud (259 cases), and pornographic content (82 cases). Other types of cybercrime in Indonesia include phishing — i.e., stealing consumer data such as user identification, passwords, and personal details — and DDoS — i.e., attacks on servers aimed at disturbing network resources and machines — or website hijacking through web defacement (Ajayi,

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2016;Hidayati *et al.*, 2021; Kemp, Miró-Llinares & Moneva, 2020). Pirated software and user ignorance facilitate such cybercrimes (Hidayati *et al.*, 2021; Nawang, 2017).

Companies in Indonesia have been accelerating their digitalization strategies, such as by implementing e-commerce, expanding social networks and digital infrastructure (Kusmiarto *et al.*, 2021; Mihardjo *et al.*, 2019; Nasution *et al.*, 2020). Digitalization is reshaping customer behaviour by increasing the perceived benefits, convenience, and risks when transacting online (Dwivedi *et al.*, 2021). Non-cash payments are becoming more common among Indonesians (Salman & Saleem, 2017; Tee & Ong, 2016; Trinugroho *et al.*, 2017). In 2021 alone, digital financial transactions in Indonesia increased by more than 45%, with e-money expanding by nearly 50% (Bank Indonesia, 2021). However, this expansion was not accompanied by security system improvements, which leaves users vulnerable to cybercrimes Astuti, 2020; Hidayati *et al.*, 2021). Moreover, digital mastery among business players and consumers remains low, and they are not fully aware of privacy issues and security threats Kusmiarto *et al.*, 2021; Nasution *et al.*, 2020).

In Indonesia, the number of fraud cases has increased in the last decade along with the rapid technological progress, growth in numbers of financial applications (Suryono, Budi & Purwandari, 2021), expansion of super apps (Fauzi & Sheng, 2020), and other advances in digitalization (Esquivias *et al.*, 2020). The Indonesian authorities have started cyber patrols to minimize cybercrime, but fraud remains pervasive. Prabowo (2012) points out that fraud prevention related to credit card services is ineffective due to poor mechanisms for collecting, managing, and distributing data. Kusmiarto *et al.* (2021) pointed out how government agencies lack cybersecurity strategies, privacy protection, and cyber resilience, suggesting that they are not ready for digital transformation.

In the banking industry, Purwanegara, Apriningsih & Andika (2014) noted that regulations and protection for consumers in Indonesia are low. However, in recent years, financial authorities in Indonesia have paid more attention to, and deployed resources for, data protection, privacy frameworks, and more stringent digital finance regulations (Lubis & Handayani, 2022; Suryono, Budi & Purwandari, 2021). These efforts are expected to enhance the perceived safety in digital transactions (Ruiz-Real *et al.*, 2021).

This study examines whether the increasing cybercrime rate for phishing, DDoS, and social engineering is linked to consumers' perceived benefits, convenience, and risks of cashless transactions. To test our research hypotheses, we used the results from a survey of 200 users of cashless services in 2021. In the analysis, we used a Structural Equation Model (PLS-SEM) to test whether consumer perception of i) benefits, ii) convenience, and iii) risk determines or influences cybercrime.

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As the cashless society in Indonesia is still young (Esquivias *et al.*, 2020), we aim to show whether the expansion of digital activities and changes in consumers' perceptions can be associated with an increase in cybercrime. This study offers a unique contribution because access to cybercrime data in Indonesia is difficult to achieve. Moreover, the data collection period covers the COVID19 pandemic, when online activities were peaking due to the strict containment measures imposed on citizens. Cyber security shapes consumers' trust and determines the future of digital businesses. Since it could also threaten a country's stability, governments need to play an active role in cyber security and develop protection policies for businesses and consumers.

Earlier studies on the cashless economy in Indonesia have examined digital financial practices (Suryono, Budi & Purwandari, 2021), the links between cashless transactions and financial inclusion (Bayero, 2015), digital competencies and cashless transactions (Salman & Saleem, 2017), cashless payments, economic growth (Tee & Ong, 2016), and consumers' digital readiness for digital finance (Trinugroho *et al.*, 2017). However, little research has examined the link between cashless transactions and cybercrime. We aim to fill this gap.

The remainder of this paper is structured as follows. Section 2 presents the literature review. Section 3 outlines the methodology. Section 4 shows the results and discussion. Section 5 concludes the discussion and outlines the limitations of the study.

Literature Review and Hypothesis Development

Most social and economic activities today are assisted by technology. Digital technologies are not only for communicating and interacting, but are also an integral part of business activities (Abad-Segura *et al.*, 2020; ACFE, 2018; Njanike, Mutengezanwa & Gombarume, 2011; Suryono, 2019; Teja, 2017). Worldwide, a transition towards a digital economy is taking place, with the increasing use of e-money and digital transactions referred to as the cashless society.

Cybercrime in the era of a cashless society

Benefits

Cashless transactions have become increasingly common in the digital era (Malesev & Cherry, 2021; Ruiz-Real *et al.*, 2021; Thaichon, Soutar & Weaven, 2021), including in Indonesia with its rapid development of digital infrastructure. Cashless transactions are supported by an entire ecosystem that includes regulators, financial institutions, device manufacturers, retailers, sellers, and consumers (Tee & Ong, 2016; Trinugroho *et al.*, 2017). A cashless society, if well-orchestrated, offers many advantages for consumers (Trinugroho *et al.*, 2017).

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Benefits for consumers are revealed in the simplification of transactions when using digital money (Chang *et al.*, 2016). In the context of the COVID19 pandemic, such benefits were evident, as digital money became a very helpful means of transacting when governments imposed restrictions on physical mobility. Besides, a number of consumers opted for digital transactions during the pandemic as a prevention measure against COVID19. As individuals increase the frequency of digital payments, and as more businesses provide cashless channels to consumers, the perception of the benefits of cashless transactions is likely to improve (Fauzi & Sheng, 2020).

Convenience

A cashless society results in improved convenience for businesses, consumers, and regulators (Bayero, 2015; Hidayati *et al.*, 2021; Tee & Ong, 2016). Increasingly, consumers find digital money convenient to access as more financial institutions provide digital payment systems, and more businesses accept digital transactions. As markets achieve network scale, the frequency in use of digital money increases, and so consumers' perceptions of the convenience of using cashless means of payment may also rise. Similarly, the greater the use of digital payments, the greater the proficiency in the use of cashless transactions, and the simpler it becomes to use digital money. Besides, companies have improved app interfaces and made instructions for using digital payments clear and understandable, raising consumers' perceptions of the convenience of using digital money (Kusmiarto *et al.*, 2021). Additionally, marketing campaigns by digital money providers (Dwivedi *et al.*, 2021) and businesses adopting digital payments may have contributed to increased public awareness of the suitability of electronic payments for daily life (Mieseigha & Ogbodo, 2013; Tee & Ong, 2016).

Risk

Users may perceive current technologies as increasingly sophisticated (Kuzmin & Menisov, 2021; Suryono, Budi & Purwandari, 2021). As digital technologies become more refined and integrated, they may increase perceptions of their increasing safety (Bayero, 2015; Hidayati *et al.*, 2021; Tee & Ong, 2016). Besides, the government's security regulations are active in preventing potential crime taking place (Hidayati *et al.*, 2021; Honigsberg, 2020; Laut & Narsa, 2021), with efforts to improve the security of fintech services (Suryono, Budi & Purwandari, 2021). On the business side, new technologies supporting cashless services are migrating to new technologies (e.g., blockchain and cloud computing) to keep consumer and business data safe (Hidayati *et al.*, 2021). As consumers feel more confident in the use of technologies, governments are active in regulatory action, and businesses provide more secure systems for consumers, so it is likely that consumers' perceptions of protection in digital environments strengthen.

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Apart from this, as consumers become more familiar with apps and digital platforms (Almunawar, Anshari & Lim, 2020), the perception of safe navigation on digital platforms may increase. Similarly, as more providers offer digital alternatives and businesses promote cashless transactions, consumers may feel that online transactions are increasingly regulated and protected by state laws. Consumers may then associate lower risk with use of digital payments as the entire digital ecosystem comes to rely more on cashless transactions.

However, public awareness of the importance of handling data safely is vital for lowering the risk of cyber fraud (Purwanegara, Apriningsih & Andika, 2014). If public awareness about data security is low, cyber criminals may find loopholes to carry out crime at large scale (Putnam & Elliott, 1999). If consumers' perceptions of safety are high, but awareness of cyber risk is low, criminals may feel encouragement to employ cyber activities to commit fraud (Archer, 2012). While the risk of crime can be reduced if collaboration between the government, fintech owners, and the community is optimized (Choi, 2021; Kemp, Miró-Llinares & Moneva, 2020), that does not always happen.

Crime threat

Although countries have been progressively linked and become interdependent on digital technologies, the downside is the accompanying increasing incidence of cyber fraud (Hidayati *et al.*, 2021; Kemp, Miró-Llinares & Moneva, 2020; Nawang, 2017). Although the cashless society offers increasing benefits, convenience, and safety for users, it may also open prospects for new types of crime assisted by the Internet. As consumers rely more on digital transactions for daily life, cybercrime is on the ascent. In criminology, the rise of cyber fraud can be explained using the institutional anomie theory (IAT), economic factor theory, or ecological criminology theory.

Anomie refers to a deregulated condition. Rapid and gripping social changes are difficult to navigate (Dearden, Parti & Hawdon, 2021). Conventional norms will blur and disappear as new prospects for development appear (Messner & Rosenfeld, 2012). Anomie occurs in modern society when achieving material success is all that matters. People who have achieved high status or cultural goals are celebrated by the community. Some people may use non-legitimate means to achieve material success (Hövermann, Groß & Messner, 2016). As new technologies expand the borders within which market transactions can take place, new digital environments offer loopholes for individuals to illegitimately profit from unknown or unregulated environments. New technologies are not entirely understood by regulators, business, and consumers.

Another driver of crime is economic inequality (Atems, 2020), which arises in societies with uneven income distribution, or in dense populations due to urbanization, among other factors.

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Tight economic competition, high unemployment, and gaps in labour skills (Muryani *et al.*, 2021) often push people to look for ways to get by, which sometimes includes committing crimes (Honigsberg, 2020; Smith, 2010; Svabova *et al.*, 2020). The technical complexity of digital transactions, the lack of awareness of consumers about cyber risk, and the lack of digital savviness of the general public may induce individuals to engage in illicit activities. Studies by Campaniello, Gray & Mastrobuoni (2016), Li *et al.* (2019) and Sugiharti *et al.* (2022) suggest that economic development and a rise in income level can be accompanied by growing levels of crime.

We argue that increasing information and telecommunication services, broader access to digital services, and a higher economic level in Indonesia may have encouraged the use of digital technologies among its citizens. As more Indonesians are using digital devices and awareness of the way cybercrime operates is low, it is likely that more space for cybercrime exists. Some of these cybercrimes include phishing, vishing, data breaches, hacking, cyber fraud, identity theft, spamming, cyber stalking, and cyberbullying, among others. However, the three largest cybercrimes reported in Indonesia can be grouped into phishing, distributed denial-of-service (DDoS), and social engineering.

Building on the above literature, three hypotheses are proposed:

H1: Cybercrime related to phishing is positively associated with perceived benefits, convenience, and risk in a cashless society.

H2: Cybercrime related to DDoS is positively associated with perceived benefits, convenience, and risk in a cashless society.

H3: Cybercrime related to social engineering is positively associated with perceived benefits, convenience, and risk in a cashless society.

Research Method

After reviewing the existing literature, this study enquires whether customer perceptions (of benefits, of convenience, and of risk) influence cybercrime. The response variable is cybercrime or fraud (y), which is defined as phishing ($y1$), DDoS ($y2$), and social engineering ($y3$). That is, the model takes the functional relationship of the following form:

$y1$ (phishing) = f(benefits, convenience, risk)

$y2$ (DDoS) = f(benefits, convenience, risk)

$y3$ (social engineering) =f(benefits, convenience, risk).

This research uses data collected through questionnaires. The questionnaires were distributed to 200 victims of cybercrime. As a reference point, the victims of cybercrime in Indonesia

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reached 3,130 cases in 2020, as reported by the Directorate of Cybercrime (Bareskrim), the Indonesian National Police. The questionnaire covers demographic data (i.e., age, gender, education, location), digital transaction experience, and the perceived benefits, convenience, and risks for digital consumers.

We also propose three blocks of questions to identify whether users have experienced phishing, DDoS, or social engineering. The questionnaire uses a 5-point Likert scale: strongly disagree, disagree, somewhat agree, agree, and strongly agree (Likert, 1932). The operational definitions of the variables are presented in Table 1.

Table 1. Variables' operational definitions and measurements

No.	Variable	Operational Definition	Indicator
1.	Cybercrime (Fraud)	A criminal activity performed through a digital device or computer network as a means, tool, or target (Hidayati *et al.*, 2021).	Phishing DDoS Social engineering
2.	Cashless society	Society brought about by behavioural shifts marked by changes in payment instruments from cash to non-cash (Trinugroho *et al.*, 2017).	Perceived benefits Perceived convenience Perceived risks

This study uses the Structural Equation Modelling (SEM) based on variance as an analytical method. The research data was analyzed using Smart PLS, verified in three stages: measuring the outer model; evaluating the structural model; and testing the research hypothesis.

Results

The analysis starts with the respondents' profiles, then continues with validity and reliability tests and the results from the SEM. The respondents' profiles include gender, age, education, and cybercrime experience. The descriptive respondent profiles are shown in Figure 1.

The SEM test results are as follows. The dimensions are considered reliable if they have a composite reliability value (ρc) above 0.7 (Table 2). The outer model test measures a construct by evaluating the composite reliability value (ρc). Table 3 displays the calculations using composite reliability (ρc).

Table 2. Research Instruments' validity and reliability test results

Variable	Dimension	Items	Correlation (r)		Coefficient	
			r	Status	Alpha	Status
Cybercrime (Fraud) (X1)	Phishing	PH01 – Phishing email or website	0.525	valid	0.827	reliable
		PH02 – Data Scam	0.899	valid		
		PH03 – Fake Accounts Ads	0.937	valid		
		PH04 – Malware (i.e., trojan)	0.934	valid		
	DDoS	DD05 – Freezing, Changing IP Address	0.944	valid	0.865	reliable
		DD06 –Internet bandwidth Attack	0.575	valid		
		DD07 – CPU Overload	0.940	valid		

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Variable	Dimension	Items	Correlation (r)		Coefficient	
			r	Status	Alpha	Status
		DD08 – Unauthorized System Updates	0.943	valid		
	Social engineering	SE09 – Baiting	0.788	valid	0.813	reliable
		SE10 – Spam and unofficial emails	0.766	valid		
		SE11 – Hack of email, social media and dishonestly used	0.869	valid		
		SE12 – Scams (SMS, Data, mail)	0.783	valid		
Cashless society (Y)	Perceived benefits	PM13 – Effective transactions	0.954	valid	0.873	reliable
		PM14 – Helpful	0.951	valid		
		PM15 – Frequent Use	0.950	valid		
		PM16 – Higher advantages over cash	0.559	valid		
	Perceived convenience	PK17 – Easy to Use	0.961	valid	0.851	reliable
		PK18 – Wider Access and Acceptance	0.961	valid		
		PK19 – Increasingly simple use	0.406	valid		
		PK20 – Easily Available – compatible	0.961	valid		
	Perceived risks	PR21 – Feel Payments are Safe	0.799	valid	0.772	reliable
		PR22 – Protection by state laws	0.777	valid		
		PR24 – Good and Safe Experience	0.741	valid		
		PR24 – Lower Risk than cash	0.771	valid		

Source: Questionnaire data, 2021.

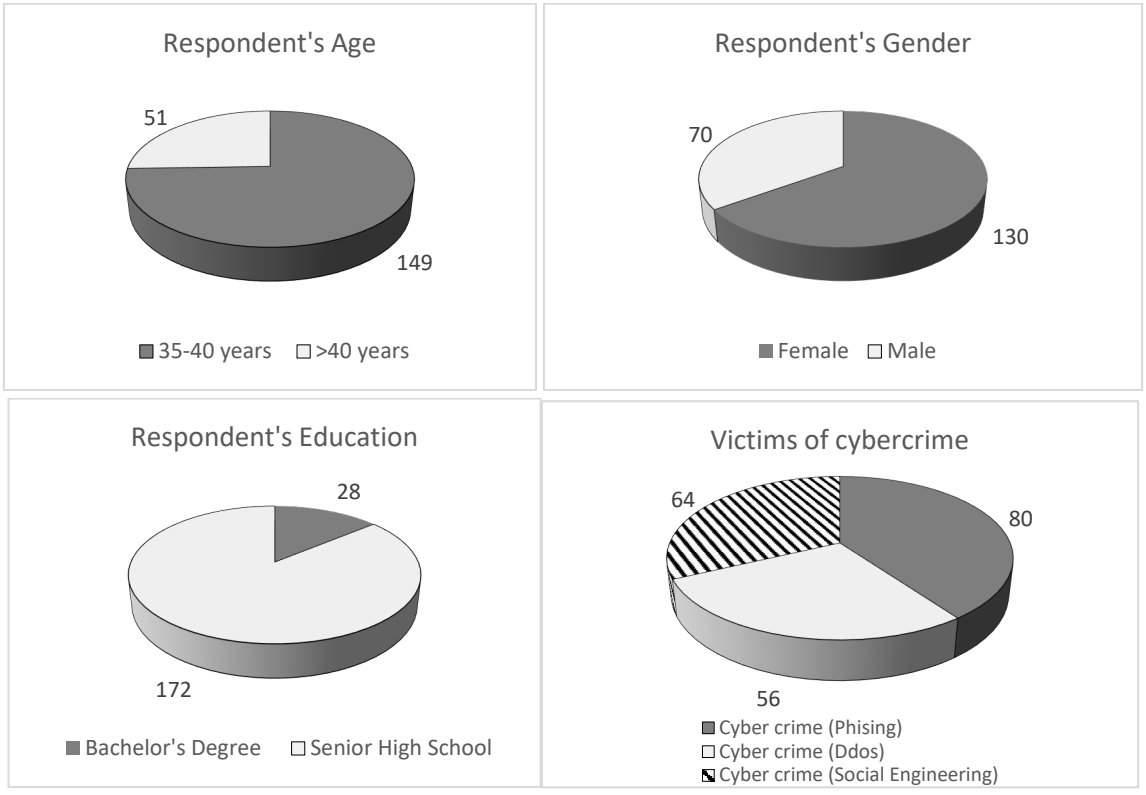

Figure 1. Characteristics of respondents (Source: Questionnaire, 2021)

The calculations that have been carried out find that the R-Square value for the cybercrime variable is greater than 0.2, so the latent predictor has a considerable influence on the structural level. Furthermore, the structural model is evaluated using R-Square for the

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dependent construct, following the Stone-Geisser Q-Square test for predictive relevance. The inner structural model was also assessed by looking at the Q-Square predictive relevance. The following is the result of the Q-Square calculation.

$$Q2 = 1- (0.968)(0.939)(0.829)$$
$$= 1- 0.753 = 0.246$$

The calculation results show Q-Square value >0, so the model can be considered as having a relevant predictive value.

Table 3. Composite reliability calculation results

Dimension	Composite Reliability	R-Square
Cybercrime (fraud)-Phishing	0.907	0.968
Cybercrime (fraud)-DDoS	0.923	0.939
Cybercrime (fraud)-Social Engineering	0.878	0.829
Cashless society (Benefits)	0.926	-
Cashless society (Convenience)	0.912	-
Cashless society (Risk)	0.848	-

Source: Smart PLS, 2021.

Testing of research hypotheses

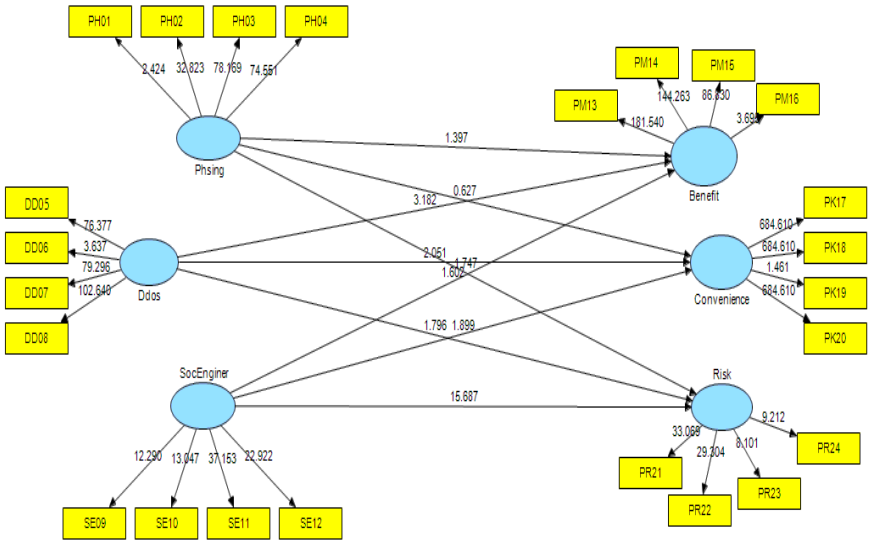

Figure 2. Empirical framework and Data Test Results (Source: Smart PLS, 2021)

Figure 2 depicts the path analysis framework, where we hypothesised that increasing levels of cybercrime (i.e., proposed as phishing, DDoS, and social engineering) are influenced by the growing perception of benefits, convenience, and perception of risk in cashless transactions. Phishing crimes are proxied by four types of phishing, as indicated in Table 2 and depicted in Figure 2 as PH01, PH02, PH03, and PH04. A similar approach follows when asking respondents to identify attacks in the fashion of DDoS (DD05–DD08), and social engineering (SE09–SE12). Similarly, respondents are asked to identify perceptions of the degree of

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benefits (PM13–PM16), convenience (PK17–PK20), and risk (PR21–PR24) associated with a cashless society.

The hypothesis testing compares the t-count value with the t-table value. If the t-count value is greater than the t-table value, then the relationship between the variables is significant and can be analyzed further. With sample data size 200, the value of the t table (α=5%) obtained was 1,652, and the value of the t table (α=10%) was 1,285. The results of hypothesis testing are presented in Table 4.

Table 4. Hypothesis Testing Results

Hypothesis				coef. Path	t count
	Cybercrime (fraud)-Phishing	→	Cashless society (Benefits)	0.542	1,505**
H1	Cybercrime (fraud)-Phishing	→	Cashless society (Convenience)	0.676	0.672
	Cybercrime (fraud)-Phishing	→	Cashless society (Risk)	0.548	1,752*
	Cybercrime (fraud)-DDoS	→	Cashless society (Benefits)	0.524	3,434*
H2	Cybercrime (fraud)-DDoS	→	Cashless society (Convenience)	0.668	2,199*
	Cybercrime (fraud)-DDoS	→	Cashless society (Risk)	0.559	1,809*
	Cybercrime (fraud)-Social Engineering	→	Cashless society (Benefits)	0.052	1,652*
H3	Cybercrime (fraud)-Social Engineering	→	Cashless society (Convenience)	0.083	1,939*
	Cybercrime (fraud)-Social Engineering	→	Cashless society (Risk)	0.054	17,540*

* Significant at the 5% level. ** Significant at the 10% level.

We proceeded with the hypothesis testing results displayed in Table 4. For each type of cybercrime, we tested three sub-hypotheses related to behavioural aspects of the cashless economy, i.e., the perceived benefits, convenience, and risks.

1a. Perceived benefits (cashless society) have a positive and significant effect on phishing, which means that perpetrators (phishing) take advantage of the increasing perceived benefits of consumers who see cashless transactions as helpful, advantageous, and effective when conducting digital payments. As digital services continue to improve and expand, authorities need to pay closer attention to the risks, as consumers may experience increasing exposure to cybercrime in the form of phishing.

1b. Perceived convenience of digital transactions does not have a significant effect on Phishing. This suggests that cybercrime in the form of phishing does not rise along with the rise in users' perceived convenience.

1c. Perceived risk of digital technologies has a positive and significant effect on phishing. Users' perceived safety is high when they think that the risks of doing an online transaction are low. Phishing takes advantage of this. The absence of safety measures, low awareness of risks, and overconfidence of digital consumers may trigger more phishing activities. The results align with those of earlier studies (Choo, 2011; Nawang, 2017; Purwanegara, Apriningsih & Andika, 2014). Trinugroho *et al.* (2017) argue that

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regulations should focus on raising users' awareness about risks, especially among ordinary users who often cannot detect them.

2a-b. The perceived benefits and convenience of cashless transactions have positive and significant effects on DDoS. As digital platforms become more sophisticated and financial providers offer more variety of services, users may perceive higher benefits in using such platforms. As consumers increasingly perceive digital services as helpful, advantageous, and efficient, DDoS crime rises.

Unlike phishing, some degree of cooperation is needed for DDoS to happen — e.g., downloading an app, opening and replying to an email, clicking on ads, and providing information to a false source. Consumers' increasing perception of the convenience of digital transactions may encourage them to blindly follow instructions — clicking and downloading quickly when prompted. Once in, criminals interfere and flood the systems, weaken the networks, drain resources, disrupt transactions, block gateways, slow access, steal users' databases, etc. This result is in line with that of a previous study by Dwivedi *et al.* (2021).

2c. Perceived risks have a positive and significant effect on DDoS. The claimed improvements in digital infrastructure (Bayero, 2015), advances in applications (Wang & Ong, 2019; Wohllebe *et al.*, 2021), more 'secure' sites, and 'stricter' regulatory efforts, can shape the perception of low risks among consumers (Aaron, Rivadeneyra & Sohal, 2017; Archer, 2012; Suryono, Budi & Purwandari, 2021). As consumers perceive lower risk in the use of cashless transactions, they provide data more widely when doing digital transactions. However, a higher perception of safety makes consumers more vulnerable to cyberattacks, as it can trigger crime in the form of DDoS. This suggests the need to strengthen the data privacy policy (Lubis & Handayani, 2022) and encourage firms to improve the safety of their services.

Users of e-money in Indonesia were less than 1% of individuals in 2016. However, by 2020, this number had risen to 11.7%. As more users are employing digital payments, greater safety is needed to protect consumers and firms.

3a-b. Perceived benefits and convenience of cashless transactions have a positive and significant effect on social engineering. This means that criminals profit from the rise of perceived benefits and convenience by maliciously acting against consumers' interests in the form of social engineering. Social engineering often employs social media, emails, messaging services, and other means to manipulate users and extract sensitive information from consumers. As cybercrime becomes more sophisticated, the faking of accounts, falsifying of news, and messages from illegitimate sources become increasingly difficult to spot. This type of fraud multiplies with the rapid growth in

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numbers of social media users, super apps, and other digital interactions experienced in Indonesia.

The regulations governing social media are still few, allowing cybercriminals to engage in malicious actions shaped through human interaction on the Internet. Digital marketing and social applications now offer more benefits for businesses and consumers (Dwivedi *et al.*, 2021; Wohllebe *et al.*, 2021), so social engineering will continue to expand.

3c. Perceived risk has a positive and significant effect on Social Engineering, which means that cybercrime relies on lower perception of risks. The difference is that social engineering may also include that for political purposes, conflicts, violence, chaos, or other sources of social disturbances employing manipulation tactics to influence consumers. Digital readiness among Indonesians is low (Kusmiarto *et al.*, 2021; Nasution *et al.*, 2020; Trinugroho *et al.*, 2017), and the findings suggest the need to tighten regulations, update privacy policies, and promote cyber security protocols to protect consumers.

Discussion

The findings of this research contribute to the literature of the cashless society in Indonesia by providing empirical evidence on the link between cybercrime and consumer perceptions. Our results use primary data collected during the COVID19 pandemic. The findings show that the shift towards a cashless economy has threats and challenges. Perpetrators of cyber crimes will continue to find loopholes in digital systems to take advantage of the rising numbers of digital ecosystems. Authorities need to tighten regulations, and international cooperation may also be required in dealing with cyber security threats (Ajayi, 2016; Aviles, Sitorus & Trujillo Tejada, 2019).

Startups in Indonesia are flourishing, banks are developing cashless services, national authorities are promoting more use of e-money, and super apps are expanding rapidly (Almunawar, Anshari & Lim, 2020; Fauzi & Sheng, 2020). To facilitate the thriving of digital businesses, and to guarantee digital users' safety, government regulations and mechanisms to monitor, prevent, and prosecute cyber crime need to be in place (Choo, 2011). Research in China (Chang *et al.*, 2016), Europe (Kemp, Miró-Llinares & Moneva, 2020), and other countries (Tee & Ong, 2016) has shown that providing safe regulatory frameworks can substantially influence the adoption of digital services.

The expansion of digital business in Indonesia needs to be supported with a more secure environment by strengthening digital readiness (Nasution *et al.*, 2020), improving digital

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strategy (Mihardjo *et al.*, 2019), increasing digital infrastructure (Kusmiarto *et al.*, 2021), and providing a more comprehensive regulatory framework (Suryono, Budi & Purwandari, 2021).

Although the number of consumers using the Internet for financial transactions in Indonesia is relatively low (around 14% of the total users), it is rapidly increasing. The use of e-money increased from less than 5% in 2018 to 11.7% in 2020. Digital transactions increased by nearly 45% and e-money use by 50% during the first year of the COVID19 pandemic. With the containment measures to minimize the virus spread, users relied much more on online transactions. Consumer behaviour is likely to remain after the COVID19 pandemic, suggesting that the more consumers use digital apps, the more they perceive the benefits, which may trigger more cyber-criminal activities.

Conclusions

This study examines the relationship between cybercrime and cashless transactions. We used data from a survey of 200 respondents in 2021 to test a set of hypotheses relating to cybercrime and perceived benefits, convenience, and risks using Structural Equation Modelling (SEM). The results show that cybercriminals benefit from the increasingly perceived benefits, convenience, and safety of cashless transactions. Cybercrime in the form of phishing, DDoS, and social engineering is triggered by the perceived benefits, convenience, and risks associated with a cashless society. DDoS and social engineering are also positively and significantly associated with the perceived benefits of digital transactions. As social media, super apps, digital banking, and other digital services become increasingly popular and part of daily life, new security frameworks are needed to protect users' safety. Cybercrime is becoming more sophisticated, taking advantage of consumers' growing interest in using cashless services. We envisage that cybercrime targeting devices, the Internet, and digital technologies will expand as technological development and cashless transactions grow. The data suggests that consumers may not be aware of the risks associated with cybercrime and that the rapid growth of digital technologies will put them at higher risk. Most cybercrimes most likely go unreported, as the survey indicates that most individuals suffer from cybercrime or are exposed to it.

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Technology Acceptance Model (TAM): A Bibliometric Analysis from Inception

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Abstract: The technology acceptance model (TAM) has long-term implications for management studies. However, the evolution of the literature on technology acceptance ideas received very little attention in the bibliographic review. Few research reviews provided a systematic overview of the development and progress of the TAM literature based on the entire citation network, while many research reviews focused on re-examining the links between TAM components through meta-analysis. This study investigates: a) how TAM research has evolved and expanded over the last 30 years; b) the main areas in which the TAM model has been used; and c) key contributors to TAM research and their collaborations. This bibliometric analysis was carried out based on 8207 papers published in the Scopus database between 1990 and 2020 to assess the feasibility of the model and its applicability. The findings revealed that early TAM research was conducted both by Eastern and Western scholars and that it has since continued to evolve and be shared widely. Nonetheless, most TAM publications have focused on the same narrow domains of computer science, social science, business, management, and accounting and the trendiest topics were usefulness, trust, ease of use, e-learning, adoption, e-commerce, and social media.

Keywords: Technology Acceptance Model (TAM), Bibliometric Analysis, Theories on Technology Acceptance, TRA Model, UTAUT Model.

Introduction

Leading companies frequently seek a competitive advantage to shape technological developments (Lovelock, 2001; Meyer-Brötz *et al.*, 2018). However, continuous technological

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change poses a threat to well-established business models while simultaneously presenting opportunities for the development of new services (Lai, Chau & Cui, 2010; Dasgupta, Gupta & Sahay, 2011; Lai, 2016). Several factors influence how quickly consumers adopt new technologies, including the availability, accessibility, usability, and prerequisites of those technologies, as well as the safety and security of those technologies, all of which are experiencing rapid and advanced technological growth (Curran & Meuter, 2005; Lai & Zainal, 2015a; Lai & Zainal, 2015b; Sahi *et al*,. 2022). The application of newly developed technologies by users has been the primary focus of some researchers.

Davis (1989) developed the Technology Acceptance Model (TAM), which illustrates the degree of interest of IT users to perceive and adopt new technology. And, since then, TAM qualifies as a remarkable achievement by any standard and has even attained the status of a sort of paradigm. Davis, Bagozzi & Warshaw (1989) have been cited more than 700 times so far, which is a very high number for a practical article like this one. In addition, the quantity and breadth of research carried out in the TAM tradition are both remarkable in terms of their respective scopes and volumes (Bagozzi, 2007; Marangunić & Granić, 2015). Since TAM has maintained its position as the dominant model as a valid, robust, and user-friendly model for close to twenty years, it has received a great deal of feedback and has been the focus of a particular issue of a journal that is devoted solely to the model. The significance of TAM can be broken down into two categories: its direct impact and its indirect impact.

Perceived usefulness and ease of use are important independent variables for TAM, but it also relies on a dependent variable, such as attitudes toward use, to be truly useful. Davis (1989) gives definitions for perceived usefulness and perceived ease of use. Perceived usefulness is the degree to which a person thinks that using a system will help them do their job better. Perceived ease of use is the degree to which a person thinks that using a system is easy. Bagozzi, Davis & Warshaw (1992) say that the user's behaviour intention shows how they plan to use the technology. This behaviour intention is based on how the user feels about the technology and how useful they think it is. The widespread application of TAM in research has led to increased levels of consistency, as scholars rely almost exclusively on constructs known as "perceived utility" (PU), "perceived convenience" (PC), or "perceived ease of use" (PEoU) (Aggrawal *et al.*, 2020; Eckhardt, Laumer & Weitzel, 2009; Dwivedi, Williams & Lal, 2008).

However, Benbasat and Barki's (2007) research showed that the overuse and excessive focus on TAM have taken researchers' attention away from other important research topics related to design and implementation, and behaviour- and performance-based impact on IS/IT adoption, which is very worrying, because constructs added over the years of research reflect one set of belief perceptions rather than expanding the understanding of what makes an IS/IT useful. In addition, several authors argued that an excessive emphasis placed on the

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application of TAM had impeded the authors' knowledge of the progress that has been made in the field of IS/IT adoption and acceptance. This will be detrimental to the field, as it adversely affects the diversification and innovation of knowledge in IS/IT acceptance and adoption (Venkatesh & Bala, 2008; Wallace & Sheetz, 2014).

The purpose of this paper is to explore the research status and development trend of TAM through a bibliometric analysis of academic publications. The first section of the paper presents TAM and its chronological evolution over three decades of the literature available. The second section provides a comparative bibliometric analysis of publications—examining the evolution of model publications over time, applications researched and studied fields, prolific countries, productive journals, and citations. The third section states the conclusion, the limitations of the study, and future research directions for budding scholars in the area.

Prior Study and Theoretical Background

The literature on information systems (IS) and information technology (IT) contains a wide range of theories, models, and theoretical structures to address various implications, especially innovation. The list is exhaustive. Some of the theories being deliberated include:

1. Theory of Diffusion of Innovations (DIT) (Rogers, 1995)
2. Theory of Reasonable Action (TRA) (Ajzen & Fishbein, 1985)
3. Theory of Planned Behaviour (TPB) (Ajzen, 1991)
4. Decomposed Theory of Planned Behaviour (Taylor & Todd, 1995a)
5. Technology Acceptance Model (TAM) (Davis, Bagozzi & Warshaw, 1989)
6. Technology Acceptance Model 2 (TAM2) (Venkatesh & Davis, 2000)
7. Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh *et al.*, 2003)
8. Technology Acceptance Model 3 (TAM3) (Venkatesh & Bala, 2008).

Some of these theories of technology acceptance are summarized in Table 1.

Table 1. Theories on technology acceptance

Theory	Proposed scholar	Proposed theory
Diffusion of Innovation	Rogers (1995)	The author introduced an S-shaped adoption curve of innovators, early adopters, early majority, late majority and laggards.
Task Technology Fit	Goodhue & Thompson (1995)	Individual impact is based on the task characteristics, technology characteristics, performance impact and utilization
Theory of Reasonable Action (TRA)	Ajzen & Fishbein (1985)	They determined the intention of a person's attitudes towards behaviour attitude was impacted by behavioural beliefs and outcome evaluation;

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Theory	Proposed scholar	Proposed theory
		subjective norms, impact factors are normative belief and motivation to comply.
Theory of Planned Behaviour	Ajzen (1991)	Extension of TRA- introduced an additional factor- perceived behavioural control
Technology Acceptance Model (TAM)	Davis (1985)	Includes two specific parameters: Perceived Usefulness (PU) and Perceived Ease of Use (PEoU)
Unified Theory of Acceptance and Use of Technology (UTAUT)	Venkatesh *et al.* (2003)	The model has four predictors of users' behavioural intention: performance expectancy, effort expectancy, social influence and facilitating conditions.

Source: Authors' compilation

Fishbein and Ajzen's research from the 1970s (published in 1974) demonstrated a comprehensive understanding of how to implement TRA in various technological contexts, such as the Internet (Taylor & Todd, 1995b). Davis (1985) analysed the factors that led to the development of technology and behaviour, and he systematically expanded TRA.

The initial TAMs included determinants for perceived ease of use (PEoU) and perceived usefulness (PU). As a result of the work of several researchers (Karahanna, Straub & Chervany, 1999; Venkatesh & Davis, 2000; Wu, Chen & Lin, 2007; Yen *et al.*, 2010), as well as academics (Venkatesh & Bala, 2008; Yen *et al.*, 2010), several revisions and extensions to the models have been made (Gefen, Karahanna & Straub, 2003; Karahanna, Agarwal & Angst, 2006). TAM has also been successfully combined with existing theories and models from social psychology, cognitive psychology, humanistic psychology, positive psychology (Flow Theory), sociology, and information technology (among many others), to improve the explanatory power of individual models (Al-Emran & Shaalan, 2021).

An earlier study by Davis (1985) investigated computer usage behaviour and improved the technology acceptance model of the TRA (TAM) framework with its PU. The extension of the TAM model, named as TAM2, developed by Venkatesh & Davis (2000), looked at PU and the intention of use from the standpoint of social influence. Different empirical platforms have evaluated TAM for the validity of measurement. A potential application of TAM for innovative technology acceptance has backed various platforms, like education (Kesting, Gerstlberger & Baaken, 2018; Castiblanco Jimenez *et al.*, 2021; Baby & Kannammal, 2020), banking (Kishore & Sequiera, 2016; Kumar, Lall & Mane, 2017), payment (Carranza *et al.*, 2021; Tassabehji & Kamala, 2009; Qi, Carbó-Valverde & Rodríguez-Fernández, 2016), trading (Raman & Don, 2021); cloud computing application (Cengiz & Bakirtaş, 2020); and social networking (Ahmad & Farooqi, 2020; Gunasagaran *et al.*, 2019). TAM has gotten far ahead in reliability and applicability across these studies. During the prolonged COVID pandemic, there has been a steep rise in the TAM model employed to comprehend the factors influencing the usage and

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acceptance of technology in different fields, especially in the education ecosystem (Castiblanco Jimenez *et al.*, 2021; Mailizar, Burg & Maulina, 2021; Mukred *et al.*, 2021).

On the contrary, previous studies have been limited in scope and relevance. They focused on the overall growth or expansion of a paradigm and its application in a particular field. Many studies considered it an outdated model, which is not applicable in the current scenario. TAM-based research is often rejected at the initial screening stage of publication in multiple high-quality publications. Bagozzi (2007) has bleakly slated TAM underpinning many advancements. According to his research, the study of TAM is "on the verge of crisis, if not chaos, in terms of explaining technology acceptance". His research reveals two critical gaps:

1. The difference between intention and behaviour, as well as between behaviour and goal attainment;
2. The relationship between individual reactions to information use and intentions.

A similar criticism can be seen in Goodhue (2007), who appreciated the work of Benbasat and Barki (2007) in the area, highlighting the way scholars have overworked the model. On the one hand, he appraised the model's importance and usefulness, stating: "Why don't people make more use of information systems?"

TAM and its adaptations during the last 30+ years are examined using bibliometric analysis in this study ranging from 1990 to 2021 to ensure the relevance of earlier studies and assess if TAM still holds validation. More precisely, the study examined the evolution of TAM publications over time from its inception, identifying the well-researched applications, domains, countries, and the most prolific journals.

Methodology

Unlike previous literature reviews, this study uses the evolving methodology of bibliometric analysis to identify the quantitative and qualitative changes in TAM and its applications. According to Zyoud *et al.* (2014), bibliometric analysis is commonly used to assess the quality of research studies and to reveal patterns and characteristics of a particular topic (Abbas *et al.*, 2020; Ali *et al.*, 2021; Abbas *et al.*, 2022; Srivastava, 2020; Alsharif *et al.*, 2021; Sikandar *et al.*, 2022; Van *et al.*, 2021). By assessing the number of publications and the number of citations received, bibliometric indicators can evaluate the scope and quality of underlying research investigations (Sahi *et al.*, 2021; Bahuguna, Srivastava & Tiwari, 2022; Roy *et al.*, 2022; Bakri & Willett, 2011; Wahid, Ahmi & Alam, 2020).

The VOSviewer tool is used for bibliometric mapping and display of results (Van Eck & Waltman, 2014; Ali *et al.*, 2022). Moreover, the tool is easy to use and advantageous for

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creating and displaying extensive scientific maps in a fluid and convenient manner (Mao *et al.*, 2015). This is due to the application of the data and the coverage of different sciences.

We used the Scopus scientific database for current analysis to examine publications containing "TAM Model" or "Technology Acceptance Model" in their title, abstract, or keywords. Scopus has one of the world's largest abstract and citation databases, with 1.7 billion cited references from peer-reviewed publications. By analyzing its data, a full picture of the world's research output is achievable. The international scientific community regards Scopus as one of the most essential sources of helpful information (Lv *et al.*, 2021). Figure 1 presents the research flow of this paper. The study takes into account all categories of publications available in the Scopus database between 1990 and 2020. A total of 8207 articles were retrieved, including all types of publications. To draw a comprehensive picture of the TAM and its applications, all publication types were taken into consideration and further analyzed.

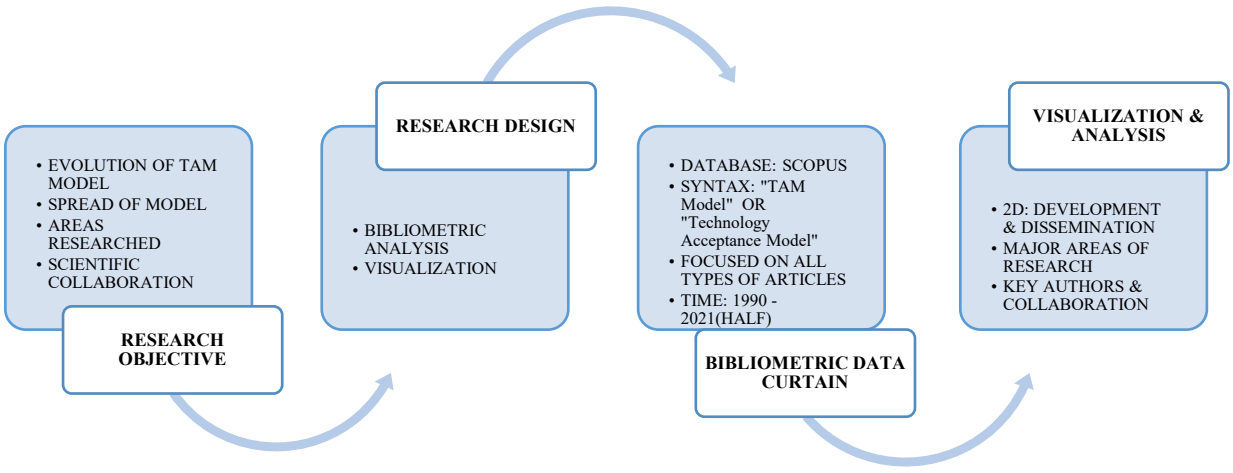

Figure 1. Research flow (Source: Authors)

The research distribution patterns in diverse subjects and eras were explained using bibliometric analysis as well as quantitative and statistical analysis in this study. The search was conducted on 14 June 2021, for all years. Although a bibliometric examination of the TAM Model was carried out by Al-Emran & Granić (2021), their study's time frame was limited to the years 2010–2020. Their findings were based on information gathered from the WoS database. In this study, Scopus databases were used to provide 8207 documents related to TAM, which will make a different contribution from a database perspective.

We used the bibliometric approach to identify the evolution of the TAM model over years, check the main topics in this field, and identify the main authors of TAM models. Through the analysis, with the help of the search results tools, several results were immediately pulled from Scopus. Other data was manually entered or exported to a new Excel file. Information such as

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percentages was evaluated from the file created for the outcomes. A VOSviewer was used to make pictures to aid the interpretation of the data. A final report was prepared, which provided findings and analysis in which we identified, analyzed, and summarised the results. We expect that this research will shed light on TAM publication trends. These findings can be used as a foundation for future research and discourse aimed at enhancing and improving this field of study.

Results

The results of this bibliometric analysis are discussed in the current section regarding the following research questions:

RQ1. What constructed and propagated TAM research?

RQ2. What are the main subject topics discussed in TAM research?

RQ3. What are the main features that authors from various nationalities in TAM research have in scientific research collaboration?

TAM Research: 2D – Development & Dissemination

This study investigated the following data to answer the topic of TAM research development and trends in its dissemination:

1. Number of publications by year;
2. Source Title;
3. Source and document type;
4. Document language.

Publications by year

Statistics on yearly TAM research publications are provided in Table 2, and they show an upward trend from 1990 through the middle of the year 2020. In the year 1990, Scopus only indexed a single piece of literature that had been published (the first year TAM documents were published and indexed by Scopus). From 1990-2003, the Scopus database contained a total of fewer than one hundred reports of TAM documents. Surprisingly, there was a significant increase in the number of publications that were made available on TAM in the year 2007, with 206 documents being uploaded during that time. From 2008 to 2020, there was a consistent increase in the number, which indicates a growing interest in TAM (refer to Figure 2). The process of collecting and analysing data for this paper was finished in June of 2021, so the rest of the 2021 publications were not covered in this analysis.

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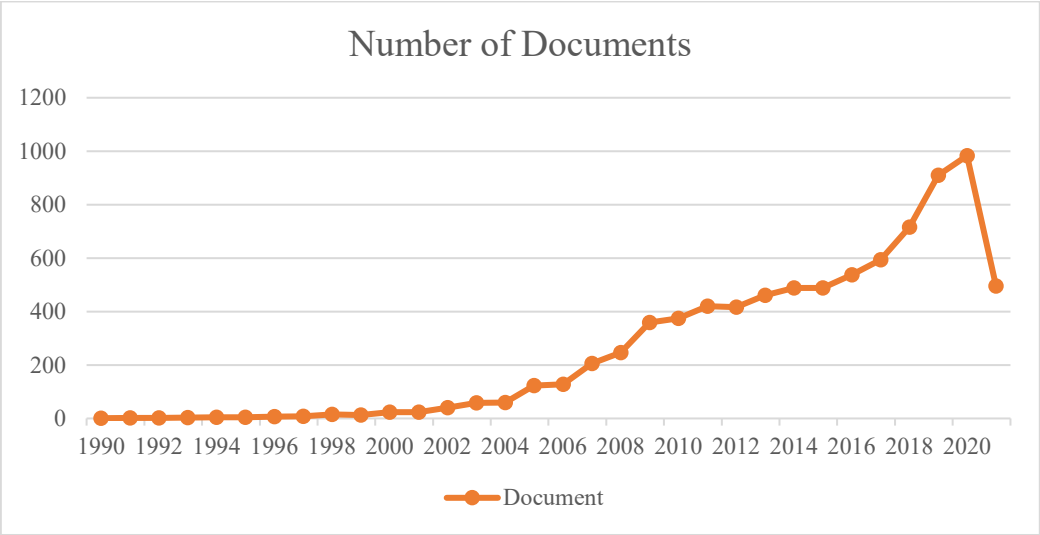

Figure 2. TAM overall publications by years

Table 2 Research Publications using TAM model (Source: Authors' analysis)

Year	Number of documents	Percentage
2020	983	11.98%
2019	910	11.09%
2018	716	8.72%
2017	594	7.24%
2016	538	6.56%
2015	488	5.95%
2014	488	5.95%
2013	461	5.62%
2012	416	5.07%
2011	420	5.12%
2010	374	4.56%
2009	359	4.37%
2008	246	3.00%
2007	206	2.51%
2006	128	1.56%
2005	123	1.50%
2004	59	0.72%
2003	58	0.71%
2002	40	0.49%
2001	23	0.28%
2000	23	0.28%
1999	13	0.16%
1998	15	0.18%
1997	8	0.10%
1996	7	0.09%
1995	4	0.05%
1994	4	0.05%
1993	3	0.04%
1992	2	0.02%
1991	2	0.02%
1990	1	0.01%
Total	**8,207**	**100.00**

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Sources and types of documents

The analysis of the documents based on the different source types is shown in Figure 3. The most popular source was journals, which accounted for around two-thirds of the total, 5,526 (67.33%); followed by conference proceedings, 2,018 (24.59%). Other sources like book series, books, and trade journals, with one unidentified source, formed 8.07% of the total sources available.

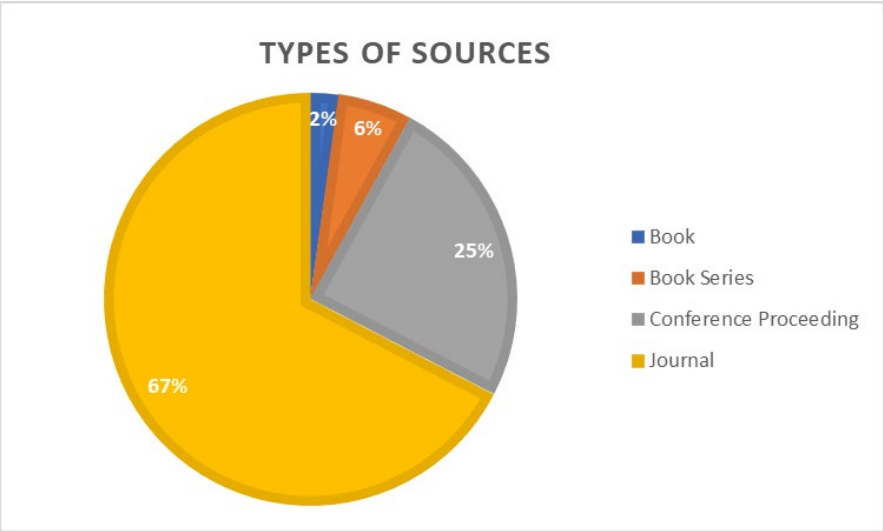

Figure 3. Types of sources contributed using the TAM model

Further, the analysis was done to identify the type of relevant documents contributed in this field. A total of 5312 articles (64.71%), equivalent to more than half of all publications, as indicated in Table 3, contributed to this field. It was followed by conference papers, which were 2,425 (29.54%) in number. This indicates that not only the articles published in journals but also conference papers are getting a good number of publications in this field.

Table 3. Document Types using TAM model (Source: Authors' analysis)

Document Type	Number of documents	Percentage
Article	5310	64.71%
Conference Paper	2425	29.54%
Book Chapter	229	2.79%
Review	164	2.00%
Conference Review	51	0.62%
Note	9	0.11%
Editorial	7	0.09%
Data Paper	4	0.05%
Erratum	3	0.04%
Book	2	0.02%
Retracted	1	0.01%
Undefined	2	0.02%
Total	**8,207**	**100.00**

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Relevant sources

According to the relevant sources contributed in this field, "Computers in Human Behavior" has the maximum number of publications using the TAM model (n=137), followed by the ACM "International Conference Proceeding Series" (n=128) and "Lecture Notes in Computer Science" (n=126). The top 20 sources for publishing TAM information are listed in Table 4.

Table 4. Top 10 sources contributed using the TAM model (Source: Authors' analysis)

Source Title	Number of documents	Percentage
Computers in Human Behavior	137	1.67%
ACM International Conference Proceeding Series	128	1.56%
Lecture Notes in Computer Science	126	1.53%
Sustainability Switzerland	80	0.97%
Advances in Intelligent Systems and Computing	75	0.91%
Behaviour and Information Technology	71	0.86%
Education and Information Technologies	64	0.78%
Information and Management	64	0.78%
Computers and Education	61	0.74%
Journal of Theoretical and Applied Information Technology	54	0.66%

Language

Table 5 shows that English is the most popular language, accounting for 98.10% of the publications. The second most popular language was Spanish; the remaining records were released in nine other languages, including Chinese, Portuguese, French, German, and Persian. It is interesting to know that publication in this field is not contributing only to the English language, but also contributing to other languages.

Table 5. Languages Used in TAM (Source: Authors' analysis)

Language	Number of documents	Percentage
English	8,053	98.10%
Spanish	62	0.76%
Chinese	36	0.44%
Portuguese	27	0.33%
French	21	0.26%
German	8	0.10%
Persian	7	0.09%

Major Areas of Research in TAM

In this section, subject area, frequency of keywords, titles for documents and the primary areas of TAM research were analyzed.

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Major research areas using the TAM model

The classification of the documents based on the area of research is shown in Table 6. The result reveals that the maximum number of articles was contributed in the computer science field with 4409 publications (53.71%), followed by numerous papers in the social sciences with 2595 (31.61%). Other areas with more than 500 publications are business, management, accounting, engineering, decision sciences, medicine, and mathematics.

Table 6. Relevant Areas of Contribution using the TAM model (Source: Authors' analysis)

Subject area	Number of documents	Percentage
Computer Science	4409	53.71%
Social Sciences	2595	31.61%
Business, Management and Accounting	2246	27.36%
Engineering	1557	18.97%
Decision Sciences	935	11.39%
Medicine	635	7.74%
Mathematics	525	6.40%
Economics, Econometrics and Finance	470	5.73%
Psychology	421	5.13%
Arts and Humanities	394	4.80%
Environmental Science	231	2.81%
Energy	168	2.05%
Health Professions	165	2.01%
Nursing	131	1.60%
Materials Science	116	1.41%
Physics and Astronomy	115	1.40%
Agricultural and Biological Sciences	98	1.19%
Biochemistry, Genetics and Molecular Biology	81	0.99%
Multidisciplinary	78	0.95%
Chemical Engineering	46	0.56%

Keyword analysis

The authors' chosen keywords are displayed in Figure 4, and each of those keywords appears at least ten times throughout the chart. Researchers made use of a piece of software called VOSviewer, which is designed to generate and display bibliometric networks so that they could map authors' keywords. In addition, the colour of the connected lines, the size of the circle, the size of the text, and the width of the lines all show connections with the other keywords. For instance, the terms associated with different colours were frequently grouped.

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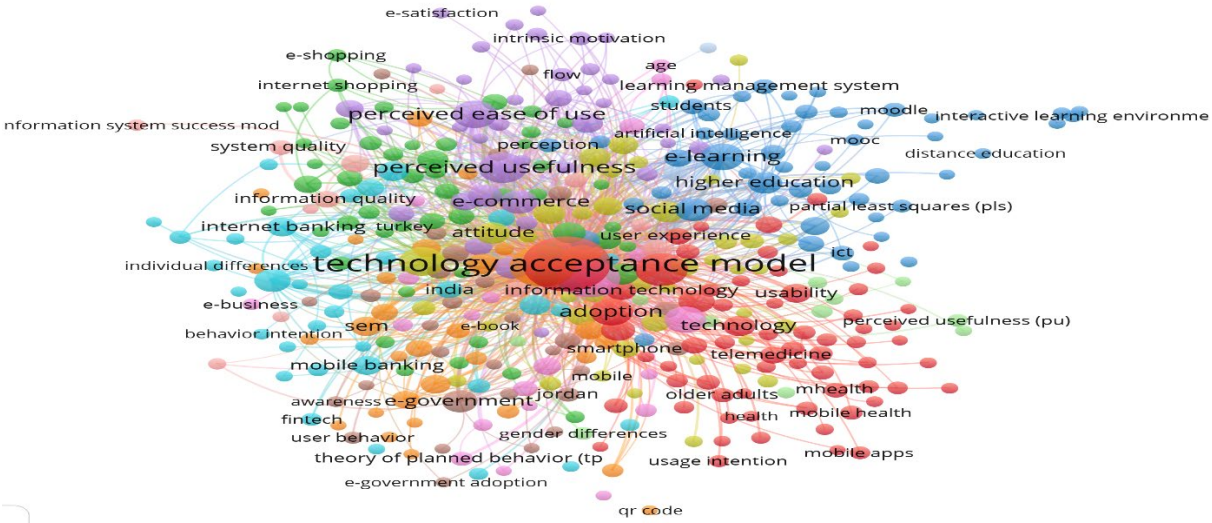

Figure 4. Author keywords in network visualization map

Table 7 shows the most frequently used keywords in the TAM model studies. The data revealed that the "technology acceptance model" was the keyword most used (n=3669) in the publications. "Perceived usefulness and trust" were other major TAM-related keywords that appeared in documents over 300 times. Moreover, "e-learning" occurred more than 200 times. Other popular keywords that appeared more than 100 times were "e-commerce", "social media", "perceived risk", "intention to use", "e-government", "higher education", "attitude", "user acceptance", "Internet", "self-efficacy", and "theory of planned behaviour".

Table 7. Keywords and their Frequency in TAM Research (Source: Authors' analysis)

Keywords	Occurrences	Percentage
Technology acceptance model	3669	44.71%
Perceived usefulness	365	4.45%
Trust	319	3.89%
Perceived ease of use	276	3.36%
E-learning	242	2.95%
Adoption	241	2.94%
Structural Equation Modelling	224	2.08%
E-commerce	171	1.84%
Social media	151	1.79%
Perceived risk	148	1.68%
Intention to use	147	1.60%
E-government	138	1.52%
Higher education	131	1.50%
Attitude	125	1.46%
User acceptance	123	1.40%
Behavioural intention	120	1.38%
Internet	115	1.28%
Self-efficacy	113	1.27%
Theory of Planned Behaviour	105	1.23%

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Title analysis

In Figure 5, the thickness of the connecting lines represents the strength of connection of the words that are related, while the size of the nodes indicates the frequency of occurrence of the terms. The use of the same colour indicates that the terms are related and frequently occur together. The examples (e.g., customer acceptance, customer intent, and integrative model) are all related and frequently occur simultaneously. In this study, VOSviewer generated 11 unique colours representing 11 clusters and 242 keywords based on publication titles. The term co-occurrence network shown in Figure 5 illustrates term occurrences in titles with a minimum of 10 occurrences. The paper used a binary counting method which means the Occurrences attribute indicates the number of documents in which a term occurs at least once. In the case of full counting, the Occurrences attribute indicates the total number of occurrences of a term in all documents, and it is unaffected by the frequency with which a term appears in the title of a publication (Van Eck & Waltman, 2014). Figure 5 demonstrates that the word "theory" was the most important keyword in TAM research, serving as a node at the centre of the entire network. In addition, "Internet", "design", and "loyalty" were divided into different clusters and appeared as the most frequently occurring terms in the title, indicating that most studies focused on the role of technologies in understanding customer behaviour.

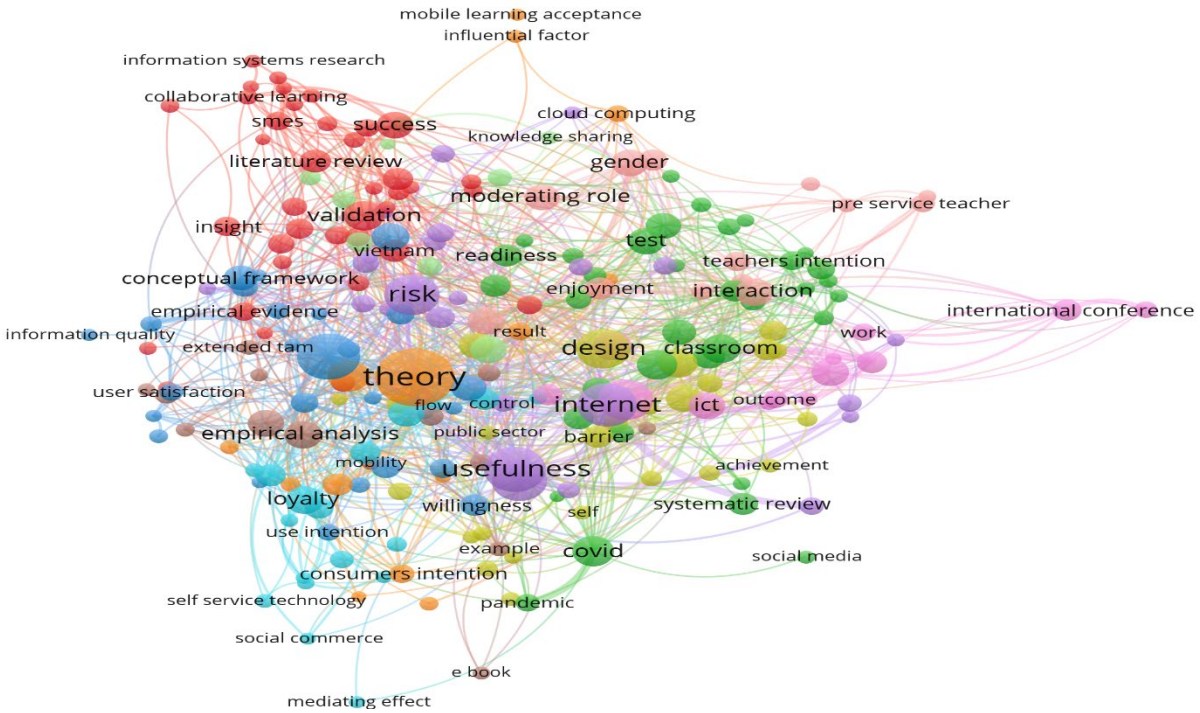

Figure 5. A network of term co-occurrences focused on title data, visualized using VOSviewer (binary counting)

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Key Authors and Collaboration in TAM Research

In this section, the physiognomies of scientific collaborations in the study of the TAM model were investigated by looking at the countries that contributed the most publications, and authorship analysis and citation analysis of the major institutions active in TAM research.

Countries making the greatest contributions to TAM

Table 8 shows the top ten countries where the majority of publications are done using the TAM model. The United States ranked first with 1491 papers (18.16%), followed by Taiwan with 872 papers (10.62%), and China with 754 papers (9.19%). The rest of the country affiliations contributed less than 10% of the total and were distributed globally. We can conclude that TAM plays an important role in different countries.

Table 8. Countries involved in publications using TAM model (Source: Authors' analysis)

Country	Number of documents	Percentage
United States	1491	18.16%
Taiwan	872	10.62%
China	754	9.19%
Malaysia	686	8.36%
United Kingdom	475	5.79%
South Korea	431	5.25%
Indonesia	405	4.93%
Australia	340	4.14%
India	305	3.72%
Spain	297	3.62%

Institutions

Table 9 lists the institutions that are the sources of the majority of publications in this field. At 16.3%, University of North Texas (US), with the status of one of the world's major universities, accounted for 134 publications. The first five institutions after the US are located in southeast Asian countries: institutions from Indonesia, Malaysia, and Taiwan contributed to most of the publications.

Table 9. Institutions contributed to research using TAM model (Source: Authors' analysis)

Institutions	Number of documents	Percentage
University of North Texas	134	16.3%
Universiti Teknologi Malaysia	78	10.62%
Universiti Sains Malaysia	72	9.19%
National Cheng Kung University	65	8.36%
Universiti Kebangsaan Malaysia	55	5.79%
National Taiwan Normal University	54	5.25%
Brunel University London	52	4.93%

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Institutions	Number of documents	Percentage
Sungkyunkwan University	50	4.14%
Universiti Putra Malaysia	50	3.72%
National Taiwan University of Science and Technology	49	3.62%

Authorship

The most productive authors that contributed significantly to the research using the TAM model are given in Table 10. With 43 publications, the most influential author is Timothy Teo, affiliated with Murdoch University, Perth, Australia. The second most productive author on TAM was Mostafa Al-Emran, with 29 publications from University Malaysia Pahang, Kuantan, Malaysia. Next in line is Said A. Salloum, a researcher from the University of Sharjah, United Arab Emirates. After the analysis, the Asian countries produced the most productive authors, which meant that TAM applications in developing countries have become popular and applicable.

Table 10. Active authors contributing to studies using TAM model (Source: Authors' analysis)

Author	Number of documents	Percentage
Teo, T.	43	0.52%
Al-Emran, M.	29	0.35%
Salloum, S.A.	28	0.34%
Ooi, K.B.	27	0.33%
Park, E.	25	0.30%
Ramayah, T.	25	0.30%
Al-Rahmi, W.M.	24	0.29%
Shin, D.H.	24	0.29%
Dwivedi, Y.K.	20	0.24%
Tan, G.W.H.	16	0.19%
Venkatesh, V.	16	0.19%
Gao, S.	15	0.18%
Arpaci, I.	14	0.17%
García-Peñalvo, F.J.	14	0.17%
Williams, M.D.	14	0.17%
Bazelais, P.	13	0.16%
Chong, A.Y.L.	13	0.16%
Doleck, T.	13	0.16%
Huang, Y.M.	13	0.16%
Kim, K.J.	13	0.16%

Network visualisation was shown using VOSviewer software. Figure 6 displays co-authorship among many authors. Mapping was done using authors' data with at least five documents and five citations. The degree of the relationship between the authors' works is shown in the connecting lines. Same-coloured authors are frequently grouped. For instance, the figure shows that "Teo T." and "Al-Emran M." have a strong link of 35 even though they form

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different clusters. From the analysis, "Zhang Y." appears to have worked closely with authors from around the world.

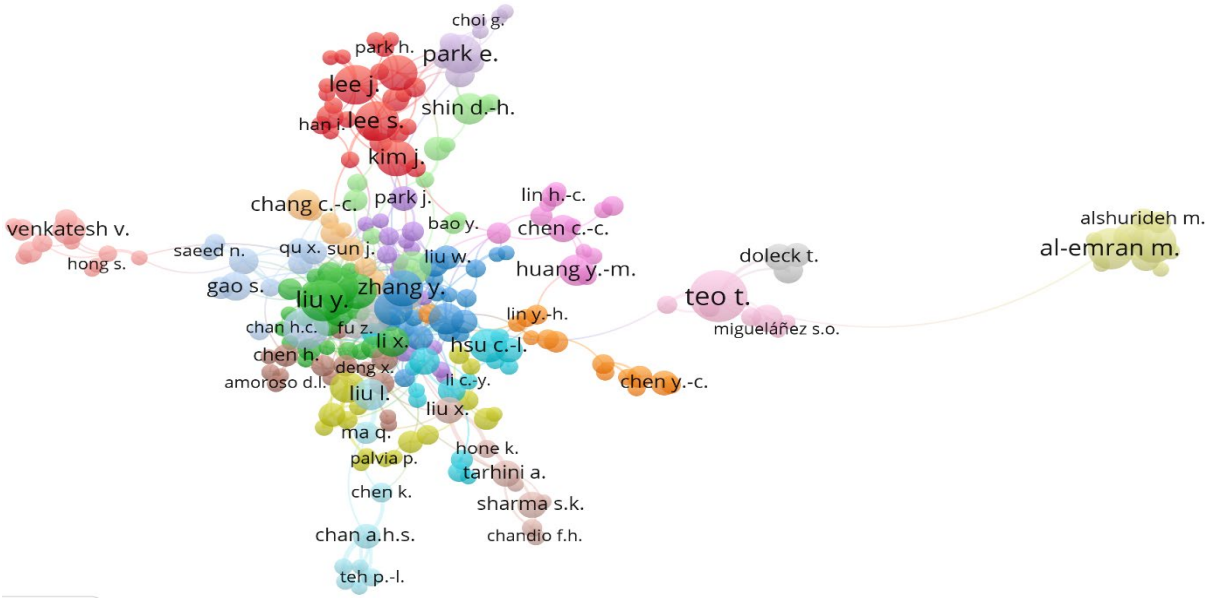

Figure 6. Network visualization map of co-authorship in TAM.

Figure 7 depicts the countries' network visualization map, where countries represent affiliation. The fractional counting approach concluded that US authors play an important role. The US has collaborated closely with Taiwan, Australia, Malaysia, the United Kingdom, and South Korea. Other collaboration activities were set up with colleagues from Spain, India, Germany, and Saudi Arabia.

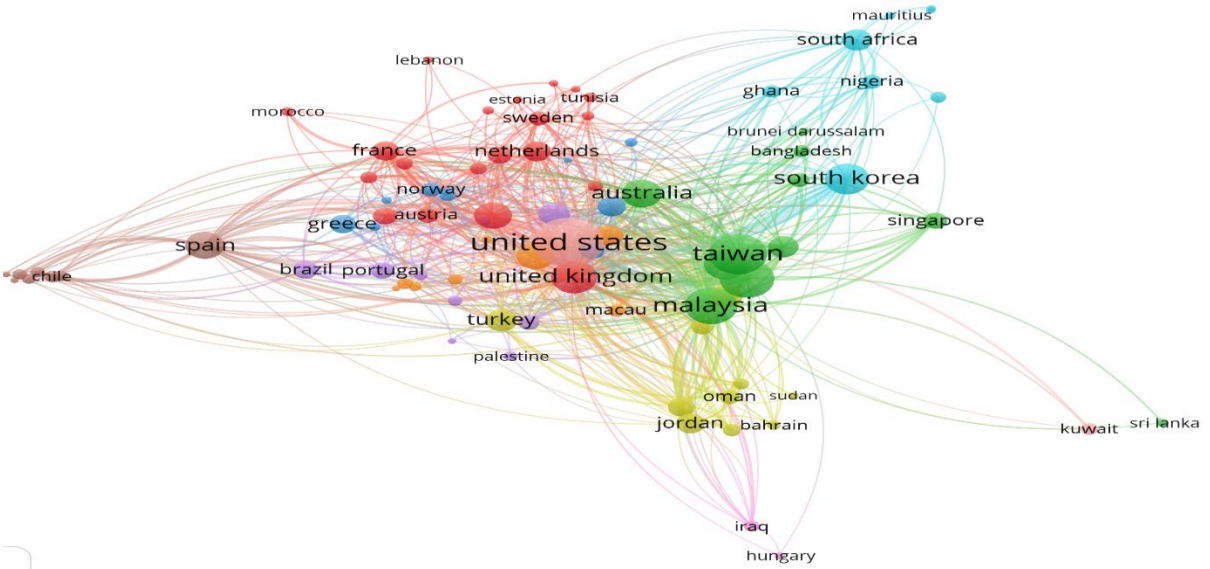

Figure 7. TAM research co-authors' geographical network visualization map

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Citation

Table 11 summarises citation metrics of the published documents retrieved from Scopus. There were 280 632 citations registered for 8207papers from 1990 to 2021 and an average of 9052.65 citations per year.

Table 11. Citation Metrics for TAM Research (Source: Authors' analysis)

Metric	Data
Total papers	8207
Total citations	280632
Number of years	(2021-1990)
Citations per year	9052.65
Citations per paper	32.48
Citations per author	2.92
h-index	209
g-index	428

Most influential documents

Citation analysis is the most commonly used method for assessing the influence of authors, journals, and documents because it identifies the most important publications in the research field. Table 12 provides an overview of the citation structure in the research area of interest. It is possible to examine which papers are most cited in the field, with the reference publication "User acceptance of information technology: Toward a unified view" by Venkatesh, which has 15518 citations. The document "A theoretical extension of the Technology Acceptance Model: four longitudinal field experiments" by the same author ranks second with 9131 citations. The remaining publications have less than 5000 citations but are still important for TAM technology. Other frequently cited documents included Technology Acceptance Model 3 and User Intentions, as well as those dealing with antecedents of perceived ease of use (PEoU), user acceptance of hedonic information systems, online consumer behaviour, user satisfaction, technological acceptance, and mobile commerce. Moreover, we discovered that the most prominent sources are *MIS Quarterly: Management Information Systems*, *Management Science*, and *Information Systems Research*. Understanding the most cited articles, both historically and on a yearly average, can help researchers identify seminal material that can be used as a reference to support their studies and provide a clear starting point.

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Table 12. Most Influential Documents (Source: Authors' analysis)

Author (year)	Title	Source	TC	CPY	CPA
Venkatesh *et al.* (2003)	User acceptance of information technology: Toward a unified view	MIS Quarterly: Management Information Systems	15518	862.11	3880
Venkatesh & Davis (2000)	A theoretical extension of the Technology Acceptance Model: Four longitudinal field studies	Management Science	9131	434.81	4566
Taylor & Todd (1995b)	Understanding information technology usage: A test of competing models	Information Systems Research	4440	170.77	2220
Bhattacherjee (2001)	Understanding information systems continuance: An expectation-confirmation model	MIS Quarterly: Management Information Systems	3640	182	3640
Venkatesh (2000)	Determinants of Perceived Ease of Use: Integrating Control, Intrinsic Motivation, and Emotion into the Technology Acceptance Model	Information Systems Research	3275	155.95	3275
Venkatesh & Bala (2008)	Technology acceptance model 3 and a research agenda on interventions	Decision Sciences	2681	206.23	1341
Pavlou (2003)	Consumer acceptance of electronic commerce: Integrating trust and risk with the technology acceptance model	International Journal of Electronic Commerce	2662	147.89	2662
Venkatesh & Morris (2000)	Why don't men ever stop to ask for directions? Gender, social influence, and their role in technology acceptance and usage behaviour	MIS Quarterly: Management Information Systems	2332	111.05	1166
Mathieson (1991)	Predicting user intentions: Comparing the technology acceptance model with the theory of planned behaviour	Information Systems Research	2232	74.4	2232
Davis (1993)	User acceptance of information technology: system characteristics, user perceptions and behavioural impacts	International Journal of Man-Machine Studies	2180	77.86	2180
Legris, Ingham & Collerette (2003)	Why do people use information technology? A critical review of the technology acceptance model	Information and Management	2106	117	702

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Author (year)	Title	Source	TC	CPY	CPA
Van Der Heijden (2004)	User acceptance of hedonic information systems	MIS Quarterly: Management Information Systems	2085	122.65	2085
Moon & Kim (2001)	Extending the TAM for a World-Wide-Web context	Information and Management	2077	103.85	1039
Venkatesh & Davis (1996)	A model of the antecedents of perceived ease of use: Development and test	Decision Sciences	1774	70.96	887
Koufaris (2002)	Applying the Technology Acceptance Model and flow theory to online Consumer Behavior	Information Systems Research	1734	91.26	1734
Agarwal & Prasad (1998)	A Conceptual and Operational Definition of Personal Innovativeness in the Domain of Information Technology	Information Systems Research	1646	71.57	823
Wixom & Todd (2005)	A theoretical integration of user satisfaction and technology acceptance	Information Systems Research	1579	98.69	790
Taylor & Todd (1995c)	Assessing IT usage: The role of prior experience	MIS Quarterly: Management Information Systems	1489	57.27	745
Pavlou & Fygenson (2006)	Understanding and predicting electronic commerce adoption: An extension of the theory of planned behaviour	MIS Quarterly: Management Information Systems	1483	98.87	742
Wu & Wang (2005)	What drives mobile commerce? An empirical evaluation of the revised technology acceptance model	Information and Management	1318	82.38	659

Note: TC=total citations; CPY=citations per year; CPA=citations per author.

The citation-mapping document, which contains at least 20 references, can be found presented in Figure 8. It illustrates the prominent authors who were working in the field at the time and demonstrates how the authors' ideas were arranged with one another. Figure 9 provides a more in-depth network representation of the documents cited by the countries of origin.

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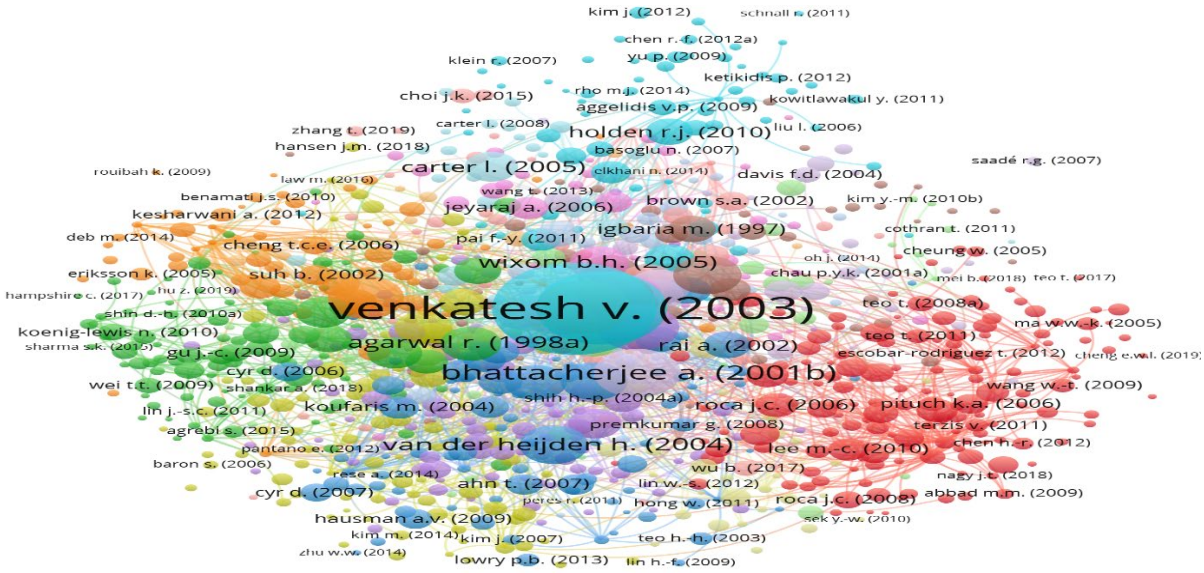

Figure 8. The network visualization map of TAM document citations

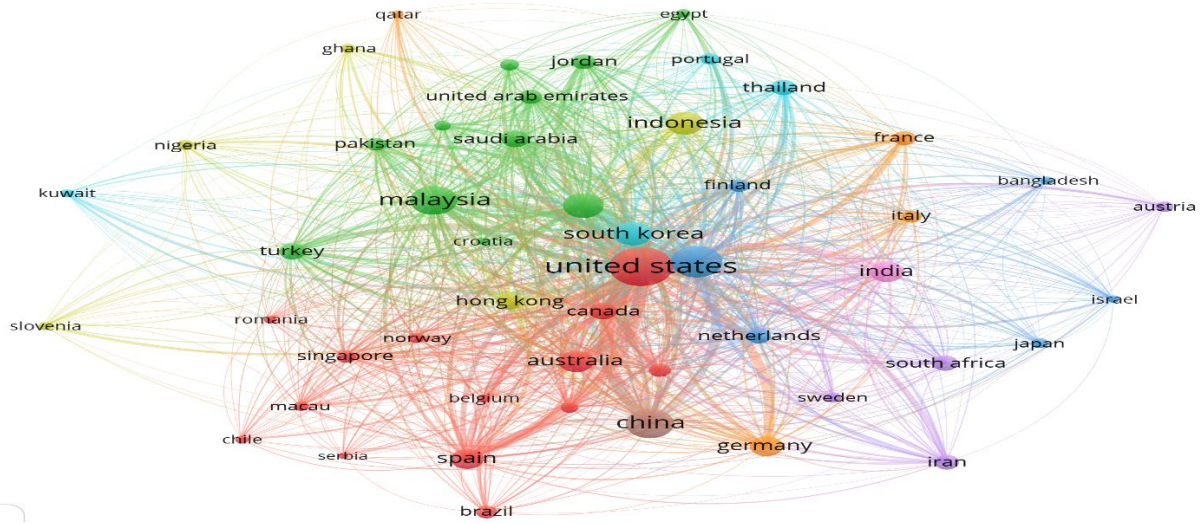

Figure 9. The network visualization map of TAM documents' citations by country

Discussion

In this study, a bibliometric analysis method is used to analyse research development on TAM. Bibliometric analysis can be used to evaluate the productivity of research and publications in a given field. The results of the bibliometric analysis can reveal the performance and influence of the analyzed research area, which can help managers and policymakers make critical decisions before engaging in the specific area. In addition, the results of the bibliometric study can help academics develop current and relevant research by identifying critical areas that need attention (Abbas *et al.*, 2022; Alsharif *et al.*, 2022).

The concept of perceived ease of use (PEoU) and the concept of perceived usefulness (PU) were developed as two fundamental principles for envisaging user acceptance (Venkatesh *et al.*, 2003). Both discuss an individual's perception towards the usage of new technology, but with a different intention. The first concept highlights effortless usage of technology, whereas

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the second concept defines the usage that will improve one's performance. Over the last three decades, there has been a significant increase in the number and variety of theoretical views that have been developed to provide knowledge of usage factors. At the same time, the majority of TAM research focuses on methods for determining the behavioural intentions of an individual. There is a growing need to have a better understanding of the factors that modify the interactions that take place between the TAM variables.

This study aims to identify and understand TAM from a holistic view, making it more valuable because there has never been a study conducted that has conducted a bibliometric review for TAM from 1990 to 2020. Moreover, the study realises that new papers are still increasing and hints at the elevated intention to use TAM to understand user adoption of technology. The selection of 8207 articles for this bibliometric analysis was published within the last 31 years. The study reveals intriguing and stimulating results that are considered important for TAM.

Regarding RQ1, which is concerned with the evolution and distribution of TAM, our results revealed that documents on TAM were first shown in 1991, just briefly after Mathieson coined the abbreviation TAM. The number of documents on TAM continued to grow steadily for the next 30 years after that. The first two papers on TAM were published in the *Journal of Information Systems Research*, and both were from the United States. This demonstrates that researchers from both the East and the West were aware of TAM's existence during the early stages of development.

Most TAM research can be found in journals and conference proceedings as research articles or a conference paper, with a few exceptions published as conference review (0.62%), review (2%), and editorial (0.09%), which accounts for a negligible percentage. The documents were most frequently seen in titles, abstracts, and keywords in computer science and social science. From a country's perspective, the major origin of publication in the area was the United States (from the West), and most of the countries from the East were China, Taiwan, and Malaysia.

Studies in TAM mostly focus on computer and social science, business, management, and accounting, which answers RQ2. The clustering of TAM research showed 11 clusters. It suggests that most TAM research focused on perceived usefulness, trust, ease of use, e-learning, adoption, e-commerce, and social media.

Since 2006, the research trend has shifted from TAM to mobile applications. For example, the study by Hong, Thong & Tam (2006) ushered in an era of mobile commerce/service from the perspective of lower-end consumers. Similarly, Hong *et al.* (2008) studied mobile data services. On the other hand, the study by Liao, Tsou & Huang (2007) examined the variables affecting the use of 3G mobile services. In 2009, the development of 3G mobile value-added services was studied by Kuo & Yen (2009). Aldás-Manzano, Ruiz-Mafé & Sanz-Blas (2009)

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studied the variables affecting shoppers' participation in mobile shopping. This stream created a platform for mobile-based TAM research before converging in the node of Zhou, Lu & Wang (2010), who further developed a task-technological-fit (TTF) model and UTAUT integration to propose a model for user acceptance of mobile banking. Following the mobile-based research line of TAM, two recent articles used neural networks (a nonlinear and no compensatory model) and UTAUT (Chong *et al.*, 2012; Williams *et al*, 2011) to examine factors that influence consumers' propensity to use 3G. The other two nodes in the tail of the network proposed NFC (Near Field Communication), a more specialised and modern application of mobile commerce (Tang, Aik & Choong, 2021). Gender, age, experience, and usage were included as moderator variables in the study by Leong *et al.* (2013), which examined factors influencing the adoption of NFC-enabled mobile credit cards. The study by Tan *et al.* (2014) examined TAM and four other factors to investigate how mobile credit cards (also known as NFC) are adopted.

Further, in terms of RQ3, our examination of countries, institutions, authors, and citations revealed that there appeared to be a good degree of scientific collaboration on TAM research taking place all around the world. While the TAM model has appeared in the USA, Taiwan and China have emerged as the two leading nations from which scholarly articles on TAM are published. The United States had the most TAM articles, indicating that it had been a leader in TAM research for the last 31 years and had possibly directed resources to it. The United States has had the world's top university contributing to TAM up to this point.

Conclusion

In practice, the paper has significant implications for academics and practitioners to evaluate various techniques to enhance their understanding of TAM as a realistic model. In addition, researchers should attempt to include more constructs, like cognitive absorption and social presence, in TAM, since they have become more important to evolving technology and the current circumstances. The assimilation of theories of acceptance from other disciplines with TAM will be effective, as it will give insights into future technological evaluations applied to other settings for further developments in the prediction of user behaviour. Although significant effort has been observed in research, application and practice still have tremendous potential in this field.

A bibliometric study between the years 1990 and 2020 was carried out in order to compile a comprehensive overview of publications that are pertinent to TAM research. In this paper, the development of TAM is documented through several published studies per year, sources, languages, subject areas, keywords, document names, contributing countries, major institutions, authorship, and citations. Additionally, this paper includes a list of authors. The

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findings indicate that early TAM research has continued to thrive and has been widely disseminated ever since it was first conducted. Despite this, the vast majority of TAM research has been focused on the fields of computer science, social science, business, management, and accounting.

Although TAM has proven to be a powerful model that can be applied to a variety of technologies and situations, the study revealed that many studies on technology and innovation adoption were published at the individual level. Moreover, the studies are still increasing during COVID-19, which means there is a huge tendency for users to adopt new technology and innovation.

The Scopus database and keywords found in document titles and abstracts were used exclusively in this study. No other databases, such as Google Scholar, have been taken into account. Extending text analysis tools to include abstracts would very certainly provide new frequencies and new information. Furthermore, multiple names were registered by some authors or institutions or provided alternative spellings in Scopus, resulting in erroneous information about authors' associations or output. In this study, we chose titles, abstracts, and keywords that produced an overall result in TAM. Hence, future studies could focus more on determining the search string by using title only; this will give fewer results and more focus on TAM research.

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Digital Marketing Strategies Driven by Wellbeing in Virtual Communities

Literature Review

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Abstract: In the new era ushered in by Covid-19, priority has been given to peoples' wellbeing. Wellbeing in virtual communities was analysed from several perspectives, such as healthcare, technology, and social science: hence, the importance of a literature review that clarifies how studying health, happiness, comfort and quality of life of virtual communities' members could guide firms to conceive their digital communication and marketing strategies. This work presents a literature review of papers spanning from 2010 to 2021, and which study digital marketing strategies driven by wellbeing in virtual communities. Results indicate a growing research interest after the pandemic regarding both positive and negative wellbeing dimensions, especially as drivers for digital segmentation, targeting and positioning strategies. Moreover, results highlight the remarkable increase of papers focusing on the tourism industry, game related strategies, and marketing analytics as relevant tools that support digital communication and influence strategies towards virtual communities. Finally, this literature review provides researchers with guidance for future studies in terms of relevant methodologies and areas of research not yet explored.

Keywords: Virtual Communities, Wellbeing, Platforms, Marketing Strategies, Literature Review

Introduction

The pandemic has significantly changed the way people all over the world live, as well as their ability to socialize and interact with one another due to incessant governmental restrictions

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(Bajaj *et al.*, 2020). The restrictions imposed by Covid-19 led to a significant separation from important people, together with immeasurable financial and job losses that challenge health and wellbeing (Pietromonaco & Overall, 2021). It is in this context of disruptive human lifestyle that the issue of wellbeing has been dealt with in healthcare, computer science/technology and social science research (Ayachi & Jallouli, 2021). In addition, the study of wellbeing features related to virtual communities (VCs) from a business perspective is gaining more relevance and scope with the announcement of commercial mega projects focusing on the magnitude of augmented reality (AR) in people's lives over the next decade.

This study aims to answer the following questions: To what extent were dimensions of wellbeing studied as drivers for marketing strategies in the literature? Have these features been evoked from a positive or a negative perspective, or both? Which fields and methodologies were involved in this area of research? What are the main related platforms? Which marketing strategies were the most impacted by wellbeing in VCs, and what guidance could this study provide to future research in terms of methodologies and digital strategies?

This research consists of a literature review (LR) of papers published from January 2010 to December 2021 studying the dimensions of wellbeing that guide marketing strategies for VCs. The remainder of this paper is structured as follows: section 1 focuses on the concept of wellbeing and VC. Section 2 presents related works on wellbeing in VCs as drivers of digital marketing strategies. Section 3 is dedicated to explaining the methodology, and section 4 displays the main results and provides the reader with a structured discussion based on the important trends revealed by this LR. Finally, the conclusion section points to the study limitations and suggests orientations for future research.

Definition of Concepts: Wellbeing and Virtual Communities

The concept of wellbeing has been defined from different perspectives. Strohmaier & Camic (2017) define wellbeing as an uncertain subjective state that entails happiness, feeling well and optimism. Other definitions of wellbeing encompass concepts including comfort, pleasure, interaction and positive thoughts; a sense of attachment to people, animals, and tasks; inclusion in a given community or practice of a certain activity; occupation like exercising, working, conversing with others or simply resting; identity like feeling healthy, having a sense of recognition, and a lifestyle continuity; and, finally, engagement, which entails self-determination, freedom of action, and independence (Kaufmann & Engel, 2014).

In this paper, wellbeing is considered as a construct that captures four main dimensions and involves both objective and subjective concepts. Objective concepts include physical and mental health, which according to the World Health Organization (WHO) is defined as 'a state of complete physical, mental and social well-being, and not merely the absence of any disease

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or infirmity'. Happiness, quality of life, and comfort are three main subjective dimensions of wellbeing. Being a relative concept, happiness is associated with a general evaluation of one's typical wellbeing depending on different factors; including individual pursuit of tangible and intangible benefits (Diener, Scollon & Lucas, 2009), social justice (Frey & Stutzer, 2010), or simply social interactions (Hall & Banaszek, 2014). Closely associated with wellbeing, comfort seems to be more related to the symptoms of relief and/or reduction of imbalances or discomfort, inner peace, security and effective communication (Pinto *et al.*, 2017). Finally, quality of life, which encompasses subjective perceptions of different areas presupposes a decent health situation and healthcare, good living conditions, an employment and a financial situation that meet daily needs, social relationships, and leisure activities (Palepu *et al.*, 2012).

Wellbeing is a growing area of research due to the outbreak of Covid-19. Lockdowns and social distancing affected people's physical and mental health, as well as social life, causing mental health disorders, including stress, anxiety, depression, irritability, insomnia and decrease in attention (Brooks *et al.*, 2020). The interest in people's wellbeing could be of some significance to marketers to know how to better align their strategies with the evolving physical, mental, and social states of targeted individuals and communities.

VCs can be defined as "groups of computer users that provide friendship, social resources, information and belongingness to each other" (Wang, Ting & Wu, 2013). Thanks to the emerging IT tools and platforms, social networks, including YouTube, Facebook, Twitter, WhatsApp, LinkedIn and Pinterest, among others, have become the daily environment for people to move from passive consumers to active ones by interacting and sharing information spontaneously (Fondevila-Gascón *et al.*, 2020).

VCs have been classified into five main categories depending on their objectives: 1) commercial communities, generally associated with e-commerce, like e-bay; 2) information communities where users contribute information or knowledge, such as Wikipedia; 3) communities of practice (COPs) that share common interests and exchange ideas and solutions on platforms like virtual classes or platforms for professional associations; 4) virtual reality (VR) communities that use VR technologies to experience imaginary environments, such as Second Life; and, finally, 5) social communities that interact online to establish or maintain social or professional relationships, such as LinkedIn and Facebook (Mata & Quesada, 2014). VCs are becoming the main source of information related to brands and considered as a determinant of the success or the failure of companies (Siuda, 2021); hence the importance of businesses' focus on consumers' wellbeing.

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Marketing Strategies Driven by Wellbeing in Virtual Communities

In the digital environment associated with the worldwide pandemic, customers are more concerned about products and services that meet their wellbeing. Several studies have conducted research that converges the three concepts: i.e., VCs, wellbeing, and marketing. Relating VCs to the marketing field has been based on creating and preserving long-term valuable relationships with customers (Das *et al.*, 2019). The evolution of Web 2.0 has empowered the customer in making the right decisions on what product or service to choose (Zaidun, Muda & Hashima, 2020). When considering customers as important stakeholders in the marketing experience, electronic word of mouth plays a significant role in the success or failure of businesses (Van der Lans *et al.*, 2010). Electronic word of mouth in marketing, defined as any positive or negative announcement about the brand and the business posted by any online consumer, is particularly effective in attracting and retaining existing customers (Chou & Sawang, 2015): hence, the importance that firms give to collecting and analyzing social media data about the wellbeing of targeted VCs to conceive effective digital strategies (Benslama & Jallouli, 2020; 2022).

Negative and positive features of wellbeing in virtual communities are inherent in marketing. On the one hand and from a health perspective, it has long been known that marketing often shapes people's health and wellbeing by promoting the values of consumerism and overconsumption through attractive images of happy family lives, love, friendship and enjoyment, leading to a global health risk (Watkins *et al.*, 2022). This is reinforced by exploitative advertising of fast food, sugar-sweetened drinks, alcohol, and e-cigarettes that mainly harm children's health (Clark *et al.*, 2020). Ubiquitous media and marketing practices, including personal data extraction, considerable experimentation and behavioural manipulation are exposing people, and more particularly children, to additional abuse (Golden & Garde, 2020). On the other hand, in the new era ushered in by Covid-19, and thanks to a significant number of technologies, including Artificial Intelligence and Internet of Things, digital communication tools have made it possible for firms and experts to promote their services all over the world (Mondal *et al.*, 2022), and for communities to support individuals in need of assistance. The interactivity allowed by Web 2.0 helped consumers and users to move from passive to active statutes (Fondevila-Gascón *et al.*, 2020), building thereby a network that enhances wellbeing in VCs (Kamboj *et al.*, 2018). However, in some cases, digital communication does not really meet the expected outcomes in terms of enhancing wellbeing. For example, based on a review by Almathami, Win & Vlahu-Gjorgievska (2020), patients are not unanimous about remotely communicating with healthcare professionals.

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This reveals the importance of outlining both negative and positive dimensions of wellbeing related to professional online networks and COPs.

With regards to happiness in VCs and marketing strategies pairwise, web accessibility is double-edged. On the one hand, paying attention to drivers that affect customer happiness, which make up significant factors leading to customer retention and competitiveness, is becoming routine for firms (Kumar, 2021). In fact, social media can facilitate communication between consumers and brands' representatives, leading to growing trust and intention to buy (Hajji, 2014). On the other hand, unhappy customers can give negative feedback and therefore contribute to the company's failure and credibility loss (Van der Lans *et al.*, 2010; Venkateswaran, Kumar & Gupta, 2021; Tseng, 2014; Zheng *et al.*, 2015).

Addressing quality of life in marketing is critical to the effectiveness of a business, given that the key goal of a marketing professional is to provide value to customers and preserve or improve a community's wellbeing (Palepu *et al.*, 2012). By creating customers' meaningful experiences with brands to interact and engage with, digital communities' marketing yearns to adopt a combination of strategy, creativity and technology to contribute to the consumers' quality of life and at the same time enhance the business brand (Dwivedi *et al.*, 2021).

Methodology

This work aims to provide a comprehensive review of papers studying VC wellbeing, including one or more of its dimensions — namely, health, comfort, happiness, and quality of life — and digital marketing strategies. To this end, this study provides a Literature Review (LR) of research articles published between January 2010 and December 2021 that studied wellbeing in VCs, in association with marketing strategies, namely product and brand strategy, price strategy, communication and influence strategy, distribution strategy, and segmentation, targeting, and positioning (STP) strategy (Campbell *et al.*, 2020).

The search method for this analysis was conducted in two phases: (1) a search by keywords and similar combinations of keywords to obtain articles from January 2010 to December 2021 dealing with VCs, wellbeing, and marketing; and (2) a content analysis, which in addition to identifying the three concepts under study, explored the relationship between them. The two stages are explained below.

Keywords-based search

Keywords-based research was carried out to obtain articles dealing with VCs, wellbeing and marketing from January 2010 up to December 2021. To this end, relevant papers in English were collected from Google Scholar and ScienceDirect databases based on a search with the three key terms and using "review articles" and "research articles" as filters. "Online

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communities" was used as a synonym for "VC". In addition to "wellbeing", the terms "happiness", "health", "comfort", and "quality of life" were used. The key terms and their synonyms were employed interchangeably to form combinations of similar pairs.

This stage enabled the selection of 660 papers, including 162 results from Google Scholar, and 498 papers from ScienceDirect. Subsequently, a floating reading was carried out. It consisted of reading titles, keywords and abstracts of the retained papers and checking if these papers provide insight regarding the relationship between marketing, VCs and wellbeing. This step enabled the selection of 64 papers.

Content analysis

In line with Erlingsson & Brysiewicz (2017), both quantitative and qualitative content analysis was used in the current literature review. Content analysis was carried out as follows: first, we read the retained papers going through titles, keywords and abstracts; second, we defined the units and categories of analysis; third, we developed coding rules, which enabled data coding; and, finally, we analyzed the results and drew conclusions.

The above-mentioned steps were implemented as follows: after reading the data, we defined units and categories of analysis by classifying the papers by order number, publisher, year, and context. To report the type of relationship between marketing strategies and wellbeing in VCs in the studied papers, we assigned a plus or a minus according to whether the type of relationship was positive or negative. Then the data were processed statistically. The final step required reading the full text of the retained papers to present an overview of the main results, draw conclusions, and suggest orientations for future research.

Results and Discussion

This section presents the main trends revealed through the descriptive analysis. Then it shows relevance-based matching in the studied corpus between wellbeing features in VCs, digital marketing strategies, related methodologies and targeted platforms. The approach of the results' presentation is as follows: first, we present a descriptive analysis of marketing approaches driven by wellbeing in VCs, the frequency per publisher, year and methodology type; second, we present a cross analysis, matching marketing strategies with wellbeing features and platforms.

Remarkable number of papers in 2021 and predominance of positive wellbeing

Paper publication indicates a remarkable increase (30 papers) in 2021 as shown in Figure 1. The disastrous effect of Covid-19 on socio-economic life (Long & Ren, 2022), as well as

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challenges to wellbeing known during the pandemic peak times, made people and businesses build some kind of resilience to face these challenges (Beninger & Francis, 2021; Pietromonaco & Overall, 2021).

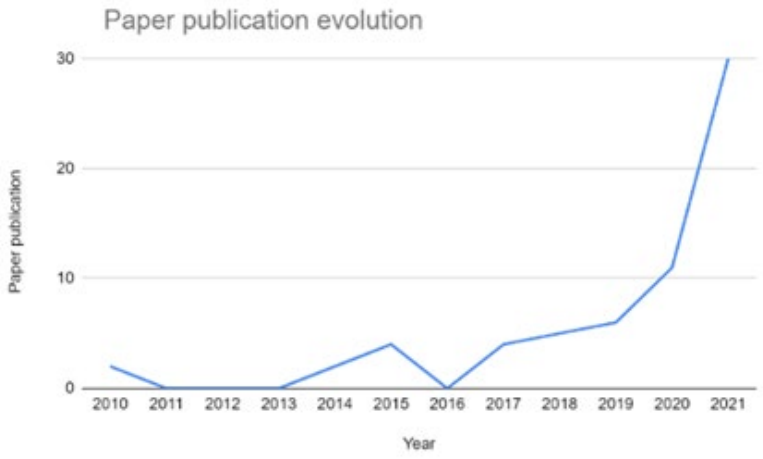

Figure 1. Number of papers per year

Table1 provides a descriptive analysis of wellbeing and its related concepts: happiness, health, comfort, and quality of life. The objective is to gain a better understanding of the way the concept of wellbeing was addressed in the selected papers.

In line with Ayachi & Jallouli (2021), findings revealed a predominance of positive wellbeing (wellbeing+) and its four related concepts (Table 1). For example, only eight papers evoked wellbeing+ in 2020, against 25 papers in 2021. Such an increase in the positive dimension of wellbeing confirms the resilient side of human beings in the face of challenges and the importance of investing in effective digital strategies to enhance this trend (Beninger & Francis, 2021).

Table 1. Occurrences of wellbeing dimensions per year

Wellbeing	**Years**												
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	**Total**
Wellbeing+	2	0	0	0	2	4	0	4	5	5	8	25	**55**
Wellbeing–	0	0	0	0	0	0	0	0	0	0	3	8	**11**
Happiness+	0	0	0	0	0	0	0	1	0	0	2	2	**5**
Happiness–	0	0	0	0	0	0	0	0	0	0	1	0	**1**
Health+	2	0	0	0	2	1	0	3	0	2	3	11	**24**
Health–	0	0	0	0	0	0	0	0	0	1	4	3	**8**
Comfort+	1	0	0	0	0	0	0	0	1	0	0	2	**4**
Comfort–	0	0	0	0	0	0	0	0	0	0	1	2	**3**
QOL+	0	0	0	0	0	1	0	1	2	3	2	5	**14**
QOL–	0	0	0	0	0	0	0	0	0	0	1	0	**1**
Total	**5**	**0**	**0**	**0**	**4**	**6**	**0**	**9**	**8**	**11**	**25**	**58**	**126**

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Research fields and methodologies

The papers were classified into three main fields with 37 papers in the social sciences field, followed by 19 papers in the computer/technology field, and finally 8 papers related to the healthcare field. Overlapping of fields and tools was revealed, and this emanates from addressing research issues from different perspectives. The main methodologies used in the studied papers included quantitative, qualitative, mixed, and review. Table 2 shows a breakdown of the methodology used according to the research field. The review methodology takes the lead, as it was adopted in 27 papers. Indeed, the review method can be used in disparate and interdisciplinary research, as it is a tool to synthesize existing research findings and uncover relevant areas in research (Snyder, 2019). The qualitative method follows with 19 papers, including 11 in social sciences and 8 papers in computer science/technology. Papers from computer science and technology (8) also used the qualitative method. For instance, Arsenyan & Mirowska (2021) adopted the qualitative method to study human-computer interactions on social media, and Mustafa, Nawaz & Lali (2015) applied the qualitative method for Search Engine Optimization to boost rankings, drive traffic and increase awareness among search engines.

The quantitative method was used in 12 papers including 8 in computer science/technology (e.g., Rauschnabel, Rossmann & Tom Dieck, 2017; Herz & Rauschnabel, 2018; Karikari *et al.*, 2017; Hajli *et al.*, 2015; Jin & Youn, 2021), and 4 in social sciences (Kamboj et al., 2018; Pesco-Torres *et al.*, 2021; Deszczyński & Beręsewicz, 2021; Rather, 2021). Finally, the mixed method, associating quantitative and qualitative studies was identified in only five papers.

Table 2. Methods and related research fields

Method	**Number of papers per research field**			**Total number of papers**
	Computer Science/Technology	Healthcare	Social Science	
Quantitative	8	0	4	**12**
Qualitative	8	0	11	**19**
Mixed	0	1	4	**5**
Review	3	7	18	**28**
Total	**19**	**8**	**37**	**64**

Related platforms

Table 3 displays the frequency of wellbeing+ and wellbeing- through the different online platforms. According to Mata & Quesada (2014), these platforms are classified as follows: 1) social networks like Facebook, LinkedIn, Twitter, YouTube, LinkedIn and Instagram;

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2) commercial websites and platforms; 3) AR/VR platforms; 4) information platforms; and 4) COP platforms.

Positive and negative wellbeing have been cited 492 times in different platforms, including social networks, commercial websites, VR/AR and COP platforms. No papers in the studied corpus evoked information platforms, such as Wikipedia, as a determinant of marketing strategies. Social networks were the most studied platforms in the literature providing insights on wellbeing in virtual communities that help shape digital strategies.

Table 3. Wellbeing dimensions and related platforms

Wellbeing dimension	Platforms cited in the studied corpus								
	Social networks					Commercial websites & platforms	VR/AR platforms	COP platforms	Total
	Facebook	Twitter	Instagram	LinkedIn	YouTube				
Wellbeing+	23	25	24	21	21	36	32	37	**219**
Wellbeing–	7	7	8	7	7	7	9	7	**59**
Happiness+	1	1	1	0	0	2	3	4	**12**
Happiness–	1	1	1	1	1	0	0	0	**5**
Health+	6	8	6	5	5	15	18	16	**79**
Health–	4	4	4	4	4	6	6	5	**37**
Comfort+	2	2	1	1	1	2	1	2	**12**
Comfort–	2	2	3	2	2	1	1	1	**14**
QOL+	6	6	7	5	5	7	6	5	**47**
QOL–	1	1	1	1	1	1	1	1	**8**
Total	**53**	**57**	**56**	**47**	**47**	**77**	**77**	**78**	**492**

Table 3 shows that COP platforms are mainly associated with wellbeing+. In comparison to other online platforms like social networks, COPs allow for a concentration of users with common interests to solve particular problems (Gritsenko, 2016). Indeed, COPs include web users, web developers and bloggers who offer, for example, solutions to businesses in order to enhance their websites' ranking (Mustafa, Nawaz & Lali, 2015). Results show that sustaining consumers' brand-related happiness through a roller-coaster of emotions was revealed to be one motivation of COPs (Hollebeek & Belk, 2021). In addition, results outline the importance of shared COP interests to guide digital marketing strategies. These interests include value co-creation (Sorensen, 2021; Eletxigerra, Barrutia & Echebarria, 2018), common concerns and suggestions to protect children from digital food advertising abuse (Golden & Garde, 2020), enhanced customer service and loyalty development (Hollebeek & Macky; 2019), enhanced e-service delivery (Sharma, Mishra & Mishra, 2021), optimum use of filter mechanisms and recommender systems (Coombs *et al.*, 2021), social support, informational and emotional constructs (Hajli *et al.*, 2015), and, finally, online community trust to e-retailers (Bi, 2019).

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Furthermore, results highlight the predominance of commercial communities in the corpus, like booking sites related to individualized room services and differentiated restaurant services. Service co-creation and innovation in the travel industry were largely studied (Eletxigerra, Barrutia & Echebarria, 2018; Oltra González, Camarero & San José Cabezudo, 2021). In addition, useful information about any modification to the safety and hygiene measures was displayed to tourists, both on hotels' websites and Social Networks (Pesco-Torres, Polo-pena & Froias-Jamelina, 2021). Furthermore, results shed light on computer-mediated communication that facilitates online friendships, with the likelihood of improving the subjective wellbeing of users as one benefit of Social Networks and VR (Karikari *et al.*, 2017). VR also offers interactive virtual tours to connect people to remote sites, which both increases awareness of cultural heritage and helps people to manage emotional and cognitive challenges, such as anxiety, that can be amplified during periods of isolation, loneliness, and uncertainty (Bec *et al.*, 2021).

This literature review shows other benefits, such as health promotion opportunities on Facebook (Loss, Lindacher & Curbach, 2014); the emergence of different business potential encompassing brand awareness, brand loyalty and sales on social networks (Hassanien *et al.*, 2020); as well as a sense of love, appreciation, acknowledgment, and a strong sense of positive emotions on Social Networks (Neuhofer *et al.*, 2021).

Wellbeing- and its related concepts seem to be less evoked than the positive side, as displayed on the digital platforms. One example is wellbeing- that was displayed on VR/AR platforms, and caused by fear of health risks associated with VR glasses (Herz & Rauschnabel, 2018). Other avoidance of virtual tools has been expressed by patients who require consultation procedures that cannot be achieved through virtual means (Wang *et al.*, 2020). Additional negative health related issues were evoked on Social Networks eliciting a rising discussion on the role of social media in exercising peer pressure resulting in problematic eating and negative impact on health (Jacobsen *et al.*, 2021). From an employment security perspective, an employee's wellbeing might be challenged by digital transformation that could be perceived as a serious threat to the employee's job, like being replaced by technology (Herhausen *et al.*, 2020).

As shown in Table 3, papers seem to study more positive aspects of wellbeing on the digital platforms than negative aspects. Concerns about wellbeing shared on these platforms are presented in the literature as challenges that need to be addressed (Golden & Garde, 2020; Coombs *et al.*, 2021; Herz & Rauschnabel, 2018; Herhausen *et al.*, 2020; Wang *et al.*, 2020).

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Related digital marketing strategies

Table 4 shows that the STP strategy was the most studied in the corpus. STP strategy involves "developing an understanding of customer segments and assisting marketing managers in their targeting and positioning decisions" (Campbell *et al.*, 2020, p. 10).

Table 4. Wellbeing dimensions and marketing strategies

Wellbeing dimension	**Marketing strategies**					
	Product & Brand	Price	Communication & Influence	Distribution & Channels	Segmentation Targeting & Positioning	**Total**
Wellbeing+	9	1	14	3	38	**65**
Wellbeing-	1	0	4	1	7	**13**
Happiness+	2	1	2	0	4	**9**
Happiness-	1	0	0	0	0	**1**
Health+	3	1	5	0	21	**30**
Health-	1	0	2	0	6	**9**
Comfort+	1	0	1	0	4	**6**
Comfort-	1	0	1	0	1	**3**
QOL+	2	0	7	2	5	**16**
QOL-	0	0	1	0	0	**1**
Total	**21**	**3**	**37**	**6**	**86**	**153**

Results show that the negative aspects of wellbeing are not numerous compared to wellbeing+ in the studied corpus. Negative features of wellbeing that overlapped with the STP strategy are mainly related to targeting children through digital food marketing, online games and virtual environments (Golden & Garde, 2020). In fact, these tools provoke childhood obesity, manipulate children's behaviour by extracting their data through digital media, and violate their rights to privacy and freedom from exploitation.

Moreover, the STP strategy seems to be mostly associated with wellbeing+, including 21 times related to health+. New-age technologies help companies provide the right content to the right customer at the right time in addition to predicting customers' future behaviours thanks to developing customer churn models (Kumar, Ramachandran & Kumar, 2020). Results show the growing role of emerging tools that guide market segmentation and targeting, especially AR- and VR-based marketing, marketing analytics and game-based marketing. For example, digital marketing through VR could reduce employee training costs, improve training effectiveness (Gupta, Kumar & Karam, 2020) and contribute to consumers' health by offering them genetic information (Saukko *et al.*, 2010). Furthermore, marketing analytics help decision makers to manage customer relationship management, control retail sales/purchases, and examine trends (Kaabi & Jallouli, 2019; Kumar & Ramachandran, 2021); as well as provide the optimum medical and social support to patients suffering from mental health problems (Asamoah & Sharda, 2021). In the video game industry, after the launch of

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new products, consumer conversations and comments are filtered to understand customers' needs, thereby enabling new products to be designed accordingly (Chiarello, Bonaccorsi & Fantoni, 2020).

Regarding the most studied field in terms of STP strategies, this LR shows the increasing number of papers focusing on wellbeing in the context of the travel/tourism industry. For example, companies are adapting the way they communicate with customers, whose profiles are changing by upgrading their services (Joukes & Gerry, 2010). Providing booking sites for customers to reserve individualized room services enhanced customer satisfaction and consequently increased sales (Pereira & Da Silva, 2015). Through VR, tourists can visit remote sites, preserve historical assets, and consequently generate revenue for the destination without visitation (Bec *et al.*, 2021). Another important trend in the tourism field is promoting peer-to-peer hosting that improves quality of life, strengthens relationships with friends, helps experiment new things (Dolnicar & Talebi, 2020), and promotes customer engagement through brand co-creation (Rather, 2021). These strategies are linked to positive aspects of wellbeing, such as the sense of love, appreciation, strong positive emotions, and sensory engagement (Neuhofer *et al.*, 2021).

The examination of the retained papers outlines the rise of several game-related strategies that offer enjoyable experiences to customers and increase their engagement (Rasool, Shah & Islam, 2020), help users track their wellness progress on a virtual map (Sardi, Idri & Fernández-Alemán, 2017), enhance children's diet (Chow *et al.*, 2020), and promote physical activity (Rauschnabel, Rossmann & Tom Dieck, 2017). Related positive wellbeing concepts evoked in the corpus help to escape loneliness, boredom, and feelings of depression (Mayor Poupis, Rubin & Lteif, 2021), elicit feelings of fun, joy, amusement, and achievement (Chapman, Chua & Fiedler, 2021), learn more about destinations, enjoy thrills, and add more sensation experience when completing game challenges through VR (Shen *et al.*, 2020). However, several negative apprehensions of game-related strategies were revealed, such as the potential risk of eyesight problems due to VR glasses and the concern about the misuse of or improper access to personal information (Herz, & Rauschnabel, 2018).

With regards to the communication strategy, which is ranked second in terms of frequency (Table 4), it often overlapped with the other marketing strategies. Indeed, shopping online impacts social wellbeing positively (Papagiannidis *et al.*, 2017). Wellbeing+, altruistic value and social good result from some commercial brands' implementation of value-facilitating resources as well as co-creation interactions (Sorensen, 2021). In addition, interactions on social media with virtual influencers, instead of human influencers, may provide users with an intrinsic pleasure of the interaction and thereby consume promotional contents while at the

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same time satisfy their needs for autonomy without being concerned about the wellbeing of the influencer behind the screen when turned off (Arsenyan & Mirowskan, 2021).

Unlike the STP strategy, communication strategy was linked to negative wellbeing. In fact, the highest occurrence concerns quality of life-, mentioned 7 times in relation to communication. Despite greater benefits delivered to the firms, like stronger brands, remarkable challenges may emerge from negative word of mouth as well as invasive and irritating online brand presence (Dwivedi *et al.*, 2021). Tailoring communication to address preferences of VCs has become an essential part of a company's effective marketing strategy (Siuda, 2021). In fact, with the changing communication tools and customers' profiles, marketing strategies use diverse and flexible tools to meet new challenges and to be efficiently resilient (Pereira & Da Silva, 2015).

Overlapping with STP and communication, product strategy was associated with the travel/tourism industry. For instance, the travel community helped renovate and innovate travel services through processes of co-creation, thanks to a sense of trust, motivation, and inspiration (Oltra González, Camarero & San José Cabezudo, 2021). Furthermore, some health-related businesses like spa services changed into a tourist attraction thanks to customers changing profiles and skills (Joukes & Gerry, 2010). In fact, young and technology savvy users forced these businesses to adapt their services to a growing and loyal client base. In Kamboj *et al.* (2018), customers' interactions in online brand communities resulted in brand trust and loyalty, which led to branding co-creation on social media. In line with Fondevila-Gascón *et al.* (2020), VCs seem to be empowered thanks to their being allowed to co-create products and services (Siuda, 2021; Eletxigerra, Barrutia & Echebarria, 2018; Rather, 2021; Sorensen, 2021).

Price and distribution strategies, mainly related to positive features of wellbeing, are evoked respectively 3 and 6 times out of 153. Future studies are invited to focus on this area and to explore the role of e-commerce distribution in delivering products and services with advantageous prices and conditions, and this leads to a positive impact on several features of wellbeing, such as happiness and quality of life.

The next section will synthetize the main results and present some limitations that can be a springboard for future works.

Conclusions and Orientation for Future Research

This paper reviewed a corpus of 64 papers spanning from January 2010 to December 2021 relating VCs, wellbeing and digital marketing strategies. The review consisted of exploring digital marketing strategies that were guided by wellbeing features in VCs, in addition to

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related platforms and adopted methodologies in the studied papers. Results indicated a significant increase in the number of papers in 2021 and showed, therefore, a growing interest in exploring wellbeing dimensions for business strategic purposes during the Covid-19 crisis.

With very few exceptions, the trend indicated the predominance of positive features of wellbeing related to digital marketing strategies, and, more particularly, positive health, comfort, happiness, and quality of life owing to interacting online. Regarding the adopted research methodologies in the studied papers, results highlighted a predominance of the literature review method, followed by the qualitative one especially in social science research.

Concerning the platforms related to positive wellbeing, COP platforms were mostly used, followed by commercial websites, VR/AR platforms, and then social networks like Twitter, Instagram, and Facebook. Furthermore, with respect to digital marketing strategies, STP was revealed to be the most studied strategy and was associated with a positive impact on wellbeing, including mainly the positive impact on health. Few publications revealed negative aspects of wellbeing.

Moreover, results showed the growing focus of studies on the tourism/travel industry. Indeed, the huge amount of data available on online platforms such as Trip Advisor help hotels and related firms collect and analyse customers' preferences and profiles to conceive effective STP, communication and product strategies. Marketing analytics and game-related strategies are also revealed as key tools applied to support these digital strategies.

This piece of research outlines several theoretical gaps related mainly to the limited number of papers that have adopted qualitative methodologies. The studies focusing on digital marketing strategies driven by negative wellbeing dimensions were also lacking. Future research could extend the number of studied papers and consider conference and book contents in addition to journal papers. Finally, in addition to the examined marketing strategies in this paper, more specific and emerging strategies, such as the digital brand-content strategy (Grissa, 2016), the social media analytics strategy or the technology-enabled personalization strategy (Riegger *et al.*, 2021, Khemiri & Jallouli, 2022), might be relevant to investigate in future work.

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Supporting Logistics Management to Anticipate Covid-19 Using the "Retail Direct Order" Concept

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Abstract: The Covid-19 that has hit the world since the end of 2019 has had a considerable impact on the Indonesian economy, especially on business people. This paper considers how businesses in Indonesia could benefit from implementing a Retail Direct Order (RDO) process to respond to social changes, particularly restrictions on movement, brought about by the pandemic. The paper first reviews the literature on supply chain management and logistics and the effects on them due to greater digitization of businesses, operational automation and globalization. It then proposes how RDO can assist businesses in Indonesia – especially department stores, supermarkets, convenience stores, and non-store retailers – to adapt to the new business environment. One benefit of properly managed RDO is to reduce panic buying by supporting a more dependable supply of goods.

Keywords: Retail direct order, Supply chain management, Covid-19, Digitization, Indonesia.

Introduction

The impact of the coronavirus pandemic (Covid-19) is very pronounced in the business and economic world. In a short time, marketing patterns also changed, especially when social distancing and lockdown were implemented, so that business actors in various sectors had to work hard to keep their business running (Lestari *et al.*, 2019). Marketers must turn their

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mind to marketing their products or services to consumers, as a brand strategy to survive amid this pandemic. Business people optimize online marketing and digital branding to communicate with their target consumers (Maria *et al.*, 2019).

From official data as of 27 December 2020, the number of confirmed cases of Covid-19 in Indonesia was 706,837 cases (WHO, 2020). To avoid the wide spread of this global epidemic, the government urged the public to adhere to health protocols, one of which is staying at home. Of course, this affects many things, including small-scale businesses (Pusriadi *et al.*, 2021). The government always strives to suppress the spread of this global virus because it has the potential to have a direct impact on the economy, including the sustainability of cooperatives, and micro, small and medium enterprises (Ilmi, Darma & Azis, 2020).

The government is also recording a crisis in the business sector, which is experiencing raw material difficulties, production process constraints, and market demand that has fallen dramatically; and then maps the impact of Covid-19 on Small and Medium Enterprises (SMEs). Based on their observations, the average SME experienced a decrease in turnover during this pandemic (Amalia, Darma & Maria, 2020).

Several business sectors that have the potential to experience a decline in sales are workshops, restaurants, salons, spas, property, MICE (meetings, incentives, conferences and exhibitions), tours & travel, hotels, transportation, flights, malls, and fashion. Several business sectors have the potential to be stable and experience an increase, such as health products needed during a pandemic, agriculture, e-commerce, convenience stores, grocery stores, pharmacies, herbal shops, Internet providers, video conference service providers, home learning applications, and others (Yijo *et al.*, 2021).

Seeing this problem, brand players must respond to change their sales strategy. It is hoped that there will be no significant drop in sales when social distancing is implemented (Kurniawan, 2020). To stay afloat amid this pandemic, brand players must be able to work around it, starting from focusing on digital marketing through websites that are used as e-commerce, social media, search engines, sales through the marketplace, and forming a reseller team to sell their products. Because not all problems can be resolved, in this pandemic there are both threats and opportunities. For marketers, of course, being able to seize this opportunity is an absolute must.

It was predicted that the logistics industry in Indonesia would only grow 1.5%–2% during the second quarter of 2020 because of the terrible impact of this pandemic. This prediction is actually better than the realization of logistics sector performance in the first quarter of 2020, where growth was around 1.27%. There was an increase in growth, and it has

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continued for the third and fourth quarters of 2020, because it was close to the achievements in 2019 and in line with national economic recovery (Wismadi *et al.*, 2020). So far, there has been no significant improvement in the activities of logistics actors during Covid-19. Industrial activities, producer goods, and wholesale trade are still hampered. These obstacles are experienced by many logistics actors who carry out business-to-business activities (Saragih, Hartati & Fauzi, 2020).

Moreover, the victims of layoffs (due to the impact of this pandemic) have reached more than one million people (Fitriyah & Luqyana, 2021; Pariyanti, Sofiyanti & Rosid, 2020). The solution for layoff victims is to find other alternatives by becoming a reseller or seller of products needed during this pandemic. Meanwhile, marketers can take social action by opening a pattern of business opportunities, such as opening resellers, drop-shipping, or other partnerships to sell their products to the public. In this pandemic, marketers must adapt to the enactment of social distancing (Khalyubi, Amrurobbi & Pahlevi, 2020), because it influences major changes in consumer behaviour trends in shopping.

The Indonesian government itself had set a period of emergency for Covid-19 until 29 May 2021, or, to be precise, until the day of the Eid al-Fitr celebration for Muslims. Of course, marketers needed to respond to this by making the right strategy, both during the pandemic period and after the pandemic ends (Rosmadi, 2021). Recognizing the prolonged recession, small, medium and large-scale companies that are still surviving adapt to take concrete steps so that their production marketing remains stable (Gu, Han & Wang, 2020). The right marketing structure will restore consumer purchasing power (Al Badi, 2018).

The retail direct order (RDO) business strategy is an application that can be used to order products directly from distributors. This digital-based application is specifically designed to make it easier for retailers to manage product supply chains to various retail outlets (Kho, 2021).

Studies that are very relevant in discussing the concept of RDO and how it is applied to the logistics sector in developed and developing countries have been reviewed. Murfield *et al.* (2017) expanded the investigation to the impact of logistics service quality (LSQ) on customer loyalty and satisfaction at Amazon's Mechanical Turk (MTurk), USA. There was an extra effort to conceptualize LSQ in retail and examine the impact of LSQ on customer loyalty and satisfaction. Yu *et al.* (2016) presented supply chain management through the role of sophisticated E-commerce logistics from a practical point of view in logistics companies in Europe, Asia-Pacific, and North America. There are perspectives and opportunities from practical implementation, so that companies engaged in logistics and e-commerce can evaluate their performance and get business guidance for the future. In

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Tunisia, there has not been well-managed logistics performance in the retail sector. By involving 180 consumers, Ltifi & Gharbi (2015) have studied the role of logistics in retail stores to determine client outcomes, such as satisfaction and happiness. From their results, happiness has a positive effect on customer satisfaction. Retail logistics performance also affects satisfaction and happiness.

From previous publications, general Systematic Literature Reviews (SLRs) have been implemented and been guided in several cases by the ambition of elaborating and summarizing concepts from many sources, but, in reality, they have not solved many problems (Okoli, 2015; Mengist, Soromessa & Legese, 2020; Xiao & Watson, 2019; Pati & Lorusso, 2018). In connection with the problems in logistics distribution when Covid-19 in Indonesia was confronted, we see that the distribution burden that has been piling up is still using the conventional system (Masudin & Safitri, 2020; Widiyanto & Nashrullah, 2020). Government regulations that had restricted products triggered this, especially from outside the island of Java, where companies or producers were most dominant in queuing at the connecting routes (ocean, air, and land). Princes (2020) and Djalante *et al.* (2020) claim that distributors need to provide an alternative to this anti-climax condition.

The novelty of this study integrates the RDO principle to recover high demand without operational risk, among other things, making it easier for consumers to get goods and services, benefiting wholesalers and producers from the financial side, playing a role in promoting products, and providing various types of products at varying prices. As to other advantages of RDO when the demand for products is increasing, it provides guidance and prevents fraud by certain parties who take advantage of market fluctuations by hoarding certain commodities to launch more massive profits in later commerce. Besides, RDO has an extensive network of outlets, making it easier to reach customers, closer to end consumers because of the direct transaction process, and supported by modern technology through sales software or applications that support operational management. The framework handles the long-term probability of trading failure.

This paper examines the distribution business strategy during the Covid-19 pandemic through RDO support for Indonesia. We summarize this paper in five parts: first, the introduction; secondly, the literature review; thirdly, the methods; fourthly, the results are presented and discussed; fifthly, conclusions.

Literature Review

Tyagi & Agarwal (2014) defines a supply chain as a system where an organization distributes its production goods and services to its customers. This chain is also a network or network of various interconnected organizations that have the same goal, which is to organize the

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procurement and distribution of the goods as best as possible. Schroeder (2007) explains that the supply chain is a series of business processes and information that provide products or services from suppliers to companies and distribute them to consumers. In conclusion, the supply chain is a network system in a company that is connected, interdependent, and beneficial in organizations that work together to control, regulate and develop the flow of materials, products, services, and information from suppliers, companies, distributors, stores, or retail, as well as supporting companies such as logistics service companies to customers as end-users.

The use of digital technology leads to positive economic effects, such as the economy of raw materials and energy resources, due to the rationalization of production and consumption, as well as in the perspective of environmental rehabilitation and restoration. All this contributes to the formation of a new economic model called the circular economy. It is an economy based on reconstruction, optimization, and resource-saving processes, facilitated by digital technology that achieves non-waste production and consumption, sustainable economic growth, and socio-economic and environmental efficiency. The key concept of the circular economy is the construction of closed-loop and sustainable supply chains.

The business models of some companies such as Google, Amazon, Alibaba, Airbnb, and Uber are built on digital technology (Ranta, Aarikka-Stenroos & Väisänen, 2021; Grabowska & Saniuk, 2022; Bican & Brem, 2020; Rachinger *et al.*, 2019; Bouwman *et al.*, 2018; Trischler & Li-Ying, 2022). Several other companies that have existed for five, ten, twenty, or even a hundred years, are forced to change and embrace digital technology to compete. This process has various names, such as digitization or digital transformation (Sarkar, 2017).

Digitalization is making digital versions of analog or physical things, such as paper documents, microfilm images, photos, sounds, and others (Rogers, 2016). So, the simple form is to convert something non-digital (including other examples of signals, health records, location data, identity cards, and so on) to a digital format, which can then be used by computing systems for a variety of purposes (Venkatraman, 2017).

As a result, humans get a continuous flow of information in digital form, which leads to the acceleration and improvement of operational accuracy and a consequent reduction of staff. Digitalization creates a foundation for operation automation and digitization. Digitalization means adding to interactions, communications, business functions, and business models, often leading to a digital and physical fusion, as in omnichannel customer service, integrated marketing, or smart manufacturing with a mix of autonomous, semi-autonomous, and manual operations (Kidder & Wallace, 2019). So, digitization is the improvement of business functions and processes with digital technology and digital data. The basis of digital

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processes is the use of detailed analysis to manage the company's operations. Digitizing production or digitizing marketing means that many functions and operations will be carried out without human participation.

Digitalization lays the foundation for the transition to digital business. Digital transformation is a transition to a digital business, a complex transformation of business activities, processes, models, and employee competencies to take advantage of digital opportunities. Oftentimes, digital transformation leads to the emergence of new markets, new consumers, and new businesses. Detail about the stages of digital transformation is presented in the study by Ardolino *et al.* (2017).

Digitalization and digital transformation are aimed at achieving goals including the use of digital information, sensory interaction with devices, managing customer experience, providing cybersecurity, automating operations and decision-making, and using external and internal social networks (Bubnov, Kopilevich, & Istomina, 2021).

Broader global trends have affected companies of all sizes. Globalization and the evolution of e-commerce have opened up growth opportunities, but present challenges, such as visibility and complexity of supply chains, at the same time. The widespread use of the Internet has made customers impatient both in retail, which is a business-to-customer (B2C) segment, and the business-to-business (B2B) segment. The future comprises forecasting the impact of e-commerce on wholesale, retail, and distribution, as well as the blending of the offline and online worlds, and the growth of home delivery alternatives. Future consumers do not want to wait and want to order and receive products as soon as possible, and companies must answer this challenge (Farahani, Meier & Wilke, 2017). Consumer buying behaviour and demand patterns are influenced by high Internet penetration rates, constant accessibility of new information, and possible comparisons of product features and prices (Bigne, Ruiz & Sanz, 2005). High levels of Internet penetration have changed consumer purchasing behaviour and demand patterns, placing heavy pressure on supply chain managers. Farahani, Meier & Wilke (2015) identified the following challenges and trends for the next few years: globalization and sales growth, supply chain visibility, process standardization and automation, supply chain collaboration, flexibility in responding to volatile markets, innovation, and new business models.

Emerging technologies are expected to provide answers to some of the most significant challenges in Supply Chain Management (SCM), leading to reduced costs and complexity, increased volume flexibility, or improved service level management. Figure 1 shows some selected digital technology innovations that will have many impacts on SCM practices.

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In today's competitive environment, businesses need to use modern technology to increase productivity and streamline their supply chains. Technologies currently used in SCM in Indonesia are electronic data exchange (EDI), barcode coding and scanning, enterprise resource planning (ERP) systems, radio frequency and identification (RFID), social media and electronic commerce, computerized shipping, and tracking (Prashant, Raju & Anbuudayashankar, 2009). But this technology is saturated and insufficient to achieve a competitive advantage in today's global marketplace, as excessive Internet use has altered consumer buying behaviour and demand patterns, which creates immense pressure on supply chain managers. Hence, there is a need to shift to digital technology to remain competitive in this global market.

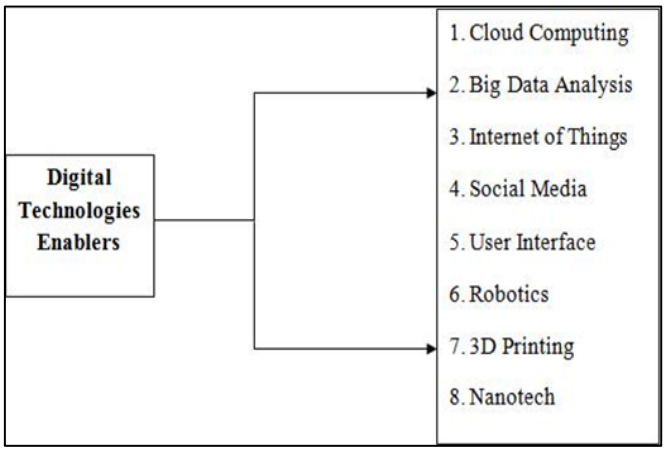

Figure 1. New technologies enabling digital SCM transformation (Source: Agrawal & Narain, 2018).

Digital supply chains can process large amounts of information and empower supply chain partners to move together to collaborate and communicate across digital platforms.

Hoberg *et al.* (2015) explain that digital transformation is a process of organizational change in which digital technology (such as cloud computing, 3D printing, Internet of Things, and big data analysis) is used to change how companies generate value in their products, how they interact with suppliers, partners, and customers, and how they compete in the global market. Thus, digital supply chain management (SCM) can be defined as a powerful innovative technology capable of changing the traditional way of carrying out various supply chain processes, such as supply chain planning, carrying out tasks, interacting with all supply chain participants, achieving integration among supply chain members, and enabling new business models. Digital transformation is changing and so any organizational change initiative must manage with great care (Wade & Marchant, 2014). Digital transformation cannot be achieved with the efforts of one person, but rather with a portfolio of initiatives that work together to achieve change.

As suggested by Farahani, Meier & Wilke (2017), each supply chain consists of various activities carried out for the procurement of raw materials, converting these materials into

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final products, storing them as finished product inventory, and sending them to the end customers. They divided SCM into seven dimensions: supplier, production, inventory and logistics, customers, information technology, human resources, and performance measurement (see Figure 2).

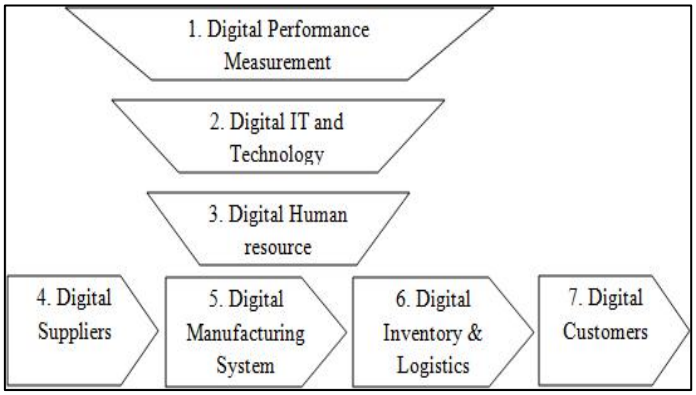

Figure 2. Seven dimensions in digital Supply Chain Management (Source: Agrawal & Narain, 2018)

The process covered includes scheduling shipments from suppliers, receiving, checking, and allowing payments for goods shipped by suppliers, selecting suppliers, and evaluating supplier performance. SCM focuses on a reciprocal relationship between providers and customers to deliver optimal values to customers at a low cost, while still providing supply chain advantages (Christopher, 2011).

According to Rutkowsky, Petersen & Klötzke (2015), any company looking to digitize its current supply chain approach should explore the opportunities and challenges their current process faces. They also need to consider the digital transformation of the entire organization (including the organization of products, services, and the interactions of partners, suppliers, and customers with their companies). Practising SCM's digital transformation agenda is important, but how SCM can contribute to digitizing the business model is also important. The extent to which SCM has to transform itself will also depend on whether the company has entered the market with a digital business model from the start as a digital native, or later adopted it as a digital migrant.

Supply chain integration refers to the integration of regional supply chains into an integrated global supply network, increasing sales growth and increasing supply chain visibility, enabling flexible response management.

Collaboration is the key to maintaining a competitive advantage. Analysis of sales patterns and buying behaviour is of great interest to all industries, as it enables a better understanding of customer needs through sensing demand and up-to-date sales information. The digital business model suggests building a network of businesses and shares a common vision of bringing their key business partners onto a platform that aims to create easy points

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of interaction. Managing supply chains must adapt to new market needs, implying maintaining a competitive advantage.

Methods and Demarcation

The systematic literature review (SLR) approach was applied for this paper. We interpret the process flow in SLR in Figure 3, which is a research phase comprising three parts, including planning, conducting, and reporting (Snyder, 2019; Xiao & Watson, 2019; Okoli & Schabram, 2010; Indarti *et al.*, 2021). First, the planning stage is the initial stage of conducting SLR; next is the conducting stage, the implementation stage of the SLR; and the third is reporting, which is the stage of writing up the SLR into a report.

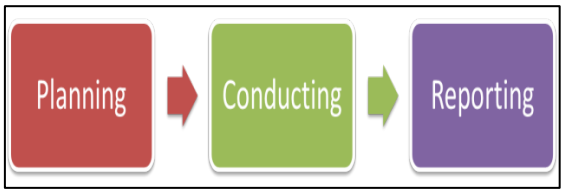

Figure 3. Flow on a SLR (Source: Apriliani *et al.*, 2020)

SLR will be very useful for synthesizing various study results that apply to a particular focused topic so that the facts presented to policymakers become more balanced, actual, and comprehensive (e.g., Sofaer & Strech, 2012; Peričić & Tanveer, 2019).

The objective of this study is to cover the intensity of business actors in implementing business strategies in the logistics sector. This step expects the disruption or threat to the distribution of food and necessities during Covid-19. The spread of the virus is quick and worrying, thus business people need to prepare new business strategies to survive.

In Indonesia itself, government policies that limit physical contact between people have hit several businesses hard. The trade sector, such as retail, has also felt the impact of this policy. Several small retailers or grocery stores have suffered losses because of a lack of buyers. The social distancing policy carried out by the government has disrupted the distribution system of goods. Not only small retailers, but large retail companies, such as department stores, supermarkets, warehouses, and hypermarkets, have also experienced the same thing.

Because of excessive fear, people flocked to supermarket outlets and shopping centres to buy up various necessities, such as rice, sugar, cooking oil, and instant noodles. The community also bought up various personal and household hygiene products. As a result, it completely depleted the stock of these products on the market. Even though it seems profitable, retail companies have limited ability to replenish used products. This panic-buying phenomenon causes a scarcity of products in retail outlets.

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If the demand for products increases, there will be an economic law of supply and demand, which causes product prices to soar. If allowed to continue, this phenomenon will trigger inflation (Kho, 2021); therefore, a new business strategy is needed.

Meanwhile, retail managers are also making efforts to prevent the spread of the global epidemic among their workers. Fear of contracting Covid-19 has also forced retail managers to refuse many vendors or salesmen who supply products. They try to limit physical contact with the salesman who represents the distributor.

At the same time, retail companies must continue to reap profits. As a result, one of the business strategies that retailers take to save the business is to sell their products online (Putri, Xu & Akwetteh, 2020). Selling products online is profitable, but what if the products sold have run out, while the retail manager stops several vendors who supply the product? There is only one solution, such as breaking the distribution chain with "retail direct orders".

Implications and Discussion

To prevent the transmission of Covid-19, the government should be more assertive in controlling transportation by optimizing freight transportation and more focused on self-sufficiency per region in meeting basic needs (Grehenson, 2020). As for the slowdown in fulfillment of basic food and health services, there is no certainty about time, cost, and administrative constraints.

Therefore, to increase the speed of logistics distribution management of staple goods and health, it is necessary to increase information and technology (IT) literacy and optimize supply chain acceleration procedures. It is necessary to change the public paradigm to adapt to the situation and IT developments to ease services through digital procedure access services.

The distribution of staple food supplies between regions is also one of the crucial things that must be checked. With good and undisturbed distribution management, regions that have a surplus of certain commodities can distribute these commodities to surrounding areas that need them (Darma *et al.*, 2020). The existence of PSBB (Indonesian acronym for large-scale social restrictions) in several provinces, regencies, and cities is indeed beginning to be disruptive, so that it requires special handling.

Electronic products, for example: they can open shopping services from home. Likewise, the retail business can open message delivery services to be optimized. There are cosmetic companies that have launched hand sanitizer products that are marketed through modern retail networks and marketplaces (Movarrei *et al.*, 2021; Pantano *et al.*, 2020). Culinary players are now starting to switch to making ready-to-eat, ready-to-cook, and ready-to-drink

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and frozen food products that are marketed through the concept of delivery, reseller concept, and sales through the marketplace.

Meanwhile, for the education business, Engzell, Frey & Verhagen (2021), Herwin *et al.* (2020), and Chu, Chan & So (2022) identify that they have now made learning services from home. Students are given access to study from home through applications that make it easier for students to learn (Nastiti & Rusvitawati, 2021); likewise with the workshop business, which is now starting to develop home workshop services. For business training, now you can immediately adapt by creating training or webinars that can be accessed via video conferencing applications. Some hotel brands have also changed hotel room facilities as a resting place for medical personnel and so on. During this difficult situation, of course, brand players must be wise in allocating campaign funds. Creativity when branding is necessary, especially when working from home like this.

The branding activities carried out also vary, starting from Corporate Social Responsibility (CSR) activities related to Covid-19, shopping campaigns from home, branding through online media, social media, official websites, creating online festivals by providing special discounts, and more. To make the marketing program successful now, principals are required to coordinate with their distributors, agents, and retail sales network. This is done to achieve the expected target.

The "RDO" is an application that can order products from distributors. This digital-based application is designed to make it easier for retailers to manage the supply chain of products to various retail outlets. Because something is based on digital applications, of course, retail managers do not have to contact distributors (for example, Dumrongsiri *et al.*, 2014; Dobrota & Vujošević, 2014). One can also place orders and fill out rare products in no time. In addition, they can design all the tasks from the smartphone screen (Verhoef *et al.*, 2021). It is undeniable that retail outlets have become the vanguard that bridges producers and consumers. Therefore, retailers must also change the system they carry on to be easier, cheaper, safer, and more efficient.

Some parties that are appropriate to connect to “RDO” are department stores, supermarkets, convenience stores, and non-store retailing (e.g., Paik & Lee, 2021). It included department stores in the category of large-scale retail companies. Department stores sell various types of products ranging from clothing, household furniture, and necessities, such as rice, cooking oil, and beverage products to vegetables and meat, which are also sold by this retail business (see Figure 4).

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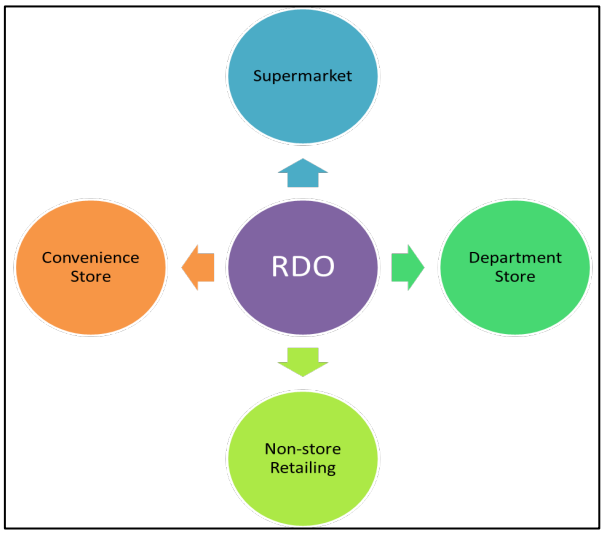

Figure 4. "RDO" user parties (Source: author's own)

Department stores are also one of the retail outlets that are often invaded by buyers lately. To avoid scarcity of goods, department store managers can integrate the retail direct order application into the goods procurement system. "RDO" can also reach for a tool that helps department stores place orders with the mobile order system. Department store managers can place orders from anywhere and without having to wait for a sales associate to come to the store.

Not much different from department stores, supermarkets also provide various needs for the community. The difference is that the prices offered by supermarkets are usually cheaper with lower quality than department stores. Supermarkets are in demand by the lower middle class. Yet, to prevent the transmission of Covid-19, supermarkets are also the target of people who carry out panic buying (Fu *et al.*, 2022; Sekiguchi *et al.*, 2022). Not only the lower middle class, but the upper-middle class also buy up various products in supermarkets. To avoid product scarcity, supermarket managers should use practical and fast applications in placing orders. "RDO" is designed for entrepreneurs who want to get products in a fast time.

All orders will enter the Distributor Management System (DMS) and are immediately processed at the same time by the distributor. Retailers and distributors can agree to cooperate, for example; each order must enter the distributor system at least the day before. This agreement will make retail and distributor cooperation more effective and efficient. These small shops or what is known as mini-markets are scattered near residential areas. Even though they sell limited products, convenience stores are often the target of panic buying by the public.

As happened recently, health products such as hand sanitizers, masks, and vitamin products are left over in most convenience stores. With this application, convenience store managers, those that are managed by themselves, can replenish more products that have run out.

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Because they base something on an online application, retailers can find out the status of the goods ordered in real time. This means that shop managers are no longer guessing whether the distributor has processed immediately the goods ordered.

As the name implies, non-store retailing runs without a physical store. They also include business people who sell their products online in the non-store retailing category. Even though they run online, online store managers must ensure product availability. Especially nowadays, consumers make purchases online. Online shops are also the target of panic buying from the public. To maintain the supply of goods in the online shop, "RDO" can place orders.

Besides making it easier for retailers to buy products from distributors, Kho (2021) emphasized that the "RDO" application also has four benefits, including providing various products, online ordering, avoiding wrong orders, and practical application. This application can be used to order various products from distributors. Because it is based on digital applications, retail direct orders can be executed from a mobile device. It will be easier to order various products that consumers need in a fast time.

Also, "RDO" is developed for high mobility retailers who can place orders online from anywhere and anytime. Every businessperson can also check the availability of products before placing an online order, so that orders are made more efficiently. Furthermore, there are no more product ordering errors. Through "RDO", all orders will be recorded. If there is an order error, producers can correct it immediately before forwarding the order to the distributor.

Currently, various applications can be found on the market. One application that is often used is "SimpliDOTS retail". This online-based application is designed to assist retailers in ordering goods. When a retailer orders a product, the order will be processed through the Distributor Management System (DMS). Orders that enter DMS will be processed immediately by the distributor on the same day, so all orders placed by retailers can be prepared quickly.

It is important for all business elements to be aware of the consequences of the Covid-19 disruption and how the motives for anticipating supply logistics failures are discussed in India, countries that are members of the Trans-Pacific Partnership (TPP), Lithuania, and globally. Holistic improvements in the logistics industry are becoming an integral part of moving goods and services on time within and outside Lithuania through third-party partnerships that operate transportation services (Perkumiene *et al.*, 2021). For Indonesia, an adaptive supply chain scenario is proposed by Ongkowijoyo *et al.* (2022) with a series of tests that allow contingency strategies to help supply chain resilience in the manufacturing

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sector. Although the current pandemic is not a new event, trade policy restrictions are vulnerable to logistics transfer from one location to another (Aday & Aday, 2020). The cessation of business activities is temporary; closing food production facilities and chain stores further protects the supply chain. Strategic planning concentrates on maintaining safety rather than thinking about profit (Barman, Das & De, 2021). Uniquely, managerial insights in some retail stores were tested in managing dynamic capabilities. Accurate decisions determine the speed of the supply chain (Raj *et al.*, 2022). Singh *et al.* (2020) simulated a responsive and robust supply chain model to adjust and change transportation routes within a certain area so that the distribution system reaches retailers and store owners. Logistics service providers surveyed by Herold *et al.* (2021) combined supply chain resilience with transportation management flexibility, optimizing operational guidelines, and digitizing finance. For example, in India and the TPP region, supply chain efficiencies in logistics companies leverage more advanced IT intelligence. Although production was hampered by port closures, rerouting and delivery delays, and cargo cancellations due to capacity reductions, it was a start to actualizing the new model. Then, the customs pattern that is configured to the sensitivity of the supplier pattern is redesigned to minimize the cost of raw materials to the factory (Nagao *et al.*, 2021; Sudan & Taggar, 2021).

Conclusions

This paper seeks to illustrate how logistics management and distribution systems can manage, despite the extreme constraints of the global pandemic. As is known, logistics management and distribution systems are different things. Logistics is a series of activities to retrieve and place goods from the planned place and time. Meanwhile, distribution is one aspect of marketing. Disruption in distribution occurred because of the decreasing activities carried out outside the home, difficulties in obtaining raw materials because of transportation constraints, and the decline in public trust in products that were from outside, especially in the culinary sector.

With "RDO", they always developed it as a positive response to the impact of PSBB. Its impact is very much felt in the real sector which has experienced a drastic decline; even distribution of staples, stagnant health, and budget allocations are unpredictable, causing confusion and panic in local government in managing the budget.

The weakness of this paper is that it does not use quantitative methods for supporting surveys or secondary data. There are no data collected by government institutions from time to time on disruptions to logistics, so it is very difficult to observe. We expect future studies that focus on similar topics to highlight how "RDOs" can be developed and evaluated for

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decision-making. Marketing constraints in the retail sector in Indonesia during the pandemic have not been explored, so there are no previous studies relevant to this topic.

The contribution, originality, and novelty of the "RDO" concept are expected to be material for evaluation and consideration for business people, governments, and various communities in the future that focus on digital marketing aspects. The rest is for broad knowledge that has a significant impact on alternative solutions in preventing the limitations and scarcity of commodity stocks, especially in emergency situations such as Covid-19.

At one point, the SLR approach relatively does not examine whether the lens of the literature can develop concepts, take initiative, and realize what needs to be recommended to solve a particular case. At this stage, the seriousness and sensitivity of the researchers have contributed to correcting and revitalizing the previous methodologies.

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Mapping Top Strategic E-commerce Technologies in the Digital Marketing Literature

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Abstract: The increasing use of e-commerce technologies has been studied in several fields and from different perspectives: technological, economic, organizational and social: hence, the need for a literature review that provides a map of top strategic e-commerce technologies from a managerial perspective and, more specifically, for digital marketing research. This paper aims to provide researchers with a comprehensive overview of the range of e-commerce technologies that have had a significant role in shaping digital marketing strategies. Based on a thematic analysis, e-commerce technologies were classified through eleven categories. The objective is to reveal how each set of technologies affected the different digital marketing strategies. Both descriptive and clustering analyses show that the most evoked technologies in the digital marketing literature are Information and Communication Technologies and platforms. Results outline the growing interest in artificial intelligence technologies. Moreover, this literature review reveals how digital marketing research has focused on technology-enabled segmentation and targeting strategies, along with the use of social platforms and the development of new products and services. The scarcity of marketing papers studying the impact of cloud technologies, IoT, blockchain and data analytics orient researchers towards exploring further the potential of these technologies for digital strategies.

Keywords: E-commerce Technologies, Marketing Strategies, Literature Review, Thematic Content Analysis, Clustering

Introduction

E-commerce has been growing rapidly alongside Internet and information technology in recent years, providing enormous opportunities and challenges for both demand and supply sides. Several studies have analyzed the growth of e-commerce in the last decade, and its interplay with consumer marketing strategy (Rosário & Raimundo, 2021). The evolution of e-commerce research was analyzed in three phases, from ecommerce to mobile commerce and

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social commerce, including the concepts of business models, service relationships and technology (Yoo & Jang, 2019). The results highlighted various issues raised by practitioners and solutions suggested by researchers at each phase, but did not cover technologies deployed, nor the marketing aspects.

On the other hand, several publications have studied a single technology as a driver for digital marketing strategies. For instance, Mustak *et al.* (2021) presented a bibliometric analysis of the deployment of AI in marketing. Furthermore, Benslama and Jallouli (2020, 2022) provided a literature review (LR) of Social Media technologies for marketing purposes and drew a map matching social media data analytics with the following marketing strategies: (1) Segmentation, targeting and positioning (STP), (2) Product, service and brand, (3) Pricing, (4) Channel and logistics, and (5) Communication and influence strategy.

Besides considering single technologies, managers should take into account a set of technologies to evaluate companies' technology portfolios and support decision-making in the context of mergers and acquisitions (Hofmann, Keller & Urbach, 2019).

Based on the studies presented above, we can conclude that previous research in both business and computer science fields has attempted to reveal how technologies enable marketing decisions, but usually focuses on a particular technology or a specific marketing strategy or tool. However, with the remarkable growth of e-commerce and the development of innovative business models based on emerging technologies, it becomes insightful for managers and researchers to have on hand a map illustrating the whole set of e-commerce technologies that drive the innovative digital marketing strategies.

This study aims to respond to this gap, and present a thematic content analysis of papers published in the last three years evoking innovative digital marketing strategies that were transformed and enabled with the implementation of technologies such as Artificial Intelligence (AI), blockchain and Internet of Things (IoT). The objective of this research is to answer the following questions: What are the most influential technologies in terms of digital marketing strategies? Which digital marketing strategies were driven by these technologies and how? What are the understudied areas in this field that could be considered as relevant orientation for future research?

To answer these questions, this paper proposes a LR of selected journal papers published from January 2018 to November 2021. Selected papers mention "e-commerce technologies" and "marketing" as author keywords. Then, a thematic content analysis focuses on keywords, titles and abstracts of selected papers. Finally, a descriptive analysis and clustering technique are applied to the corpus.

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This paper is organized as follows: The first section presents an overview of e-commerce technologies and data analytics tools, and defines the main areas of digital marketing that will be retained in this research. The second section explains the methodology used. The third section describes and discusses the main results related to thematic analysis of e-commerce technologies, descriptive analysis, cross analysis, and the clustering analysis. The last section includes the conclusion and lists recommendations for future research.

E-commerce Technologies and Digital Marketing Strategies

Adams et al. (2019) analyzed three types of strategic orientations — customer, technology, and combined customer/technology orientation — and studied their impact on innovation performance. According to Gartner (Nguyen, 2021), "Emerging technologies provide a strategic roadmap to firm differentiation over the next three to five years". Several organizations such as Gartner and Forbes publish periodic reports on top impactful technologies to enlighten businesses regarding the opportunities for implementing these technologies at an early stage, and ensure strategic competitive advantage via innovative business models. According to Gartner (Nguyen, 2021), the top strategic impactful technologies in 2022 are AI, IoT, 5G, cloud technologies, quantum computing, augmented reality/virtual reality, data mining, visualization and blockchain technologies.

In addition to their impact on the effectiveness of e-commerce operations, emerging technologies, such as AI, IoT, and blockchain, are playing an insightful role in collecting relevant real-time data during the e-commerce process with the aim of well targeting, communicating and satisfying markets and communities of interest. Kaabi and Jallouli (2019) presented an overview of e-commerce technologies and data analysis techniques, and attempted to clarify the importance of the analytical phase for the extraction of marketing insights enabled with e-commerce technologies (Figure 1).

The following subsection attempts to structure the domains of digital marketing strategies and specifies for each strategy some examples of transformation driven by emerging technologies in the last years. Based on Campbell et al. (2020) and Kotler et al. (2017), marketing strategies are structured in five categories:

(1) Targeting and positioning strategy (TPS), which includes analyzing the current situation, understanding markets and customers, customer/market selection, planning direction and objectives, and, finally, marketing investments. Emerging technologies such as mobile, cloud and Customer Relationship Management (CRM) technologies enable firms to understand customers' requirements, develop marketing strategies of positioning and build relationships with customers, suppliers and other strategic partners. Identifying customers' needs is the most important capability that

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influences the positioning development process and digital strategies (Butt & Ahmad, 2021).

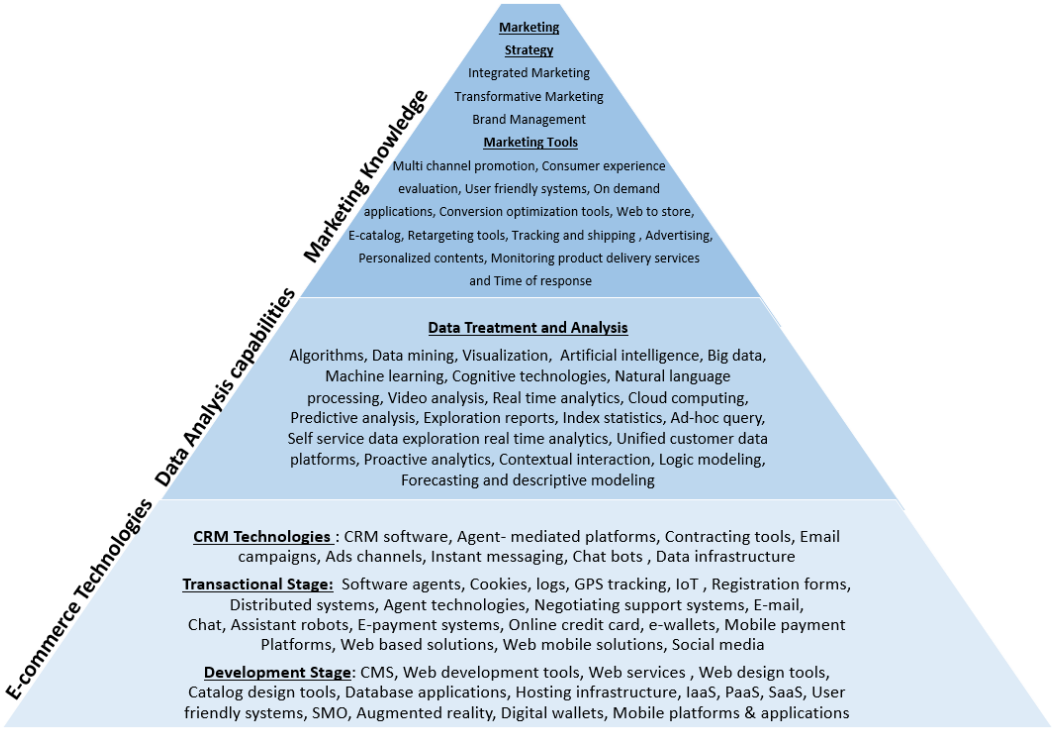

Figure 1. Overview of e-commerce technologies, data analysis capabilities and marketing knowledge (Kaabi & Jallouli, 2019)

(2) Product, service and brand strategy includes all decisions regarding product line, multi-product and portfolio strategies, new products' development, services and product quality, and brand management (Developing, positioning and managing brands). Collaborative platforms, IoT and CRM technologies are tools that help firms to co-create innovative products based on feedback from active virtual communities.

(3) Pricing strategy (PS) includes technical, technological or market related processes that help define prices of products and services. AI, Recommender Systems (RS), visualization and modelling techniques are technologies that support decision making regarding the price strategy especially for digital businesses.

(4) Channel and logistics strategy (CLS) includes channel management (strategy, design, and monitoring) and salesforce management (size, allocation, and compensation). IoT, AI, cloud and mobile technologies (MT) provide managers with valuable tools to allow the firm to manage several interconnected channels, including physical stores and online channels such as websites, CRM systems and platforms. The objective is to draw a total experience strategy based on the real-time data collected and analyzed with the aim to support intelligent decisions targeting customers.

(5) Communication and influence strategy (CIS) includes promotion, advertisement management (Spending, planning and design) and Relationship management (Customer value assessment and maximization, acquisition and retention). Platform

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technologies and privacy-enhancing computation are providing customers with the opportunity to play an active role and communicate intensively with the firm. Therefore, innovative digital content strategy and community management capabilities are becoming extremely important to collect relevant data and satisfy personalized needs of virtual communities (Ayachi & Jallouli, 2022).

These five areas of digital marketing will be adopted to map top strategic e-commerce technologies proposed in this LR.

Research Method

The aim of this study is to provide researchers with a map of top e-commerce technologies that have had a significant role in shaping digital marketing strategies, and to specify which digital strategies were mostly driven by these technologies and how. Indeed, the cycles of emerging technologies published by Gartner show that the ranking of top technologies changes in a significant way every 2 to 3 years. Hence, this study targets research papers published from January 2018 to November 2021. The data collection is based on a search of the terms "e-commerce technologies" and "Marketing" in search engines of, respectively, Springer, Elsevier, IEEE and Emerald. Springer and Elsevier are the top-ranked editors in terms of number of journals (Pagliaro, 2020). IEEE and Emerald were selected due to their focus and high number of publications, respectively, on technologies and business strategies. This LR does not pretend to be systematic, but, rather, is exploratory research that could be extended in future work with an exhaustive list of all editors that publish in this area.

Only papers in English language were retained. This stage enabled the selection of 210 papers. The second step consists of floating reading of titles, keywords and abstracts. Exclusion criteria are duplication, editorials, prefaces, proceedings, corrections or papers out of scope. Twenty-six results were eliminated for the following reasons: 2 duplications, 8 editorials, 6 prefaces, 1 proceedings, 1 correction and 8 papers out of scope. The third step consists of a content analysis focusing on titles, keywords and abstracts of the 184 papers retained (Shim *et al.*, 2019).

After performing a floating reading and rereading that identifies e-commerce technologies along with the digital marketing strategies, the division of the corpus was carried out according to a thematic content analysis grid. The purpose of this step is to apply statistical treatments, using SPSS software, on the corpus of data. The coding was applied as follows: number one is assigned to the theme if the related term (e-commerce technology or marketing strategy) is present in the corpus (title, keywords and abstracts); and number zero is assigned if the theme is not cited in the corpus. The final step is the thematic content analysis where technologies

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cited in the corpus were classified into categories. Figure 2 illustrates the research method adopted.

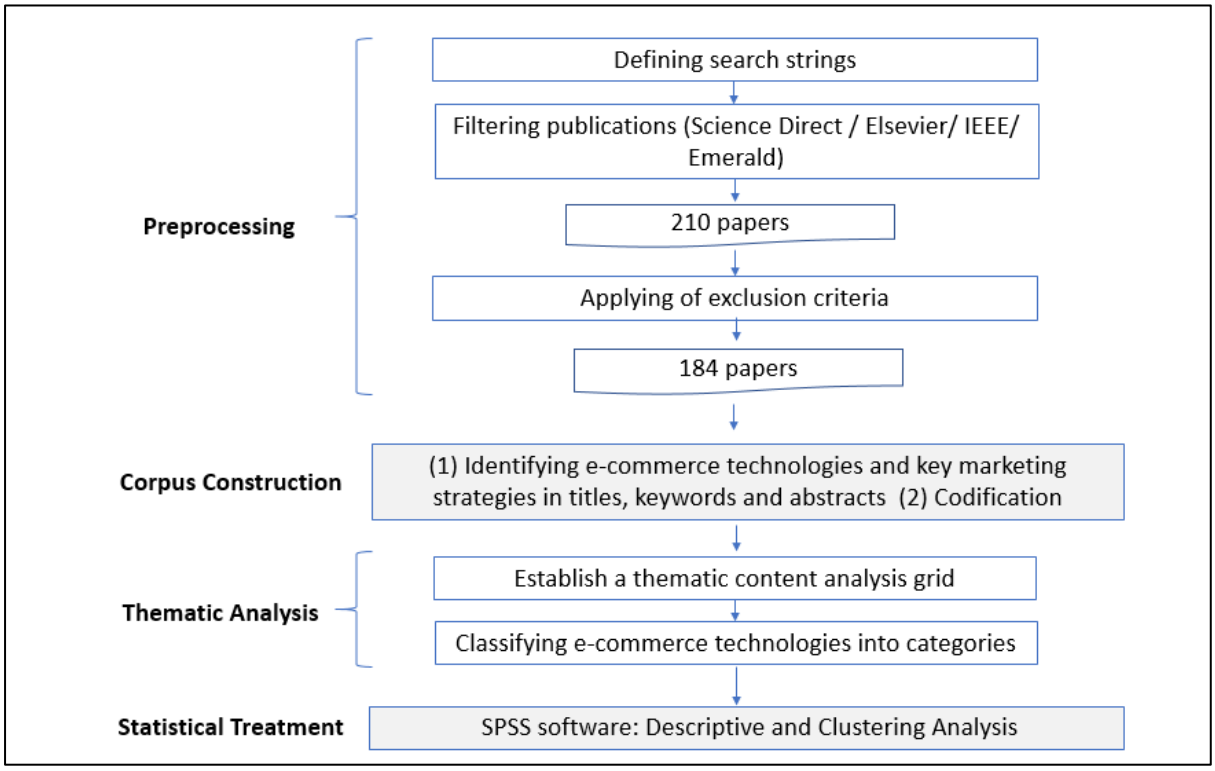

Figure 2. Process of corpus identification, construction and treatment

The final grid includes 184 lines (papers) and 5 columns of marketing strategies, 11 columns of e-commerce technologies, and 3 additional columns mentioning the name of the Publisher, the year of publication. and the Impact factor of the journal.

Research Findings and Discussion

This section is structured as follows: after a short description of the corpus, a first subsection is dedicated to the thematic analysis that aims to propose a categorization of e-commerce technologies. These categories will be useful to build the cross tables showing technology-enabled strategies in the studied corpus. The second subsection presents the results of the clustering technique that help to draw the map of top strategic e-commerce technologies linked with marketing studies.

The overall set of papers is composed as follows: 94 papers selected through Elsevier; 35 papers selected through IEEE; 29 papers selected through Emerald library; and 26 papers selected through Springer. Fifty-nine papers were published in 2018, 78 in 2019, 29 in 2020, and 18 in 2021. The Impact factors of the journals in which the papers were published have values between 0 and 9.50 (Table 1).

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Table1. Impact Factor (IF) of selected journals

	N	Minimum	Maximum	Mean	Standard Deviation
IF	184	.00	9.50	2.83	2.14

Thematic analysis and categorization of e-commerce technologies

E-commerce technologies refer to services, capabilities, practices and solutions used in the context of e-commerce. This section explains the thematic content analysis of revealed technologies in the studied corpus. The corpus included mention of many e-commerce technologies, such as IoT, blockchain, information and communication technologies (ICT), virtual reality (VR), big data, data mining, AI, workflow, resource sharing, Business intelligence (BI), platforms, decision-making, RS, algorithms, stochastic process, data visualization, payment, web programming, security, telecommunication, MT, algorithms and web-crawler technology.

Revealed terms related to e-commerce technologies are then sorted into the eleven categories shown in Table 2. Related terms are gathered in the same category. For example, "mobile devices", "mobile applications" and "mobile programming" are regrouped in the category MT. Classification was based on the occurrence in the abstract, title or keywords of the exact name of the category or terms that are related to the category. Technologies with rare occurrences were associated with other keywords to obtain categories with a minimum of five occurrences.

Table 2 summarizes the content analysis of e-commerce technologies. The second column presents the total number of terms cited for each category. The third column presents all terms related to the same technology.

Results show that Platforms and ICT are the most evoked technologies in the corpus. These two categories are regrouping a large set of essential technologies and infrastructure related terms. The high number of their occurrences could be explained by the high common understanding of these technologies and their popular use in e-commerce projects. The two categories that are ranked in the third and fourth places in terms of occurrence are AI and DSS. This result confirms the increasing focus on AI technologies in the field of marketing.

Table 2. Categorization of e-commerce technologies in the corpus of scientific papers

Categories of E-commerce technologies	Frequency	Related terms as cited in the corpus
CLOUD	5	cloud
BLOCKCHAIN	5	blockchain, bitcoin, Ethereum
IOT	11	IoT

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Categories of E-commerce technologies	Frequency	Related terms as cited in the corpus
MT	12	mobile computing, mobile commerce, mobile devices, mobile services, mobile applications, mobile payment, smartphone games
ICT	37	ICT, E-commerce, telecommunication, fiber channel, network optimisation, new generation networks, machine-to-machine communication, IT, information systems, fintech, virtual reality
IT SERVICES	16	workflow, resource sharing, self-service parcel delivery service, website ranking, web programming, web 2.0
SECURITY	13	electronic signature, trust, two-factor authentication, secure system, encryption, e-commerce vulnerability, computer security
PLATFORMS	39	social networks, e-commerce platform, third-party websites, multi-sided platform, third-party payment, social information systems, dual-purposed information systems
AI	32	mobile agent, agent system, deep learning and RS, neuronal networks, reinforcement learning, chatbot, AI, prediction algorithm, training, machine learning, deep learning
DATA ANALYTICS	16	machine learning, BI, big data analytics, big data and decision support systems, data visualization, data mining and RS, Big Data, data mining data
DECISION SUPPORT SYSTEMS (DSS)	25	RS, decision making, decision support systems, multiple-criteria decision-making, cluster analysis

Indeed, several special issues and conferences were dedicated to the deployment of AI in marketing strategies, such as in *Journal of the Academy of Marketing Science* and *International Marketing Review* (Davenport *et al.*, 2020; Grewal *et al.*, 2020; Turban *et al.*, 2018). Companies need AI applications to process business data and to make the shopping experience more personalised. Dau and Salim (2019) for instance proposed a sentiment-aware deep RS based on the neural networks paradigm. Thanks to the power of AI, online retailers provide chatbot services and analyse customer comments. Multiple e-commerce platforms use multi-agent systems in various contexts, such as e-commerce logistics (Barenji *et al.*, 2019).

Strategic e-commerce technologies in marketing research

Regarding the frequencies of marketing strategies driven by e-commerce technologies, the evoked terms are sorted within five groups as detailed in Table 3.

Table 3. Occurrences of Marketing Strategies

Marketing strategies	Frequency
Segmentation, Targeting and Positioning strategy (STP)	92
Product, service and Brand strategy	65
Pricing strategy	9
Communication and influence strategy	45
Channel and logistics strategy	120

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Table 3 shows that channel and logistics strategy occurs with 120 papers out of 184. This finding outlines a focus on improving the current solutions provided by ICT and platforms for marketers to exploit the full potential of e-commerce opportunities in terms of channels and logistics. Marketing research attempts to explain and study new ways of delivering products and services based on opportunities offered within an e-commerce context.

Moreover, results shows that 92 among 184 studied papers in this LR focus on STP strategies. This result highlights the role of emerging technologies in segmenting and targeting markets. Indeed, market segmentation is based on data collected and analyzed to better understand the needs and evolution of the market segments. ICT and platforms play an increasing role to help collect in real time a huge volume of data about the socio-demographic characteristics of clients and prospects, the consumer experiences, and the trends of consumption in the future. Based on collected data, decision support systems and data analytics help marketers to draw effective strategies of targeting and positioning.

Product, service and brand strategy occupies the third place in terms of occurrence, with 65 papers. This result indicates the role of ICT and platforms in the STP strategy, which affects in a significant way the product, service and brand strategy. AI technologies are helping to customize services delivered to each segment. Indeed, researchers and marketers are more and more focusing on branding strategy in response to customer needs and feedback.

Table 3 indicates also that 45 papers out of 184 studied the communication and influence strategy. Indeed, platforms, MT and AI are technologies that support the communication strategy. More specifically, social networks, e-commerce platforms, data analytics, RS, chat bots and web services are tools that marketers are implementing to obtain effective communication decisions.

Finally, pricing strategy occurs rarely in papers studying e-commerce technologies. Data analytics and decision support systems are the main technologies involved in this area. Consequently, the low cost of network access and e-commerce transactions, and the development of cloud and AI technologies are future investigation areas about how the marketing pricing strategy takes advantage of these advances.

Results of cross analysis show the main associations between retained categories of technologies and marketing strategies in the corpus (Table 4).

Cloud technology contributes to orienting the product, service and brand strategy, mainly with the development of cloud micro-services and cloud service platforms that enhance business performance. The integration of cloud technologies and big data infrastructures contributes to performing logistic strategy based on real-time data and transforms the way e-commerce firms do business (Barenji *et al.*, 2019; Li *et al.*, 2019).

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Moreover, blockchain technology provides solutions to STP strategies especially in the data market. As an example, a blockchain-based fair data trading protocol provides data consumers with information that guarantee fairness and traceability of data providers (Liu *et al.*, 2019). Blockchain technology allows also automation of high-volume tasks, such as reconciliations, payments and settlements, and contributes to implementing end-to-end instrumented data-rich micro-segmented supply chains (Liu *et al.*, 2019; Narayanaswami *et al.*, 2019).

Table 4. Cross analysis of 'Marketing strategies' and 'E-commerce technologies'

Technology / Strategy	Cloud	Blockchain	IOT	MT	ICT	IT services	Platforms	AI	Data Analytics	DSS	Security
STP	0	3	4	6	15	9	18	15	8	12	6
Product, service & brand	3	5	7	5	14	10	12	14	7	8	2
Pricing	0	0	0	1	0	1	0	1	0	2	0
Communication & influence	0	3	3	3	6	6	11	10	5	5	3
Channel & logistics	3	2	8	8	25	12	24	19	9	16	10

Table 4 shows that IoT, MT, ICT, IT services, platforms, AI, data analytics, decision support systems and security are mostly studied in relation to the channel and logistics strategy. Indeed, new perspectives of e-commerce channels are raising in the literature, such as the theoretical and practical features of sustainability (Shukla, Mohanty & Kumar, 2018). Exploring and evaluating aspects and performance of e-commerce channels call up a set of related technologies such as IoT, MT and security (Liu *et al.*, 2019). In addition, data analytics techniques and decision support systems, like, for example, fuzzy cognitive maps, provides researchers and practitioners with tools that aid in strategizing decision situations related to evaluation and improvement of e-commerce channels (Shukla, Mohanty & Kumar, 2018).

Finally, the results highlight the rising number of papers associating AI with STP, product, and channel strategies, especially in the last two years. Indeed, an increasing number of researchers have implemented AI tools combined with big data, virtual reality and augmented reality to conceive new products and services that meet the consumers' need (Huang & Rust, 2021). Fashion and tourism sectors are among the most concerned with the implementation of this set of technologies, especially because of the high use of social platforms providing researchers and practitioners with contextualized data about the product, the brand and the preferences of consumers and prospects (Koubaa & Jallouli, 2019; Samara, Magnisalis & Peristeras , 2020; Silva & Bonetti, 2021).

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Clustering analysis

Clustering is the process of grouping a set of objects into classes of similar objects. There are two types of algorithms for clustering: flat, also called partition algorithm; and hierarchical algorithm (Ramasubbareddy *et al.*, 2020). Based on the cluster hypothesis, papers in the same cluster behave similarly regarding the presence of e-commerce technologies and key marketing decisions. In this study, there was not an *a priori* number of clusters; a hierarchical clustering was therefore adopted. This method produced a family of clustering options represented by a dendrogram from the set of 184 selected papers. There are many variants to define the closest pair of clusters: Single-link (Similarity of the most cosine-similar); Complete-link (Similarity of the "furthest" points, the least cosine-similar); Centroid Clusters whose centres of gravity are the most cosine-similar; Average-link, calculated based on the average cosine between pairs of elements.

In this study, we tried all these methods, and then we retain the results of the centroid variant, which has provided the better representation that maps how the eleven categories of e-commerce technologies have affected the five digital marketing strategies. A good clustering should produce high quality clusters in which the intra-class (intra-cluster) similarity is high, and the inter-class similarity is low. Figure 3 presents the dendrogram using a centroid linkage applied to the 184 papers published from 2018 to 2021.

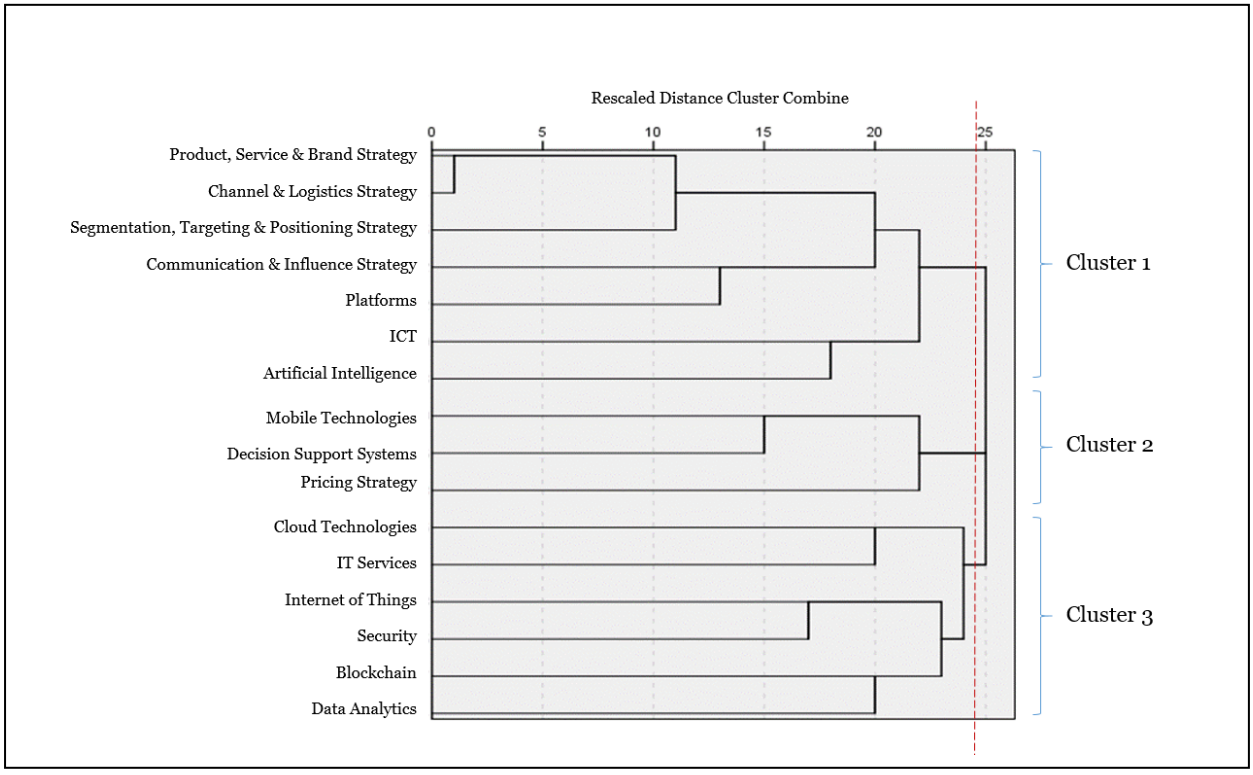

Figure 3. The dendrogram using a centroid linkage

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Based on the hierarchical clustering method, studied papers mentioning "e-commerce technologies" and "marketing" are divided in three groups that behave differently.

The first cluster links all marketing strategies, excluding pricing, with AI, Platforms and ICT. Table 4 indicates that these three technologies are widely studied by marketing researchers in the last four years. As explained earlier, ICT and Platforms are general terms and were largely evoked in marketing papers, especially in relation to communication and influence strategy.

More specifically, marketing researchers were highly interested in studying social media contents to meet virtual community's needs. Indeed, marketing researchers are appealing to text-mining techniques, such as topic modelling, sentiment analysis and classification, to extract insightful marketing knowledge and guide marketing decisions (Adams *et al.*, 2019).

Moreover, AI is gaining interest in the published papers, especially during 2021. The number of studies that link AI with product and brand strategy, channel and logistic strategy and STP strategy has risen at a remarkable rate. Consequently, several frameworks for strategic marketing planning incorporating AI benefits have been proposed (Huang & Rust, 2021).

The second cluster consists of papers that studied MT and decision support systems in relation to pricing strategy. Based on Table 4, the number of papers in this cluster is relatively low. Future marketing research is expected to further explore how new technologies in general, and more specifically MT and decision support systems, enable managers to design profitable pricing strategies based on collected demographic and real-time contextualized information about prospects and customers.

The third cluster defines papers evoking cloud technologies, IT services, IoT strategy, security, blockchain and data analytics. This cluster concerns papers that focus more on technical aspects and show weak association with marketing strategies. Table 4 illustrates the low number of papers studying specifically cloud and blockchain technologies in relation with marketing strategies. This area is indeed a recommended field for future studies, especially with the high performance that cloud computing is offering regarding the cost of IT services, and also the large set of mobile applications based on IoT technologies with high potential for meeting user needs.

The results of the hierarchical clustering highlight the relevance of initiating more research projects on e-commerce technologies and marketing strategies, involving researchers from the fields of computer science and marketing.

Conclusion and Directions for Future Research

Recent advances in technologies have been widely integrated into the different phases of e-commerce process. Marketing literature has been deeply impacted by the transformation of

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strategies and tools integrating emerging e-commerce technologies. This paper has described a LR of 184 papers published from January 2018 to November 2021, evoking a set of e-commerce technologies in association with marketing strategies, namely, STP strategy; product and brand strategy; pricing; channel and logistics; and, finally, communication and influence strategy.

This study followed a rigorous process of identification, construction and treatment of retained papers, using a thematic analysis and statistical treatments with SPSS software. Thematic analysis allowed sorting the revealed e-commerce technologies, and classifying them into eleven categories, namely: blockchain, MT, ICT, security, platforms, Internet services, AI, cloud computing, IoT, data analytics, and decision support systems. This categorization is insightful to guide future research in the area of e-commerce technologies and marketing, especially future LRs, since this classification provides essential keywords to adopt in the stage of corpus identification.

Moreover, results show that platforms, ICT and AI are the most studied categories in association with digital marketing strategies. This finding sheds light on the increasing focus in the marketing literature on new methods and tools, such as netnographic studies and text mining techniques applied by researchers and practitioners to explore social media contents and meet virtual communities' needs.

In addition, this research highlights the increasing number of papers studying the potential of AI in the marketing context, linked mainly with product and brand strategy, channel and logistic strategy and, finally, STP strategy. However, few papers linked MT and decision support systems with pricing strategy. This result defines, then, a relevant gap to study in the future, and invites marketing researchers to explore more technologies, such as cloud technologies, that provide opportunities to design profitable pricing strategies.

Finally, this LR outlines that few marketing papers have studied in depth the technical features of a range of technologies, such as IoT, big data and blockchain, and their contribution to shape effective digital strategies. Hence, there is relevance in future joint projects involving researchers from the fields of computer science and marketing management to focus more on understudied e-commerce technologies and reinvent digital marketing practice and research.

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Percy Rollo Brett OBE (1923–2022)

Research Leader and Public Servant

James Richardson
Former PMG/Telecom Australia Engineer

Abstract: Percy Rollo Brett OBE (11 November 1923 to 8 August 2022) was a highly respected head of the PMG/APO (later Telecom Australia/Telstra) Research Laboratories between 1964 and 1975. He was promoted to Head of Planning for Telecom Australia in July 1975, and then State Manager, Victoria for that organization in 1980–1983. Rollo's achievements as Director of the Research Laboratories included building links with Australian universities to strengthen the Laboratories' expertise in longer term research, and masterminding the Laboratories' move from six different sites in central Melbourne to a single site, in purpose-designed buildings in Clayton, opposite Monash University's main campus. In the early 1970s, he used the expertise he gained as Chairman of the Telecommunications and Electronics Standards Committee of the Standards Association of Australia to lead the Australian Post Office's conversion of all its standards to metric. Upon retirement in 1983 he was awarded the OBE.

Keywords: History of Australian telecommunications, obituary

Early Life and Education

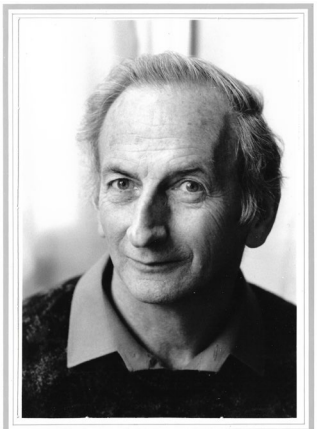

Figure 1. Rollo Brett in retirement

Rollo Brett was born in Kyabram, north central Victoria, as the second eldest of five children of Harry and Matilda Brett. They had just moved to a mixed farm in nearby Lancaster. His siblings were Betty, Harry, David and Bryan, now all deceased.

His parents strongly encouraged education. Rollo attended high school at Kyabram until Intermediate, and then went on to high school at Bendigo, where he completed Leaving Honours in 1939. He sat for the exam to enter the Commonwealth Public Service and topped the State. He

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was offered a free university place but was unable to take it up as it did not include a living allowance. Instead, he joined the Engineering Division of the Postmaster General's (PMG) Department as a base grade clerk in 1939 at age 16. He also enrolled for a science degree at the University of Melbourne, initially as a part-time student (and full-time clerk!)

In January 1942, he was called up for military service in the Survey Corps. While travelling from Melbourne to Darwin in April 1943 with this group, he learnt that he had been exempted from military service. This ultimately allowed him to complete his science degree as a full-time student with a living allowance. He graduated in 1944 as a Bachelor of Science majoring in physics. Rollo really wanted to be an engineer but had failed to obtain a cadetship, which was rather surprising. He once remarked: “I have always been intensely interested in the study of electrical phenomena”.

After graduation, he joined the Research Laboratories of the PMG's Department as a Physicist Grade 1 in the Physical Sciences Section. His main technical contributions there were in the field of materials and components and their environmental behaviour. He was also involved in establishing and understanding the standards required for adapting modern polymer materials for use in telecommunication equipment.

Figure 2. Rollo Brett as a young research physicist at the PMG Research Laboratories

When Rollo returned from Darwin in 1943, he met Beryl Williams. She was then working at the YWCA as a youth worker. They were both members of the congregation at St John's Anglican Church in Latrobe Street and were married there in 1946. Their first child, Judith, was born in 1949. Soon afterwards, the couple moved out to their newly built home in Nunawading, which was then an outer suburb of Melbourne being opened up for residential development. Two more children were born there, Ian in 1951 and Helen in 1956. Rollo was

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an enthusiastic gardener and a skilled handyman around the home. As a young couple, Beryl and Rollo became foundation members of All Saints Anglican Church in Nunawading. Rollo was a lay preacher there, the vicar's warden, ran stewardship campaigns and worked to raise funds to build the church hall and later the church itself. In addition, he was a member of the Council at Nunawading High School, where all three children attended, and he later served as its President. He had a strong commitment to public education and believed that it contributed to a fairer and more cohesive society.

Professional Life

During the 1950's, Rollo was active in the Professional Officers' Association (POA), preparing and presenting cases to the Central Committee of the Public Service Board (PSB). These actions led to substantial organisation and classification improvements in the Physical Sciences Section. In 1953, he was promoted to Senior Physicist and, in 1958, to Section Head. By this time, the section had expanded to include two other related specialities, chemistry and metallurgy.

Following the re-organisation of the Research Laboratories in 1963, Rollo was appointed Assistant Director General (ADG) and head of the Apparatus and Services Branch. Then, in 1964, he rose to Senior Assistant Director General (SADG) as head of the Research Laboratories, succeeding Len Harris. His career was now moving from research work into executive leadership.

In 1970, Rollo departed on an overseas visit to investigate the management and development of telecommunications in other research organisations. These included Siemens (Germany), Philips (Netherlands), Ericsson (Sweden), the British Post Office (UK), Northern Electric (Canada) and the Bell Telephone Laboratories (USA). The purpose of this visit was to investigate how the output from a research and development group could be utilised to serve the needs of the parent organisation in the manufacture and application of telecommunication equipment. During the period when Rollo was in charge of the Research Laboratories, from 1964 to 1975, he concentrated on managing its research program to align it with the longer term needs of the PMG's Department. To expand this advanced knowledge, he fostered relationships with Australian universities involved in postgraduate research relevant to telecommunications.

During the late 1960s and the early 1970s, Rollo also tackled the problem of poor accommodation and facilities at the Research Laboratories. The Labs were then scattered over six separate sites in the Melbourne CBD. His initiative eventually led to the consolidation of the Research Labs at a single location in specially designed buildings in Clayton, across

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Blackburn Road from Monash University. The first of these buildings was occupied in 1975 and all facilities were finally transferred there by 1980.

Rollo's earlier career had involved him participating in relevant working groups of the Standards Association of Australia (SAA). He eventually became a member of its Council as well as Chairman of its Telecommunications and Electronics Standards Committee. He also became a member of the Faculty of Engineering at the University of Melbourne and a member of the Academic Policy Committee of the Victorian Institute of Colleges. Moreover, he graduated from the Staff College at Mount Eliza just prior to taking up his job as Head of the PMG Research Laboratories. He was also a Fellow of the Institute of Radio and Electronic Engineers and a member of the Radio Research Board.

In 1970, the Australian Government passed legislation which created the Metric Conversion Board to facilitate the conversion of measurements from Imperial to Metric. This included the changes needed in all aspects of the PMG's Department. Rollo, then Head of the Research Labs, was chosen to lead this change, both in Postal and Telecommunications. This affected such matters as the sizes of and charges for letters and parcels, the standardisation of postal packets, the charges for long distance calls, and, of course, all heights and weights. Rollo's extensive knowledge of the standards requirements was recognised and respected throughout the Department.

Rollo was from the generation of nation builders shaped by World War II and Labor's post-war reconstruction; leaders who believed in the central role of Government in making Australia a better society. As a public servant, he truly believed in serving the public good and, as a nationalist, he believed that Australia should develop its own solutions to the communication challenges of its unique environment. As Head of the Labs, he strengthened its links with other institutions, especially the universities with research into telecommunications.

In 1975, the PMG's Department was divided into two parts: Telecom Australia, which handled telecommunications; and Australia Post, which handled mail. Rollo was appointed Head of Telecom's newly created Planning Directorate in 1975. He was a member of the task force which investigated the feasibility of Australia developing a domestic satellite. However, he was somewhat sceptical of this, considering that Australia already had a high-quality terrestrial communication infrastructure.

In 1980, Rollo became State Manager of the Victorian Division of Telecom Australia. In 1982, Rollo presented a formal appreciation to Harry Wragge ("Council of Control Function", 1982) to mark his retirement as founding Editor-in-Chief of the journal, *Australian Telecommunications Research* (ATR). ATR had been an initiative of Rollo's in 1967,

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influenced by the model of the highly regarded *Bell System Technical Journal*, to provide a wider audience for the engineering and scientific advances in the then PMG Research Labs[i] (Gerrand, 1996, p. 34). Harry later on became Director of the Telecom Research Laboratories.

Figure 3. Rollo demonstrating Telecom's videoconferencing system in the early 1980s

Later Life

Rollo retired from Telecom Australia in 1983 at age 60 after 44 years of service. In that year he was awarded the Order of the British Empire (OBE) in the New Year's Honours List. He would have preferred an Order of Australia, but such an award was not available at the time! It was still a splendid recognition of his many contributions.

After retirement, Rollo and Beryl bought a house at Mount Martha. which became their actual retirement home in 1989. Here, Rollo pursued his hobbies of gardening and woodworking, as well as entertaining family members and old friends. Both were active in the Balcombe Probus Club and the local Anglican Church of St Martin's. It was a very happy period of their lives. However, Beryl was to die suddenly in 2006, after almost 60 years of marriage to Rollo. A few years later, Rollo married a fellow parishioner, Anita McDonald, and she remained with him until her own death five years later. In 2014, he moved into a retirement village at Mount Martha, and in 2019 was admitted to hospital. No longer able to live on his own, he came to stay firstly with his elder daughter, Judith, and partner Graeme in Northcote and then later

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with his younger daughter, Helen, and partner Trevor in Adelaide. Rollo suffered from dementia and was eventually transferred to a nursing home in Westgarth in Melbourne. He received excellent care and remained there until he died peacefully in 2022. His funeral was conducted at St John's in Flinders. His life was one of love to his family and of service to his nation.

Acknowledgements

This obituary was compiled with contributions from Rollo's daughter, Emeritus Professor Judith Brett, and former PMG/Telecom/Telstra engineers David Smyth, John Costa, John Lewis and Peter Gerrand.

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Endnotes

[i] At different times before 1 July 1975, the Laboratories were known as the PMG Research Laboratories and the APO (Australian Post Office) Research Laboratories.

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