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## 5G and Wi-Fi 6 Milestones

### Editorial

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**Abstract:** Papers in the March 2020 issue of the *Journal* include discussion on the future of the \$51 billion National Broadband Network (NBN), IoT device and system management and the mobile cellular networks in Indonesia. The Telecommunications Association is hosting public forums on the future of the NBN in 2020 at RMIT University in Melbourne. The Australian mobile network operators continue to rollout 5G and Telstra has announced a 5G milestone. In the U.S., the FCC has announced the allocation of 1,200 MHz in the 6 GHz band for unlicensed use including Wi-Fi 6. The *Journal* welcomes contributions on telecommunications and the digital economy.

### In This Issue

In this issue of the *Journal* papers cover public policy related to the National Broadband Network (NBN), IoT, Immersive Virtual Reality, mobile cellular in Indonesia and a historical look at the telephony engineering history of Western Australia from 1887 to 1987.

*Novel Display and Control for IoT-Based Home Automation* presents a proposed approach for the display and control of IoT-based home automation devices and systems.

*Synchronous Reality: Enhancing Sensory Perception in Immersive VR* introduces synchronous reality and how it combines sensory, physical and virtual inputs into one environment.

*Mobile Cellular Technology Forecast for the Indonesian Telecommunications Industry* investigates the growth of mobile cellular networks in Indonesia.

*The NBN Futures Forum: Learning from International Experience* provides a summary of the talks on international league tables, New Zealand's experience and the requirement for broadband for the global digital economy, at the third NBN futures forum held at RMIT University in Melbourne.

*The Telephony Engineering History of Western Australia from 1887 to 1987* provides a historical look at the development of the public telephone system in Western Australia between 1887 and 1987.

## 5G and Wi-Fi 6 Milestones

The recent announcement by Telstra that it had upgraded part of its mobile network to be “5G standalone ready” is a significant milestone that is expected to be quickly replicated by the other mobile network operators, Optus and Vodafone Hutchison. The promise of 5G as an enabling technology cannot be understated and, as with earlier increments in mobile cellular technologies, the move to 5G promises much for new and improved applications and services.

As Australia struggles to find a way forward for fixed broadband at a time when the global economy is shifting to digital platforms at a faster pace than ever before, it is possible that the telecommunications markets both here and overseas will benefit from the momentum provided by 5G until such time as national rollouts of FTTP are completed.

A key aspect of the move to 5G has been the reallocation and redistribution of spectrum to meet the perceived need for current and future demand. Mobile cellular utilisation of frequencies above 6 GHz is expected to blossom and provide the additional data-carrying capacity needed to meet demand in high density urban areas.

The introduction of a cloud-based 5G core network capability provides Telstra with the flexibility needed to evolve its network to one that is not dependent on existing core infrastructure and systems.

Over coming years, the move to reduce the 3G footprint will lead to the eventual migration of spectrum used by 3G devices to 5G. Fourth Generation (4G) networks are expected to remain in service for more than five years and possibly as long as the next decade in regional and remote areas.

And any expectation that 5G would replace Wi-Fi should now be quietly shelved with the recent decision by the U.S. Federal Communications Commission on 23 April 2020 to increase unlicensed spectrum — from the current 70 MHz in the 2.4 GHz band and 500 MHz in the 5 GHz band — with the addition of 1,200 MHz in the 5.925-7.125 (6 GHz) band. Wi-Fi 6 (not to be confused with Wi-Fi use of the 6 GHz band) is seen to be complimentary to 5G and the additional spectrum should significantly boost the data carrying capacity of Wi-Fi-6-enabled devices over short distances in very high density urban environments.

## The *Journal*, Looking Forward

The *Journal* welcomes papers on telecommunications and the digital economy, including, theory, public policy and case studies.

Technological change is happening at a rapid rate and consumers anticipate that governments and industry keep pace to ensure that the benefits can be fully utilised. The *Journal* is calling for papers on how new technologies will affect Australian telecommunications consumers.

The topics of *International Telecommunications Legislation and Regulations* and *International Mobile Cellular Regulation and Competition* are set to continue for some time, as the opportunity to attract papers from around the globe continues. We encourage papers that reflect on where the global telecommunications market is now, how it got to where it is, and what is going to happen next.

Papers are invited for upcoming issues. With your contributions, the *Journal* will continue to provide readers with exciting and informative papers covering a range of local and international topics. The Editorial Advisory Board also values input from our readership, so please let us know what themes you would like to see in the coming year.

All papers related to telecommunications and the digital economy are welcome and will be considered for publication after the double-blind peer-review process.

*Mark A. Gregory*

# Novel Display and Control for IoT-Based Home Automation

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**Abstract:** Home automation systems have long been dependent on a permanent central controller, which has many problems, but a significant barrier to eliminating this controller is its ability to supply user interfaces to display the status of devices and control them. This paper proposes a novel protocol which allows any device or several devices, such as a smartphone, to control many devices from any manufacturer in one application in a plug-and-play manner without a central controller. Current approaches to home automation do not offer this functionality, requiring many applications from many manufacturers. The proposed novel protocol uses a standardised dictionary of UI elements and a minimalist XML device description that describes not only the UI layout for a device but also the device's capabilities and the control procedures for the device. This light-weight all-in-one XML description is a novel combination of display, capabilities, and control and is ideal for the highly contested domestic 2.4 GHz Wi-Fi space. This is achieved without the need for a permanent central controller or an Internet connection and together with other protocols allows the elimination of the permanent central controller.

**Keywords:** Home Automation, Internet of things, Smart homes, device description, User interface.

## Introduction

Innovation in automated functionality within the home has been an area of interest for many decades now, but there has been little penetration into the mass consumer market. Recent trends have seen individual automation devices make their way into the market, but little change has been made in wider Home Automation Systems (HAS).

Such systems continue to employ a topology dependent on a Permanent Central Controller (PCC), which is responsible for coordinating the system, from configuration to display and control. However, these PCCs make systems expensive, more complex to use, and lock users

into a particular manufacturer, thus reducing competition, alienating consumers and inhibiting the ubiquitous uptake of the technology.

A new paradigm for home automation is needed that allows the average home user to purchase low-cost simple Internet of Things (IoT) devices that they can take home and install and configure themselves. These devices should allow users to build up a system that is easy to use and maintain. This would replace current approaches where a different smartphone app is needed for every different device. This new paradigm will eliminate the Permanent Central Controller as the source of much complexity, cost and inflexibility in contemporary designs.

Recent work has proposed the Decentralised Home Automation Protocol (DHAP), which eliminates the PCC and redistributes its responsibilities between individual smart IoT devices and Intermittent Control Devices (ICDs) with a series of novel protocols ([Steane & Radcliffe, 2018](#), [2019a](#)). These ICDs, which can be any smartphone, tablet or PC, are not like PCCs as they only offer an interface to the existing system, but the system is not dependent on the ICDs to operate.

The work with DHAP has thus far demonstrated that a HAS can achieve secure device joining ([Steane & Radcliffe, 2017a](#), [2016](#), [2017b](#)), efficient device discovery ([Steane & Radcliffe, 2019b](#)) and communications ([Steane & Radcliffe, 2018](#), [2019a](#)) without a PCC. The final component to consider is the display and control of devices independent of a PCC. This will require devices to be able to describe their capabilities, how they may be controlled, and a user interface layout. This will allow ICDs to present a user interface that can display the status of a device and allow a user to control or interact with the device.

This paper presents a novel protocol that allows users to display and control home IoT devices and completes the DHAP functionality. This is done using a single XML device description file that brings together the description of a device's capabilities, command and control procedures, and user interface (UI) layout. Using this single and compact file stored out-of-the-box in IoT devices, ICDs can generate a fully functioning UI to display the state of the IoT devices, as well as provide the commands to control the IoT device. This will allow ICDs to achieve plug-and-play integration for IoT devices, with many devices from various manufacturers all controlled from one ICD application. Furthermore, the novel description file summarising multiple aspects of a device will allow for future development to accommodate machine-to-machine (M2M) communication between devices within the home.

## Interoperability and the Perils of Lock-in

Commercial home automation products are now available that offer individual smart devices which can be managed as a single device from a smartphone or computer. This approach has

some success but reduces the scope of what a smart home can achieve. Since each device may require its own app, this may reduce the number of devices that users are willing to implement or curtail the ease with which they use devices as they navigate the many applications on their phone.

This is a far cry from the vision for home automation proposed by this paper, in which many devices from many manufacturers could be connected together and controlled from one smartphone application. Some manufacturers are expanding their product range, which may have started with a single smart light bulb but now includes smart mains switches and even kitchen appliances. This does little to improve the situation as it reintroduces the lock-in strategy where users who have bought one device from a manufacturer are locked in to that manufacturer's product range and its feature offerings, or are faced with the drastic complexity increase and inconvenience of operating and maintaining multiple systems and their apps.

This is not a new concern: early research has considered more formal Home Automation Systems and the need to integrate these for optimised user experience. The idea pursued then was interoperability ([Aragues \*et al.\*, 2012](#); [Miori, Russo & Aliberti, 2010](#)). The main issue with most of this work was that it inevitably increased reliance on the central controller; in some cases it compounded the issue by creating a kind of 'super' central controller, translating communications between central controllers of other home automation systems ([Miori & Russo, 2014](#)).

Recent commercial developments have seen a new approach to interoperability offered by the Google, Amazon and Apple voice assistants. These are offering different manufacturers the ability to make their smart devices compatible with their voice assistants. However, this again compounds the issue of the central controller, this time moving it to the cloud, which raises more concerns, but also offers less interoperability than previous work. In this approach, the Permanent Central Controller (PCC) is now in the cloud but, like all approaches seeking this topology, the central controller cost is multiplied. At this stage the costs of the local CC, the voice assistant hub or speaker, are minimal and cloud resource costs are borne by the voice assistant manufacturer but, as ever, 'if you are not paying for the product, you are the product' and many concerns have already been raised as to the privacy of the data collected by these voice assistants ([Brodkin, 2019](#); [Lee, 2019](#); [Washenko, 2019](#)). For all this trade-off, little interoperability is achieved as the voice assistant merely offers a central interface for all devices, a one-app solution as it were. This goes some way in bringing together smart devices from different manufacturers, but the voice assistant market is still new and manufacturers do not support all voice assistants and will even vary their supported assistance between products.



## Literature Review

The display and control of IoT devices in Home Automation Systems can be categorised into three major types: device hosted, externally hosted and custom apps.

In the device hosted approach the smart device itself hosts its own user interface, often running a cutdown web server to host a webpage interface. Recently, the more common implementations of this approach utilise a Raspberry Pi as the smart device and run a webserver to host the UI ([Patchava, Kandala & Babu, 2015](#); [Rukmini & Devi, 2016](#)).

This approach greatly reduces the dependence on wider infrastructure and can be considered independent of a PCC. However, they do not by themselves constitute a HAS as they offer only one specialised functionality and do not easily interact with other devices. So, while devices do not need to describe themselves, this is due to their isolation from other devices. Additionally, the extra computational capability and power requirements add to the initial and maintenance costs of the device.

Externally hosted methods house the interface on a central server and the interface is then accessed via some connection to the central server. This allows greater integration with other devices and reduces the computational load on individual devices when compared with device hosted approaches.

External hosting can be further broken down into locally hosted interfaces like Miori and Russo's DomoNet ([Miori & Russo, 2014](#)) or Baresi, Sadeghi and Valla, who proposed TDeX ([Baresi, Sadeghi & Valla, 2018](#)), while others have hosted the interface in the cloud ([Dickey, Banks & Sukittanon, 2012](#); [Gurek et al., 2013](#)). DomoNet and TDeX have some valuable contributions for device description and UI generation but this approach greatly increases costs with continued reliance on a PCC, which is a single point of failure for the whole system.

This vulnerability is far worse in clouded approaches where manufacturers must maintain the central servers for the products to continue to function; this has already resulted in smart devices losing functionality due to manufacturers closing their servers ([Dellinger, 2019](#); [Statt, 2019](#)). While this is a favourable model for manufacturers who can charge ongoing service fees, for example Nest security cameras ([Nest, 2019](#)), it raises concerns for users who still have to pay the initial outlay for devices that are only useful while manufacturers support access to the control server in the cloud.

All other hosting options allow for devices to be run offline but, if the central control and interface hosting is in the cloud, then all functionality is lost without an Internet connection. There are additional concerns over security as to who can see your devices and their data, and who can gain control.

The use of custom apps splits up the responsibilities of display and control, allowing the interface to be hosted on a control device like a smartphone and the control to be held elsewhere. Implementations such as Cheuque *et al.* (2015), and Thiyagarajan & Raveendra (2015) host a user interface in a custom-designed Android app, which can send control commands to a local central controller or directly to the device. Others have shown that the same approach can be adopted with a clouded central controller (Fahim *et al.*, 2012; Sutiono, Nugroho & Karyono, 2016).

These solutions maintain the reduced computational demands seen in external hosting but may still have increased hardware requirements depending on where the control functionality is hosted, so cost benefits vary greatly. If a home has devices from multiple manufacturers, then many custom apps must be used to control the home, which makes for a poor user experience.

Very little work considers the combination of device display with work already considering device descriptions for capabilities and control. UPnP is perhaps the first exception with its “step 5” presentation allowing for a URL pointing to a user interface (UPnP Forum, 2015). However, this is as far as the standard goes and does not give scope for how the interface might be defined and would ultimately rely on one of the previously discussed methods for presenting a display.

DomoNet and TDeX, however, have perhaps come the closest to bringing device descriptions together with displays. Primarily motivated by interoperability, DomoNet’s standard makes XML descriptions of each device from different HAS to allow interconnectivity. The super central controller integrates central controllers from at least 6 different HAS, then generates a webpage to control the devices based on their capabilities. However, this approach does not produce particularly user-friendly interfaces and layout is really an afterthought.

Similarly, TDeX allows for interoperability of devices from different manufacturers; unlike DomoNet it does not host the UI’s for smart devices but instead serves out description files to interface devices like an Android smartphone. This approach reduces the system’s dependence on a central controller but, none the less, it is still dependent on the “M4HSD” service, which perpetuates the need for a Central Controller.

Others have considered describing graphical user interfaces (GUIs) from XML (Layouts, 2019; XUL, 2019; Thommes *et al.*, 2012) but no work has considered how a single schema could be used to include device capabilities to control devices.

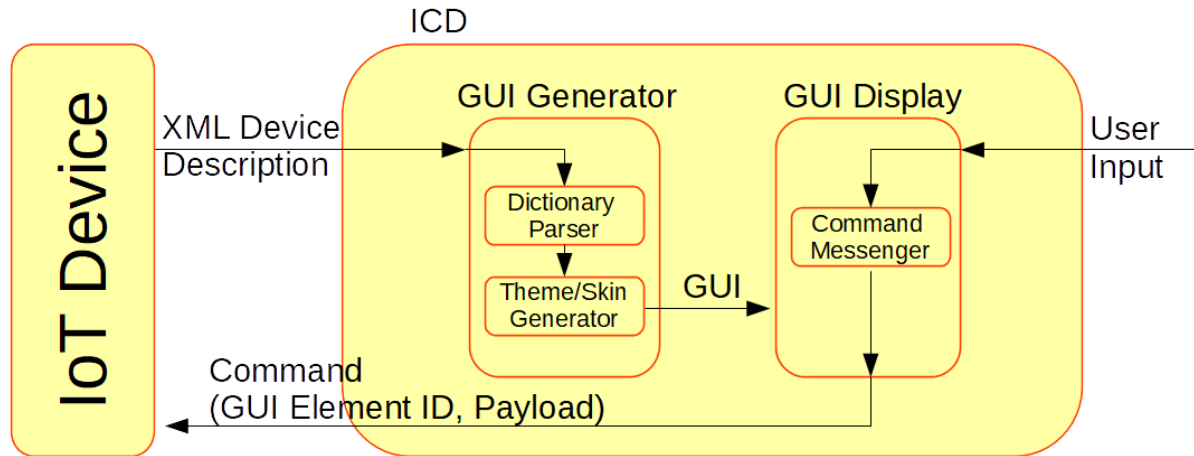
## Proposed Solution

As has been described, device description in one form or another is not a new idea, but no work to date has offered a solution that allows one description file to enable an ICD to display a device's status, present a layout for a control UI, and co-ordinate control commands. Our proposed solution achieves these key goals and also requires small and simple packets, and no dependence on a central controller. It is envisioned that this solution will become a standard for describing device capabilities and how to display and control devices but that multiple different applications might be developed to implement the standard, thus allowing customers to choose the implementation that works best for them. Manufacturers could also contribute applications that might be best suited to their devices but that would also connect with devices from other manufacturers.

Devices will be described by a minimalist XML device description stored on the IoT device that will allow open implementation of device interfaces while maintaining some control over the UI's layout and structure for manufacturers. This description will define all control and display elements that should be present in a UI for a device. When an ICD discovers a new IoT device on the network for the first time, it will receive the IoT device's description allowing the ICD to generate a UI based on the description.

ICDs will generate GUIs from the XML device descriptions using a local dictionary parser and a theme/skin generator, installed as part of the ICD app. The dictionary will be an open and public standard that defines what each element is and how it should be described, while the theme/skin generator will be an implementation-specific definition of how an element should appear. This is similar to the concept used in HTML where a web page uses the standard definitions to create a section of text that is "bold" but individual browsers will determine what bold actually looks like. This will allow different ICD developers to produce their own themes and skins that may choose alternative colour schemes or representations of elements — for example a toggle element may be represented as a switch or as a button changing colour — but the standard set of elements will allow manufacturers to control the essential layout and functionality of the GUI. (Manufacturers could produce their own themes/skin generators and apps).

Each element in a description will have an ID, which will allow a device's status data to be directed to the correct display elements. IDs will also be used when control elements are activated; the ICD will send a generic control message to the IoT device identifying the element's ID and any associated payload, thus allowing the ICD to remain agnostic as to the nature of the IoT device or the commands the user is sending. Thus, a description based largely around the UI layout will also cover device control and capabilities.



**Figure 1. Display and control protocol diagram**

The proposed protocol, summarised in Figure 1, uses an XML device description and requires all IoT devices to store this file and distribute it to ICDs as requested. ICDs can then use this description and run it through a dictionary to generate a GUI. Users can then interact with the GUI and requested actions will be sent back to the IoT devices as generic notifications, which can then be interpreted into the appropriate actions.

## The abstract description

The abstract XML, see Figure 2, defines individual UI elements and groups them based on how they should be displayed, and IDs are used to help add order to these groups. The ICD takes this definition and generates the appropriate UI, which will return any user interaction as a reference to the UI element ID and any relevant payload that the IoT device can interpret and act accordingly. Thus, the ICD can remain largely agnostic as to the nature and behaviour of any device, while still providing a user-friendly UI and the ability to control the device.

```

<device>
  <name> string </name>
  <location> string </location>

  <group permission = INT visibility = Bool
    frame = Bool orientation = Bool>
    <label> string </label>
    <gui_element> </gui_element>
    .
    .
  </group>

  <gui_element id = UNIQUE INT>
    <type>string from dictionary</type>
    <disp_settings>string</disp_settings>
    <status_location> INT </status_location>
    <comment> String </comment>
    <topic> String </topic>
  </gui_element>
</device>
  
```

**Figure 2. Abstract XML device description**

The XML device description does not include any status variable or values, as these are requested later in a separate status update packet. This allows a distinction to be made

between regularly changing values and immutable or less variable values, which reduces packet sizes and therefore airtime, which is crucial in the highly contested 2.4 GHz Wi-Fi space ([den Hartog et al., 2017](#)). (Though 5 GHz or Ethernet may alleviate this issue, they each come with their own limitations. For example, 5 GHz is still not as common and has less range than 2.4 GHz and Ethernet is less flexible, needing the cable to be installed.) These update packets are ordered (comma separated) and can be decoded in order to update the relevant UI elements. Again, all the specificity of the IoT device is handled by the device itself, while the ICD merely acts based on its definitions of each element; thus no data types are defined by the XML as the definition of each element is standard and thus the data type is implied.

The <device> tag bounds the full description of a device. Devices will also have a name and location specified, using the corresponding tags. These tags will be populated based on how users assign names and rooms/areas to devices. This will allow the device to be easily identified by users and be grouped by rooms or areas. The user experience will therefore be improved as all devices used in the Kitchen, for example, could appear under a heading “Kitchen” as these interfaces will likely be used together, while the user is in that room.

The <group> tag is used to collect <gui\_elements>, which correspond to individual elements of the display, and ensure that they are displayed together for increased usability. Groups have permission attributes to allow for different XML descriptions to be generated from a master file to control read/write permissions. The remaining group attributes control layout settings, for example if a group relates to advanced settings and should be hidden by default or if the collection of elements should be bound by a frame and stacked horizontally or vertically.

Each <gui\_element> has a unique id attribute for identification and then the <type> tag selects the element type from a predefined dictionary standard, e.g. Button, Toggle, Textbox or Radio. The <disp\_settings> tag primarily supplies a label to the elements for human readability, but also includes any other details (using comma separation) for display settings, like the limits of a slider’s range or the maximum number of characters for a text field.

The <status\_location> tag specifies the position, in a status update packet, of any data to be displayed by this element, while the <comment> tag specifies a help message or prompts for users and the <topic> tag identifies that corresponding status value as a variable of potential interest to other devices, allowing for M2M functionality.

The abstract XML in Figure 2 could be used to describe any device and could specify any gui\_elements but, in working towards a public standard, a dictionary of known gui\_elements would be available. Manufacturers could be certified as compliant with the standard by using only gui\_elements as described in the public dictionary. Likewise, certified applications for

ICDs would need to be capable of appropriately handling all specified dictionary `gui_elements`.

## Method

In order to assess how comprehensive this abstract XML is and how easy it is to work with, two developers with experience in Android, iOS and web development were asked to use the abstract XML to develop UIs for 10 IoT smart home devices:

1. Wireless Speaker;
2. Security Camera;
3. Thermostat;
4. Light Globe;
5. Mains switch;
6. Oven;
7. Television;
8. Garage door;
9. Kettle;
10. Curtains/blinds.

From these UIs a list of unique UI elements was compiled, and the developers assessed the viability of properly implementing each element from the XML abstract and provided feedback. After changes were made to the abstract XML from the developers' feedback, two instances of the XML were implemented to generate full UIs for two of the example devices considered.

## Refinement

The developers identified 12 unique elements that were required to comprehensively implement convenient user interfaces for the 10 devices considered. In considering the implementation of these interfaces, the developers' feedback highlighted the need to add the orientation attribute to the group tag to give better control of the layout in groups. It was also suggested that the scope of the `<disp_settings>` tag be expanded from a simple label to include more details that vary between GUI elements, such as ranges for sliders and details for drop-down menus. These changes were integrated as discussed above.

The 12 unique elements identified are summarised in Table 1. Several of these elements have been chosen to offer very specific functions, such as a password field shown in Figure 3 and Figure 4, while others have been kept as general as possible to maximise usage. A good example of maximum used usage is the button Group, shown in Figure 5 and Figure 6, which

is a 2-D array of buttons which can also be used to generate a single button (1x1) as well as a row or column of buttons.

**Table 1. Essential GUI elements with description**

| Element             | Description                                                                                                 |
|---------------------|-------------------------------------------------------------------------------------------------------------|
| Switch Toggle       | A two-state element                                                                                         |
| Button Toggle       | A two-state button                                                                                          |
| Plus-minus Button   | A pair of buttons for increment/decrement functions                                                         |
| Button Group        | A 2-D array of buttons, including 1-by-1.                                                                   |
| Directional Buttons | Four buttons arranged for directional inputs e.g. N, S, E, W; or up, down, left, right                      |
| Drop-down selection | Element to select one option from a list.                                                                   |
| Range Input         | Element for numeric value selection using a sliding bar.                                                    |
| Status/Label        | Text String                                                                                                 |
| Progress            | Element to visualize progress                                                                               |
| Scheduler           | Collection of elements used to schedule events, includes a list of events to select and a date/time picker. |
| Text Input          | Text input field                                                                                            |
| Password            | Text input field which hides input.                                                                         |

```

<group id="1" permission="WR">
  <gui_element id="1">
    <type>password</type>
    <disp_settings>Password,
      Submit</disp_settings>
    <status_location>1</status_location>
    <comment>Enter your password</comment>
  </gui_element>
</group>

```

**Figure 3. Example XML instance for a password entry field**

**Figure 4. UI-generated password field using XML in Figure 3**

```

<group id="1" permission="WR">
  <gui_element id="1">
    <type>buttongroup</type>
    <disp_settings>Numpad,1,2,3,4</disp_settings>
    <status_location>1</status_location>
    <comment>Numpad</comment>
  </gui_element>
</group>

```

Figure 5. Example XML instance for a row of 4 buttons

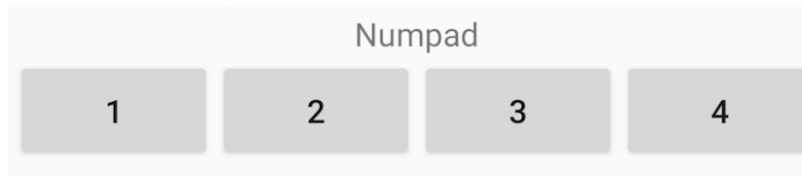


Figure 6. UI-generated row of 4 buttons using XML in Figure 5

## Implementation

To support this novel protocol, applications have been developed to run on smartphones under Android and iOS, as well as a cross-platform electron application for desktops, laptops and tablets running Windows, Mac and Linux (Steane *et al.*, 2019). All these applications are supported by libraries that allow an abstract XML file from an IoT device to be read and run through the elements dictionary and generate a fully functional UI that can display the current state of a device and send commands to control the device. All 12 elements identified by the developers have been successfully integrated into these libraries.

The full functionality of this simple abstract definition is demonstrated in the fully functional UIs it can generate. Two fully implemented XML abstract files from the developers were used by the Android application to implement a Thermostat UI, Figure 7, and a Security Camera UI, Figure 8.

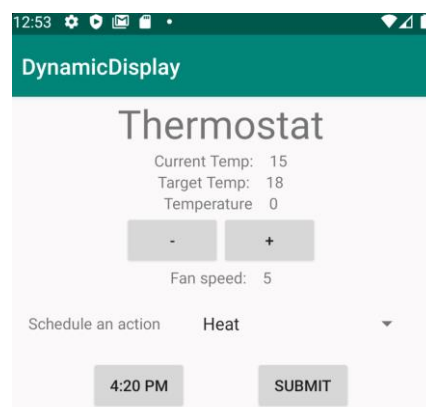


Figure 7. Example of a Thermostat UI generated from an XML device description

Figures 7 and 8 demonstrate the capabilities of the proposed simple XML abstract to develop intuitive and user-friendly interfaces without the need for a central controller.



As has been mentioned, the 2.4 GHz Wi-Fi space is highly contested in the home environment and so minimised airtime is crucial to both minimise usage of this space and to maximise successful usage. The protocol proposed already minimises the impact of transmissions by limiting them to one-off communications when an ICD first discovers a new device. The XML device descriptions further minimise this impact by using the simple and concise XML Abstract, as presented. The UIs in Figure 7 and Figure 8 both have file sizes under 2 KB; and this is with a human-readable form that could be surrendered for a more lightweight machine-readable form to further reduce airtime.

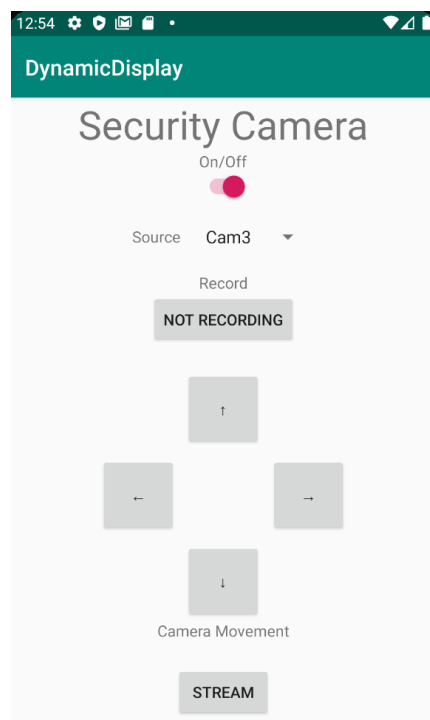


Figure 8. Example security camera UI generated from an XML device description

## Analysis and Comparison

Our proposed solution offers an approach that would ensure interoperability from all complying manufacturers and control all devices from a single application. Table 2 shows a comparison of the protocol proposed in this paper and the single product or small product range systems available today from Philips ([Meethue, 2019](#)), Belkin ([WEMO, 2019](#)) and Nest ([Nest & Google—The best of Google. The best of Nest., 2019](#)). It compares the application size as shown on the Android Play Store for a Pixel 3 (app sizes can vary from device to device), the opensource nature of the application and protocols, manufacturer independence for interoperability, OS independence of the application for interfacing with products and, finally, any dependence on a central controller.

**Table 2. Comparison of Home Automation products with proposed system**

| System          | App Size (MB) | Open Source | Manufacturer Independent | OS Independent                     | PCC Dependent |
|-----------------|---------------|-------------|--------------------------|------------------------------------|---------------|
| DHAP            | 2.13          | Yes         | Yes                      | Yes                                | No            |
| Philips Hue     | 20.36         | No          | Limited                  | Custom App per Platform (No Linux) | Yes           |
| Belkin WeMo     | 39.37         | No          | Limited                  | Mobile OS only                     | No            |
| Nest Thermostat | 56.42         | No          | Limited                  | Mobile OS + Web App                | No            |

Application size is of most significance if multiple applications are being installed and, while all the applications considered are minimal in comparison to the typical availability of memory on smartphones, it is evident that DHAP has a much smaller size owing to the fact that much of the UI is generated after install and with the addition of XML files from the smart device itself.

Manufacturer independence is the key to interoperability and, while DHAP is designed to completely satisfy this criterion, the other systems are not truly independent but do allow for some interoperability with other devices via a voice assistant or some other negotiated arrangement, all of which require custom integration. Notably, the Nest thermostat is widely compatible with a variety of heating and cooling systems, but this is not the same as interoperability where a smart device is cooperating with another. For example, the Belkin WeMo smart switches controlling power to a lamp, a TV or a radio are not exhibiting interoperability.

Compatibility with different Operating Systems is important for accessibility and market uptake ([Steane & Radcliffe, 2017a](#)). This paper has demonstrated the accessibility of the DHAP application on Android, iOS and major desktop OSs including Mac, Linux and Windows thanks to the Electron cross-platform application. The other systems considered have all identified the importance of the mobile Operating Systems but have largely neglected the desktop systems. Philips has covered Windows and Mac but with custom applications which would introduce a heavy development burden, while the Nest thermostat offers a web app for cross-platform access at a reduced development burden, much like the electron app.

Finally, dependence on a Permanent Central Controller (PCC) is a key question, and most of the manufacturers offer some way around using a PCC. However, as has been discussed, this has come at the cost of interoperability. So, while Philips Hue still requires a central controller to bridge Wi-Fi and ZigBee protocols, WeMo and Nest, like DHAP, can operate without a central controller in some configurations.

DHAP shows real promise to provide a universal protocol to connect smart devices in the home. The union of display, status and control provides an application that is small but allows

devices from any compliant manufacturer to connect and be controlled from the one application. DHAP allows cross-platform access and is not dependent on a central controller in any configuration.

## Future Work

The current state of the DHAP protocol allows many devices from many and any compliant manufacturer to be joined to and discovered on a Wi-Fi network, and now to be viewed and controlled from a single application. This gives the protocol a reasonable level of completeness. Current work is finalising the full integration of all these features into one library for easy development of HAS devices independent of a PCC.

Further work should consider the ability of the proposed abstract XML file to allow M2M communications in which an IoT device may be able to communicate to another IoT device as configured by an ICD using information from the abstract XML files.

Finally, this paper has not considered in great detail the many aspects of security that need to be addressed, not just in home automation but in IoT systems generally. This is an important area worthy of careful consideration and should be the subject of a future paper.

## Conclusion

This work has demonstrated that a single application on an Intermittent Control Device (ICD), such as a smart phone, can provide a functional User Interface (UI) for devices from any manufacturer. Recent work has made this protocol open and freely available ([Steane \*et al.\*, 2019](#)).

This novel protocol allows manufacturers to compactly and easily describe the capabilities, control procedures, and UI layouts of their devices in a single XML file, which they embed in their devices, using the novel abstract XML proposed. This allows manufacturers to retain influence over the UI, in its structure, layout and elements — and therefore user experience — without having to maintain custom applications or cloud services.

The novel protocol allows users to easily display and control many home IoT devices from many manufacturers using a single application, without dependence on a permanent central controller or an Internet connection. This allows users to more easily construct their own home automation system, at more competitive prices, and have the ability to select the best device with the best features for their use case.

The abstract XML file proposed in this protocol is a single compact file that describes a device's capabilities, how it can be controlled, and how it should be displayed to users. The combination of all these tasks in a single XML abstract is a novel and powerful approach.

A simple abstract XML description and dictionary has been presented. It has been proven to allow IoT developers to create XML device descriptions of complex IoT devices which can automatically generate fully functional UIs on ICDs.

The abstract XML and supporting protocol presented will allow plug-and-play integration of many IoT devices from various manufacturers. Together, these will all be accessible from one application on smartphones, tablets or PCs and will eliminate completely any dependence on a Permanent Central Controller (PCC) for home automation systems.

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# Synchronous Reality: Enhancing Sensory Perception in Immersive VR

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**Abstract:** This paper introduces the concept of Synchronous Reality whereby a combined sensory physical and virtual installation is created. The research is presented examining how the practice work evolved to establish the concepts which make up a Synchronous Reality installation. The research ultimately focused on creating a sensory landscape to complement the virtual layer of the installation, thus making a coherent whole which encompasses Synchronous Reality. The findings and conclusions indicate that this type of installation can increase the immersive quality and presence for the participant. The important considerations when making such an installation are also presented. The paper also touches upon a brief examination of the wider issues of how immersive virtual reality affects the digital economy and telecommunications.

**Keywords:** Synchronous Reality, Virtual Reality, Sensory input, Immersion, Presence.

## Introduction

In 2019, this researcher completed a practice-based Doctoral thesis at the Auckland University of Technology (Bailey, 2020). This paper is intended to present some of the key findings from that research, which could be useful to practitioners and others working or researching in the field of Virtual Reality (VR). The research centred primarily upon placing participants into immersive installations which combined sensory-based physical and virtual components which might then, in turn, elicit sensory recollections. The installations became a focus of visual, aural, olfactory and other perceptions which would attempt to evoke certain emotive responses to the reconstruction of a place from the researcher's past in the form of a composite memory. The term "Synchronous Reality" was developed during the research in order to adequately describe an installation which created a coincidence of physical sensory information with that of the virtual environment. For example, physical elements such as the seats of the major practice work Caravan (a virtual reconstruction of this researcher's live-in caravan) were 'synchronised' with the virtual seats so that a participant could sit, feel the 'give'

of the squabs, and experience the kinaesthetic positioning of the body. The research drew upon Mark Hansen (2006) who sees the body as the primary vehicle of sensory experience in a virtual installation. It was with this objective that the body itself was used to channel physical sensations through such components, for example, as objects which could be touched, or sounds which could be heard, in conjunction with the visual cues provided within the virtual environment itself. Participant feedback and observation indicated the Synchronous Reality environment enhanced the immersive quality and presence within the installation for the participants.

## Review of Literature

The review of literature for the study focused on the philosophical underpinning of the work, and research which was particularly relevant to immersive VR and sensory input. Gaston Bachelard's *The Poetics of Space* (1994) became central to the work in terms of orienting it through the senses, particularly his discussion of memory and how a space can trigger recollections which can engender a feeling of intimacy with the space. Bachelard implies that a reader's attention goes from the room they are reading about to the memory of a room of their own when he says: "The values of intimacy are so absorbing that the reader has ceased to read your room: he sees his own again" (Bachelard, 1994, p. 14). The research asked if this same type of engagement could be possible within an immersive VR environment and the subsequent findings from the qualitative interviews suggested it was. The project also focussed on the virtuality of the mind drawing parallels with a Virtual Space.

Bergson (1988) argues that a memory, daydream or mind perception could be suggested as virtual, which engendered the idea to use memory as a vehicle for the practice work. He suggests that the mind simplifies matter into a virtual representation, a superficial skin (1988, pp. 5-6). This is not unlike a virtual environment which paints textures onto hollow three-dimensional models. Thus, the creation of a memory in virtual space was something akin to the way, according to Bergson, the mind would perceive it. Massumi (2002) proposed the idea of a connection between a sensation and its articulation as an emotion or feeling. The sensation, Massumi says, is not immediately articulated, and may never be (Massumi, 2002, p. 28). However, sensation is needed for emotional response, they are co-conspirators in the production of an affect or emotional response. As the practice work progressed, there was more focus on putting sensation at the forefront of the work with the aim of eliciting certain emotional responses in the participant.

Bringing the philosophical terrain to the virtual one ultimately involved the creation of a combined virtual and physical space where a memory would be reconstructed as a virtual/physical installation and a participant could experience it. The two important factors



to the success of a virtual environment are immersion and presence. It is not enough to simply fulfil the first by dint of using immersive technology, there are certain aspects which will ensure the feeling of immersion itself. Murray refers to the concept of virtual immersion as being similar to that of being immersed in water ([Murray, 1997](#), p. 99). Slater more clearly explains it as preserving 'fidelity' to the real-world senses where the immersive quality is dependent on this factor ([Slater, 2003](#), p. 1). He goes on to contend that presence, noted by Skarbez ([2017](#)) as 'being there', is the reaction to immersion. The two being connected, one could assume greater immersion gives a greater feeling of presence. Slater also says that, due to the activation of different sensory perceptions (perceptual, vestibular, proprioceptive and autonomic), the immersed individual will react as if it was a real-life situation. Thus overall, a focus on the sensory aspects of a virtual installation should increase the level of immersion and consequent feeling of presence. Given Hansen's assertion that the body is the primary access to the world ([Hansen, 2006](#), p. 5), the more sensation a participant receives through their body, the more they are likely to feel part of the virtual environment they are immersed in. The practice work continued to develop its sensory aspects over the course of the research.

A number of researchers have examined particular aspects of sensory stimulus in VR. Anatol Lecuyer ([2017](#)) speaks of a conflict between the real world and a virtual world where the real-world senses are not supplied. He notes that a psychological or behavioural reaction can be elicited where this conflict is resolved by supplying a strong sensory and immersive experience in the virtual environment ([Lecuyer, 2017](#), p. 20). Whitelaw ([2012](#)) argues in favour of an aesthetic aural experience where moments of intensity or otherwise fleeting or more visceral feelings might be engaged in the listener. Indeed, the Proust Effect is well-founded in the work of Marcel Proust ([1992](#)) where sensations gradually evoke memories, which become more distinct over time, and exposure to those particular sensations. Proske and Gandevia ([2012](#)) offer the idea that proprioception of the body, being those muscular sensations providing information on position and bodily movement, assists in orienting the body to the virtual environment and enhances the feeling of immersion. Mine ([1997](#)) indicates that where an actual object in VR is located coincident to the user's hand position, they would also acquire a sense of the position of the object. If physical elements are also located corresponding to virtual ones in the installation, this should result in increasing the proprioceptive sense of position. Lecuyer ([2017](#)) further argues that interruptions to the feeling of 'being there' may be more common where a noticeable disparity is evident between the physical and virtual elements of a simulation; the corollary being that a more seamless coincidence of these elements should give a more fluent and uninterrupted immersive experience. Then, examining sound, Larsson, Våljamäe, Västfjäll, Tajadura-Jiménez and Kleiner ([2009](#)) investigated the effect on presence using aural input in mixed-reality environments. Their conclusion is that

“while a visual scene – real or virtual – may be completely static, sound is by nature constantly ongoing and ‘alive’; it tells us that something is happening” (Larsson *et al.*, 2009, p. 225). Nordhal and Nilsson (2014) assert that sensory feedback should be presented in a way that mimics the real world. They argue the credibility of the virtual world increases if the participant is surrounded by aural stimulation, much as one is in the normal physical environment we inhabit. Munyan *et al.* (2016) concluded in an examination of factors increasing presence that olfactory stimulus is one of them. The common theme of such research appears to be that sensory components are an important part of immersive content and improve the factor of presence.

Using immersive technology centred around the HTC Vive, as the most suitable technology available to the project at the time of its commencement, the research project proceeded through a number of phases to develop the concept of a Synchronous Reality. The philosophical framework helped to shape the focus of the work towards place and memory as a way of examining emotional response to the created installations. The literature guided the practice towards an increasingly sensory-based platform which contributed to combining physical and virtual components as part of the same installation. The results from the study provide material for further work by artists in the field and other practitioners within VR.

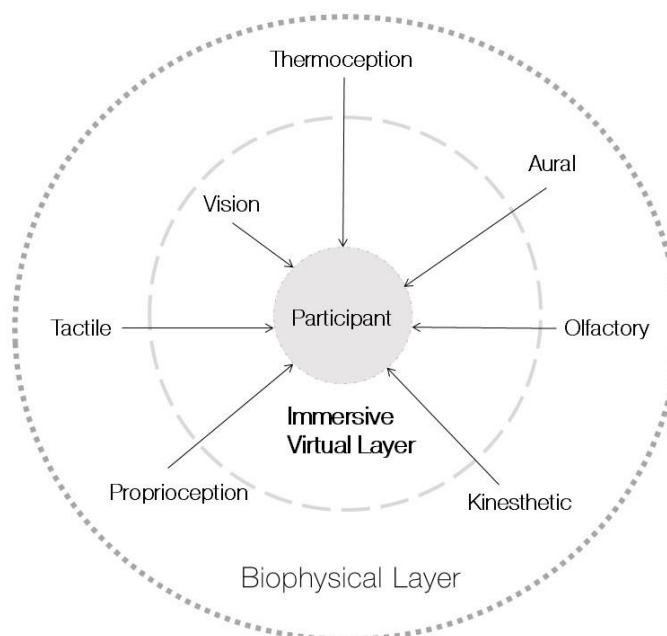
## Synchronous Reality

This term emerged through the Doctoral research project. Other terms used to describe Virtual Reality environments including Mixed and Augmented Reality, did not sufficiently define how the installations created through the practice functioned. This new term was offered as a better and more appropriate articulation of what was actually being done. The word ‘synchronous’ is defined by the *English Oxford Living Dictionaries* (2019), as “to occur at the same time or rate” and derives from the mid-seventeenth century late Latin *synchronous* (from Greek *sunkhronos*, from *sun* ‘together’ and *khronos* ‘time’). A companion word ‘synchronise’ also means to “agree with something else” or “coordinate; combine” and derives from the Greek *synchronízein*, to be contemporary with. The term Synchronous Reality thus describes the co-ordination of the physical environment with the virtual one. This doesn’t imply they mimic each other precisely, but that instead they are in agreement, or have a form of mutual coherence.

There is also a temporal element to Synchronous Reality. Time passing in the installations is conveyed by the passage of light and does not necessarily relate to ‘real time’ in the physical world or an inner sense of time. In the installation, eight minutes may mark the passing of an entire day, which in the ‘real world’ would amount to twenty-four hours. The participant encounters time at a different rhythm to normal, as Bergson confirms — “The duration lived

by our consciousness is a duration with its own determined rhythm” ([Bergson, 1988](#), p. 205) — while Digital media researcher Timothy Scott Barker ([2012](#)) suggests that we place ourselves between the time in the present and the aesthetic images and processes of the past with digital artworks. This makes an intersection between the memory of what was and what is. A Synchronous Reality can have a time of its own which, although it might run counter to accepted real-time, is nevertheless acceptable to the participant when immersed in the installation.

The following diagram attempts to represent a Synchronous Reality as the combination of the virtual computer simulation and biophysical environments as an immersive whole. It is not a binary either/or, but rather a combined sensory-driven environment. The diagram is a simplified depiction which at the same time suggests the difficulty of the endeavour of describing how the multiple conditions of Synchronous Reality operate in an installation.



**Figure 1. Multiple sensory modes in a Synchronous Reality installation where both the simulation and our biophysical reality are equally ‘real’.**

## Research Methodology and Practice Work

The research was conducted within a practice-oriented paradigm with, as noted by Skains ([2018](#)), an element of experimentation which is inherent in any medium where work is created. It was also subject to imaginative and yet robust enquiry ([Sullivan, 2006](#)) through the use of interviews and observation of participants in the work. The primary methodology was ‘autoethnography’ which as per Adams ([2015](#)) facilitates personal experience to engage an examination of ourselves and other people in various facets. From this, we can gain a perspective on perhaps wider experience than our own. Since this researcher’s personal

memories formed the subject matter of the practice work, autoethnography was a suitable choice.

The particular final vehicle for the practice-led installations was the recreation of a caravan in which this researcher had once lived for a number of years on an isolated campsite in Yorkshire. The development of the Caravan installation through a number of iterations evolved into a tight registration between its physical and virtual elements, which formed the *raison d'être* of the created term Synchronous Reality. The installation focused upon the qualities of sensory and imaginative immersion as noted by Ermi and Mayra (2005), as opposed to being challenge based. It was designed as an experience where the participant was not required to 'do' anything in particular, other than enjoy or partake of its perceptive qualities. The installation developed further through participant feedback to become one where quietude and solitude could be felt.

Installations of the work Caravan were exhibited in gallery spaces at the Auckland University of Technology, where participants and audience were invited to experience it on an individual basis. The final exhibition took place in a theatrical 'black box' to emphasise the aesthetic qualities of the physical parts, using focused lighting in an otherwise darkened room. The physical and sensory aspects of the caravan consisted of the benches, squabs, one side of the caravan, the kitchen unit, toaster, mug and kettle. Aural sensory input was supplied by a recorded and created soundscape of ambient bird and other incidental sounds. Olfactory input was supplied by toasting 'cinnamon muffins' in a toaster, and the thermoceptive sensation of the sun rising was produced by a two-kilowatt spotlight strategically placed, which was manually activated in synchronisation with the virtual sun rising. Other incidental smells noted by participants included such odours as the varnish on the woodwork of the benches. The virtual caravan and accompanying landscape was effectively another sensory visual layer which was registered with the physical components in the space. The participant could only see the virtual environment once they had donned the HMD (Head Mounted Display). However, because of the Synchronous Reality, the physical elements corresponding to parts of the virtual environment would still be present. Thus, when a participant saw a seat, they would be able to sit on it in the exact place they could see it in the virtual environment. Similarly, they could touch other virtual/physical objects such as the caravan side, toaster, mug and kettle. There was a high degree of tactile 'feel' supplied by the physical parts to correlate with what the participant could see once immersed in the virtual component. In addition, the ambient soundtrack provided auditory sensory information, with olfactory and thermoceptive sensory input as described. Each one of these components helped to build a more complete immersive environment for the participant.



**Figure 2.** Bailey, D. (2018). First iteration of *Caravan* installation, July 2018. [Photograph].

The virtual world was scripted with a repeating day/night cycle, and animated creatures: birds, a cat, an owl, sheep and a fox. These animations served to assist in bringing the installation to life. The participant could witness the sunrise, the movement across the sky, the sunset, followed by moonrise and moonset. The light quality and colour changed according to the time of day, and the shadows cast by the sun and the moon moved with the motion of those objects. The repeating sun/moon cycle ran for eight minutes. During this time the participant could experience all of the sensory input connected either directly or indirectly to what they could see virtually. Participants were given the opportunity to remain in the installation for one or more cycles.

## Findings

Fifteen participants engaged in the qualitative research where they had experienced the caravan installation alone with the researcher as an observer. Each participant was individually interviewed afterwards. Two iterations of the Caravan were used for data gathering, the second including more physical components than the first. The feedback gained from participants guided the enhancements to the installation. The final exhibition was convened for the purpose of PhD examination. A further exhibition was held in conjunction with the School of Clinical Sciences at the North Campus of AUT for their academic staff. Thirty-one staff members individually experienced this exhibition at the North Campus, which provided some further interesting observational points.



Figure 3. Bailey, D. (2018). Caravan, Iteration Two. Participant seated in the interior. [Photograph].

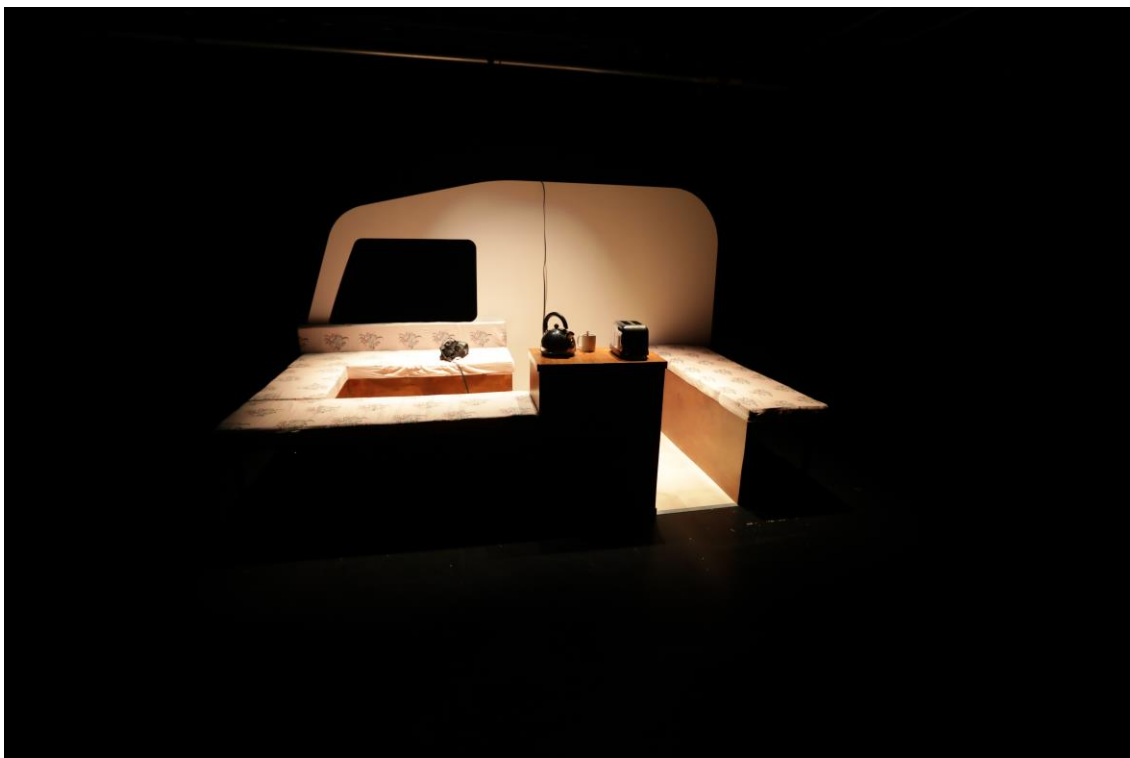


Figure 4. Bailey, D. (2019). Caravan, Iteration Three. Installation in the Black Box AUT [Photograph].





**Figure 5. Bailey, D. (2019). Caravan Reverie. Exhibition at AUT North Shore Campus, School of Clinical Sciences [Photograph].**

Participants were typically observed to have exhibited two types of behaviour within the installation. The first could be termed an active or exploratory phase. At this juncture, they were seen to be examining or testing the limits of the environment, touching physical components and looking out through the windows or even exiting the caravan to view the exterior virtual world. Following the active phase, there came a phase, which was usually much longer, of absorption. The participant would simply sit or remain in one place for a longer period, looking and listening. Typically, at this point participants would note they also engaged or connected with their own memories of similar spaces or places as a result. As mentioned, this was the point of intimacy with the installation where they overlaid something of themselves into the space. In the North Campus Exhibition, many remained in the installation for up to thirty minutes without prompting and through several day/night cycles of the virtual world.

The immersive quality and factors of presence in the caravan installation were found to be high by observation and from feedback. Comments such as these were typical of those received:

It felt so real. I really felt like I'm in the space (P.M., Caravan Iteration One, 2018).

Completely immersed. Completely forget the fact that I was not there (A.T., Caravan Iteration Two, 2018).





**Figure 6. Bailey, D. (2018). Caravan, Iteration Two. Participant relaxing in the installation. [Photograph].**

Observed behaviour such as attempting to squeeze through the small opening made by the half-closed caravan door indicated the achievement of the ‘illusion of nonmediation’ (Lombard & Ditton, 1997, p. 32). Lombard and Ditton state this illusion of nonmediation is achieved when the person responds to the virtual environment as if it was the real world. Furthermore, participants also articulated their thoughts in terms of feeling deeply immersed or feeling as if they were ‘really there’ during interviews. The Synchronous Reality aspect of the installation was also a contributing factor to its immersive quality. Some participants noted a high level of trust in the virtual environment due to the presence of the physical benches similar to the trust placed in their normal everyday environment. For example:

So, as long as I knew that I was navigating around the seats, I was okay. And they were kind of my safe haven where I knew that they were solid. So, I could navigate around them in the virtual space...Yep, I completely trusted them. (A.G., Caravan Iteration Two, 2018)

Conversely, participants were observed to have forgotten which parts were really there and were seen attempting to touch things not physically present, again an indication of their high level of environmental acceptance. An example of this immersion level was observed when the mobile phone of one participant rang and they attempted to answer it with the headset on:

I felt so natural with myself and the environment. So, first of all, I forget about the fact that I’m not seeing my body...I felt completely natural and my phone rang and, “Let

me check my phone”, and I grabbed my phone out. I just remembered, “Okay. I can’t see it,” because it’s in real mode. (A.T., Caravan Iteration Two, 2018)

The contemplative quality of the installation also provided a space for the participant’s own recollections. Most of those interviewed indicated they had recalled either experiences of their own in caravans or at least places which were similar in content to the installation. One of the aims of the work was to foster an atmosphere which would allow this. The fact that participants became part of the space and accepted it as real is attributable certainly in a large part to the created Synchronous Reality. The recollections were often quite detailed:

My parents had a similar caravan...It was sort of a retro caravan that they bought second hand in New Zealand and travelled around for many years [in] it and I came along with them...I had a flashback to when we stayed in a particular campsite in, I think it was, Coromandel...This also reminded me of another campsite...It was a very deserted one by Invercargill...was very sort of lonely and wild kind of, and there were sheep somewhere, and it was misty, and it was very cold. (S.S., Caravan Iteration Two, 2018)

I’ve got a friend [who] used to have a little cute, little yellow caravan, like one of those really old-fashioned ones. And she’s just now gone away and she’s living in a van. It’s quite open but it reminded me of that. It reminded me of going away in her caravan. And the other thing was the scene where it was parked. Yeah, it was kind of memories of being in the country and having birds around and being quite peaceful, yeah. (E.C., Caravan, Iteration Two, 2018)



**Figure 7. Bailey, D. (2018), Caravan, Iteration One with participant. [Still from Video].**

Overall participants liked the calmness and quietude of the space. It provided an immediate location for contemplation. In its simplicity, it was, a place to just be and assume, perhaps, a

more reflective state of mind. It is useful to note that, even from such a small cadre of participants, thirteen of the participants (87%) gave one or more of the following words or variations when relating their experience: calm, relaxed, safe, cosy, peaceful. Calm and peaceful were found to be the most common words, given by half the participants. Other words included exciting, melancholic, pensive, solitude, alone, lonely, isolated, moody, curious, eerie, creepy, and intimate. One of the aims of the practice work was to create a space of calm contemplative solitude, and the results indicated this was successful.



**Figure 8.** Bailey, D. (2018). *Caravan, Iteration Two*, virtual interior showing part of landscape, with participant. [Still from Video].

Achieving a high degree of confidence in the installation and environment is evidently key to also gaining a high level of immersion and presence. This allows the participant to then take in the emotive content and qualities of the installation itself. Although no specific comparison was made with an environment which was wholly virtual, it can nevertheless be said that the Synchronous Reality environment seems to have been a major factor, based upon the qualitative research. One can, therefore, conclude that a VR type of environment is inherently more immersive when physical sensory inputs are combined with the virtual landscape, creating a coherent merging of the physical and virtual layers as in a Synchronous Reality.

## Analysis and Discussion

The creation of a Synchronous Reality environment relies on a number of factors and considerations to be taken into account when planning or building such an installation. This type of installation is obviously not suitable for all types of VR content or applications. One constraint is the fact that physical objects and virtual objects need to be coherent and thus inherently tied together. The ability to move freely through the virtual space is thus restricted by the size of the physical space which can be made. The virtual layer which sits over the

physical layer is not moveable once it has been properly registered with the physical components.

When considering a Synchronous Reality installation, there are fundamental choices to be made as to what physical components to put in and what to leave out. This can be a logical and an artistic choice. With the caravan, for example, participants strongly indicated that sitting down was something they desired in the space. It was also logical, since the positioning of the windows meant that it was easier to see out of them when seated, just as in an actual physical caravan. Beyond that, it was an artistic choice to install only one physical side of the caravan suggesting the physical shape, and the lino on the floor, or the kitchen bench with items. These were placed there for physical context and also to provide a more authentic tactile experience. The participant reaction to the objects in the space cannot always be anticipated and one might contend this is part of the experiment. The squabs on the benches supplied the feel of ‘give’ when sat on and fulfilled that expectation when they were viewed virtually. It wasn’t necessary to visually show the ‘give’ in the virtual component since the participant simply accepted it without needing to see it happening. The same level of acceptance is supplied by the registration. It is not necessary to have pinpoint registration of virtual and physical objects, such as seating; also it is not always achievable with the technology being used. However, there is a point of leeway beyond which the immersion will be broken if the physical objects are not close to being in the right place. There is no hard rule for this, and the determination of the acceptable distance can be discovered during the process of registering the virtual layer to the physical layer.



**Figure 9. Bailey, D. (2018). Caravan, Iteration Two showing virtual interior. [Still from Video].**



Figure 10. Bailey, D. (2019). Caravan, Iteration Three. Interior of caravan with sun rising. [Still from video].



Figure 11. Bailey, D. (2019). Caravan, Iteration Three. Participant in Installation in the Black Box AUT [Photograph].

The siting of the physical installation is also an important point. Different settings for Caravan were tried, in a gallery and in a more theatrical (black box) type of space with theatrical lighting. The gallery setting had limited lighting control and thus it was harder to create an atmosphere prior to the participant putting on a headset. The theatrical setting allowed for much more controlled and intimate lighting. The darkness contributed to that sense of intimacy and meant that the virtual layer acted almost like a reveal when the headset was put on. For participants, the setting and the appearance of the physical ‘set’ was important. It created an expectation and anticipation of something more. It was particularly noticeable in



the North Shore exhibition that putting on the headset was often greeted with surprise. Sixty-eight percent of these attendees had never experienced VR before, which could also be a factor in the 'surprise' they felt on viewing the virtual environment. When creating a Synchronous Reality environment, the setting of the installation is an important part of the decision-making and should be given sufficient attention.



**Figure 12. Bailey, D. (2019). Caravan, Iteration Three. Participant in Installation in the Black Box AUT. Rear console, and 2000 KW Spot for thermoception sun effect [Photograph].**

A soundscape is of prime importance for Synchronous Reality. This contributes to bringing the scene alive. Sounds don't necessarily have to register directly with objects in the scene, although they can. The sounds may be ambient, or they may relate directly to, for example, an animal such as a sheep. The inclusion of music would change the atmosphere and careful thought needs to be put into whether this would be beneficial. Further types of sensory input are desirable, where possible, and creating them in a physical form rather than simulating them is to be recommended. The aim of the Caravan installation was that only the headset would be used and no affordances would be required. No controllers were used, which would have perhaps rendered it more 'game-like', and no other sensory simulators directly connected to the body. Thus, for example, heat was supplied by a lamp, smell by an actual smell of toast in real-time. There are many choices to be made in regard to such sensory additions, which are part of the formation of the installation and need careful consideration. What to include is dependent, in a large part, on what the intention of the installation is and what response is being sought from the participants.

Within the virtual environment, a number of decisions also need to be made. Animation of the environment in some form seems to be desirable. This can be accomplished by the inclusion of environmental movement such as wind, which then raises the consideration of whether to provide actual wind in the form of a fan. Temporality in the form of the passage of the sun and moon and shadows was a feature which participants liked. The accelerated time and movement of these objects seemed easily accepted. How fast or slow this temporal movement should be is another consideration for the artist or creator. Other types of animation can include animals, such as flying birds, or butterflies and insects. The relevance of such elements to the virtual scene can be important. The choice of textures and how realistic or otherwise these are, is also another aesthetic decision to make. The acceptance level of participants to the environment does not appear, by observation, to depend on the level of textural realism. The Caravan textures were realistic but not exact representations of real-world objects in all their detail. There was no feedback or specific mention on this aspect of the installation by participants, which indicates they accepted the reality level of the textures. How the virtual environment compares texturally to the physical is also important. The choice with Caravan was to create similar textural choices in the squabs, bench items and varnished wood of the seating for the virtual and physical parts. This provided artistic continuity. However, the physical components could equally have been left plain white as another choice, suggesting an overlay of colour and texture when in the virtual environment, as if one completes the other.

Attention to the above details and decision points is important to create a successful immersive Synchronous Reality installation. The artist or practitioner is bringing together a number of elements to create their installation where these choices are very much dependent upon their own objectives. It might be said there are no wrong choices, but the inclusion of certain elements is more beneficial to the installation. The physical tactile components and the soundscape are two of the most important parts beyond the virtual content and environment itself. One might state that these are the building blocks of Synchronous Reality. At this stage, all such endeavours are to some degree experimental since this is a relatively new concept in a burgeoning field.

## The Digital Economy

The support of virtual spaces in general by telecommunications is usually reserved for multi-user types of environment. Such applications as VR Chat have found a niche for this kind of application where multiple users can congregate within a virtual space. Those types of applications are wholly concerned with a virtual environment as opposed to a Synchronous Reality one. The applications, in general, rely upon a server to retain positional and other data related to all of the actors in the scene. As noted, the graphical interface is generally built on



the individual desktop of each participant in the environment. The idea of extending a Synchronous Reality installation in particular through the use of telecommunications is complex. The presence of the physical sensory components adds an overhead of replicating these at each location to be used. It would be entirely possible to have the graphic virtual component in a server-driven context, where the VR graphics are built at each location. The registration of physical components against virtual would be done on a location by location basis. The application of such a setup as a multi-location art piece is therefore possible. There are perhaps other fields where it also might be applicable, for example, where a fixed physical environment for simultaneous teaching across several locations may be required. These uses have yet to be determined.

The economics of virtual spaces is also a changing field. Much of this is due to the continual development of technology to facilitate VR in both the immersive and augmented form. The technology is moving from setups which require motion capture lighthouses, like the HTC Vive, to integrated self-tracking headsets, like the Oculus Quest. Only the HTC Vive was used for this research for reasons of continuity across developing installations, to reduce the financial investment and the overhead of reworking virtual environments. Different technologies would potentially change the way that virtual and physical environments can be registered together and it would be a matter of experiment to discover the best approaches. Nevertheless, in terms of cost, Synchronous Reality environments must factor in physical sensory components as well as the virtual ones. There is the cost of materials and building the physical installation, as well as a site for it, which may be either temporary or permanent. These types of installations are unlikely to be viewed as mainstream based on the constraints involved in creating them. Their impact on the digital economy as a whole is unlikely to be great compared to the overall use of virtual technology across the board. However, it is hoped the concepts behind Synchronous Reality and its further application for future research or installations will continue to help to push forward the boundaries of this field.

## Conclusions/Recommendations

There are potential applications for Synchronous Reality outside of the obvious artistic ones in the field of health and wellbeing. As an example, an installation such as the Caravan could be set up as an environment for contemplation. The depth of immersion and presence provided could help to transport a person away from daily life to a more relaxing or destressing environment. Clinical tests of such an environment are recommended since, if it was effective, then the cost of providing it to larger numbers of people is potentially lower than an actual arranged trip to the country and users can avail themselves of it whenever they like.

Synchronous Reality is also a field open to more explorative and experimental art using sensory physical environments. It might also have potential in such applications where particular emphasis is wanted on particular senses, such as mental health or disabilities. It is hoped that researchers, artists and practitioners will build on this research with experiments or projects to explore the concept of Synchronous Reality further.

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# Mobile Cellular Technology Forecast for the Indonesian Telecommunications Industry

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**Abstract:** Current mobile telecommunications deployment in Indonesia, based on 2G, 3G and 4G technologies, lags behind many other developing countries because of Indonesia's larger territory. This paper presents recent data on revenue growth (%) and the number of Base Transceiver Stations (BTSs) in Indonesia, divided among 2G, 3G and 4G technologies, and forecasts future revenue growth and numbers of BTSs for the next few years. The results show that, while revenue growth from 2G operation is decreasing and 4G deployment is significantly increasing, there are still significant revenues from 2G services and many 2G BTSs in operation at the end of the forecast period, making it difficult to shut down the 2G networks in the near future.

**Keywords:** Telecommunication, 2G, 3G, 4G, Comparison analysis

## Introduction

In Indonesia, the development of mobile telecommunications is growing rapidly because customers need cheaper prices and higher speeds of data transfer. To fulfil customer needs, investors in the mobile telecommunication industry invest in each new generation of technology. Second generation (2G) mobile technology is the oldest generation currently deployed. Customers of 2G are moving to 3G because of cheap prices and ease of content access in 3G technology: 3G technology uses data packets for internet access ([Charoenlap & Uthansakul, 2016](#)) and provides good connection speeds ([Becona et al., 2017](#)). The newer technology, 4G, also called Long-Term Evolution (LTE), gives even better connection speeds and so will become the primary choice for customers. The effect is that 4G technology is gaining lots of customers ([Ezhilarasan & Dinakaran, 2017](#)). Nevertheless, 2G and 3G

technologies are predicted to last for a long time because these technologies can support *machine-to-machine* (M2M) communication ([Labib, Marojevic & Reed, 2016](#)).

Today, mobile phone customers not only send messages (SMSs) via 2G technology but also use data services for sending messages with 3G and 4G technologies. To provide for this opportunity, every operator improves its 2G technology to 3G or 4G technology. The improvement impact of technology on revenue can be seen in Table 1. Below the table is further discussion of the revenue growth for each technology that is used by customers.

**Table 1. Revenue growth (%) at the end of a year from each technology in Indonesia ([Kominfo, 2017](#))**

| Technology           | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  |
|----------------------|-------|-------|-------|-------|-------|-------|
| Voice (2G)           | 45.43 | 43.15 | 37.43 | 35.64 | 33.78 | 31.52 |
| SMS (2G)             | 17.46 | 16.69 | 15.45 | 14.05 | 12.33 | 9.58  |
| Data and VAS (3G/4G) | 11.86 | 14.52 | 18.92 | 23.90 | 29.73 | 36.22 |
| Other                | 5.25  | 5.64  | 8.20  | 6.41  | 4.16  | 2.68  |

VAS = Value-Added Services

During 2011-2016, as shown in Table 1, revenue growth of 2G technology always decreased because some 2G sites were upgraded in some regions to be 3G or 4G sites. Because of high population in some regions, 2G sites can be upgraded by mobile operators to be 3G or 4G sites to improve service. To upgrade a site, research on market demand in the relevant location should be conducted. There is also a need to source appropriate capital for cellular technology advancements in Indonesia.

In this paper, we describe forecasts to predict future trends among the three generations of technology. The next section outlines the 2G, 3G, 4G technologies and indicates the plans in other countries for switching off 2G technology. The following section describes our research method and results, and discusses our forecasts. The last section provides conclusions and future work.

## Cellular Technology Generations

### 2G technology

2G technology is the 2nd generation of mobile telecommunications using GSM in certain frequency bands: 200MHz, 250MHz, 400MHz, 500MHz, 1000MHz, 1600MHz and 1700MHz ([Celik, 2015](#)). A GSM network is built from several functional components, which have specific interface functions. Generally, a GSM network can be divided into three main parts: (1) Radio Sub-System (RSS); (2) Network and Switching Subsystem (NSS); and (3) Operation and Maintenance Subsystem (OMS). GSM uses cellular technology supported on BTSs ([Ibrani et al., 2017](#)).

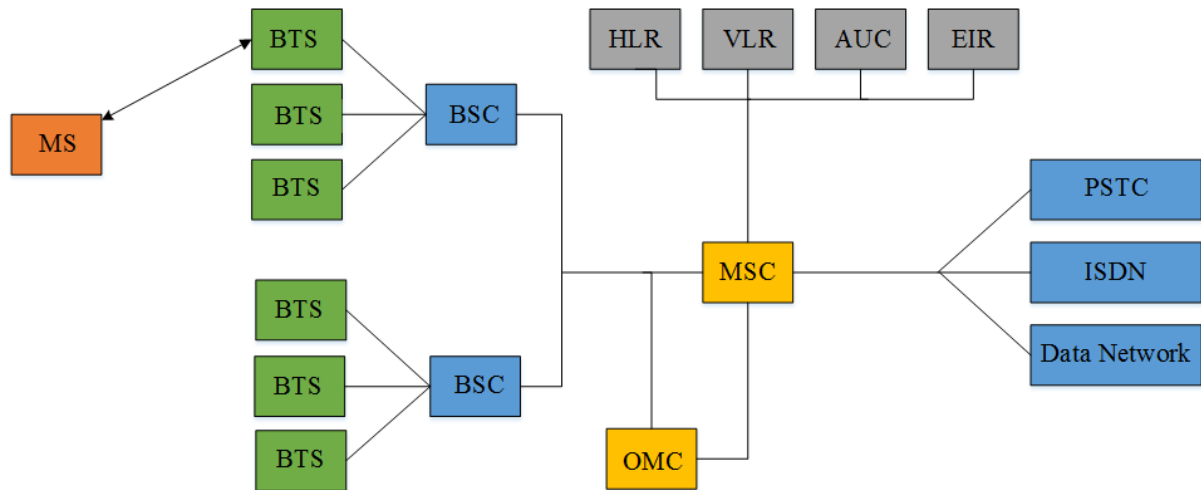


Figure 1. 2G infrastructure (Buchanan *et al.*, 2004)

## 2G switch-off

Many countries and operators have already switched off 2G technology in order to improve communication quality. Table 2 exhibits the 2G switch-off dates in several countries.

Table 2. 2G switch-off dates by operator and country (Fadrian & Arifin, 2018)

| Date of switch | Operator                                            | Country             | Technology |
|----------------|-----------------------------------------------------|---------------------|------------|
| 2017           | Reliance JIO                                        | India               | GSM        |
| 2019           | Airtel                                              | India               | GSM        |
| 30.06.2015     | CTM, Hutchison, Smartone                            | Macau               | GSM        |
| 01.08.2019     | CTM, Hutchison, Smartone                            | Macau               | GSM        |
| 01.04.2018     | M1, Singtel, Starhub                                | Singapore           | GSM        |
| 2011           | KT, LG Uplus, SK Telecom                            | South Korea         | GSM        |
| 31.10.2019     | DTAC, AIS, TrueMoveH                                | Thailand            | GSM        |
| 31.12.2017     | Chunghwa, Far East Tone, Taiwan Mobile, Taiwan Star | Taiwan              | GSM        |
| 01.12.2016     | Telstra                                             | Australia           | GSM        |
| 01.04.2017     | Optus                                               | Australia           | GSM        |
| 30.08.2018     | Vodafone                                            | Australia           | GSM        |
| 15.03.2018     | 2 Degrees                                           | New Zealand         | GSM        |
| 01.10.2018     | NTT Docomo                                          | Guam & Saipan       | GSM        |
| 31.12.2016     | AT&T                                                | USA                 | GSM        |
| 30.04.2018     | Antigua Public Utilities Authority                  | Antigua and Barbuda | GSM        |

## 3G technology

3G technology is the 3rd generation for mobile telecommunications and uses Universal Mobile Telecommunications System (UMTS) (Turniški *et al.*, 2016); 3G works on 1700-2200 MHz frequencies (Letavin, Konovalov & Sychugov, 2018). Based on International Telecommunication Union (ITU) IMT2000 standard, 3G technology is a standard technology for mobile phones that replaces 2G technology. A 3G network enables an operator to give a wider range of services by increasing spectrum utilization (Masmoudi *et al.*, 2017). 3G

technology supports voice and video calls. Additional facilities include HSPA data transmission, which has the capability to send data with download speeds up to 14.4 Mbps and upload speeds up to 5.8 Mbps. Internet access in a 3G network is slower than in a 4G network (Tamgno, Alidou & Lishou, 2018).

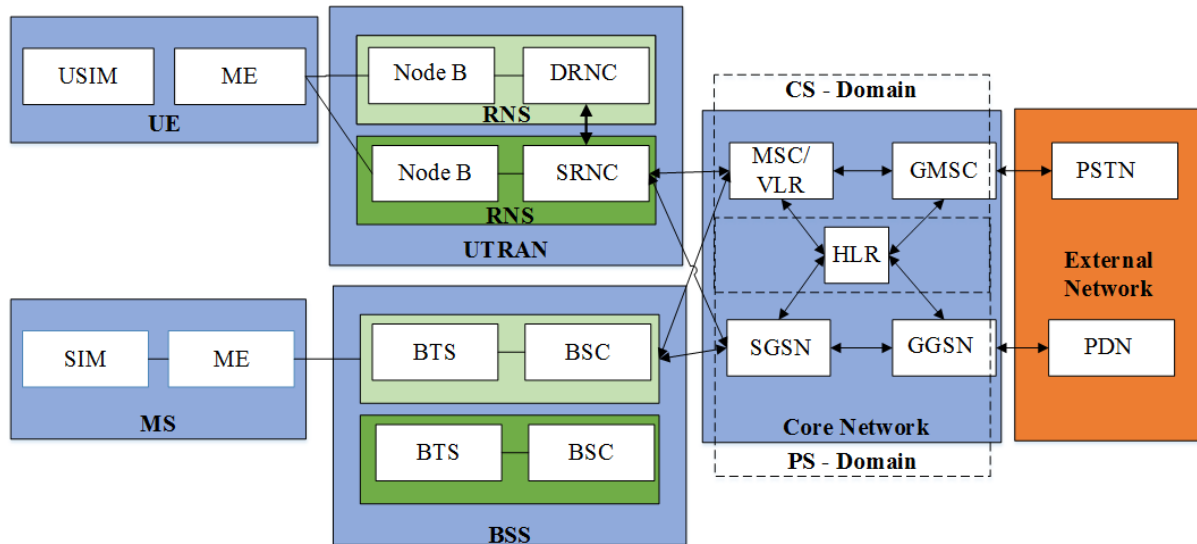


Figure 2. 3G infrastructure (Jung & Kwon, 2015)

## 4G technology

LTE technology is the 4th generation of mobile telecommunication. LTE has been developed by the 3rd Generation Partnership Project (3GPP) (Choi *et al.*, 2015). This technology is based on Internet Protocol (IP). The wireless communication system of 4G technology uses Orthogonal Frequency Division Multiplexing (OFDM). OFDM has good noise performance characteristics and can support high quality wireless data services (Jia, 2017).

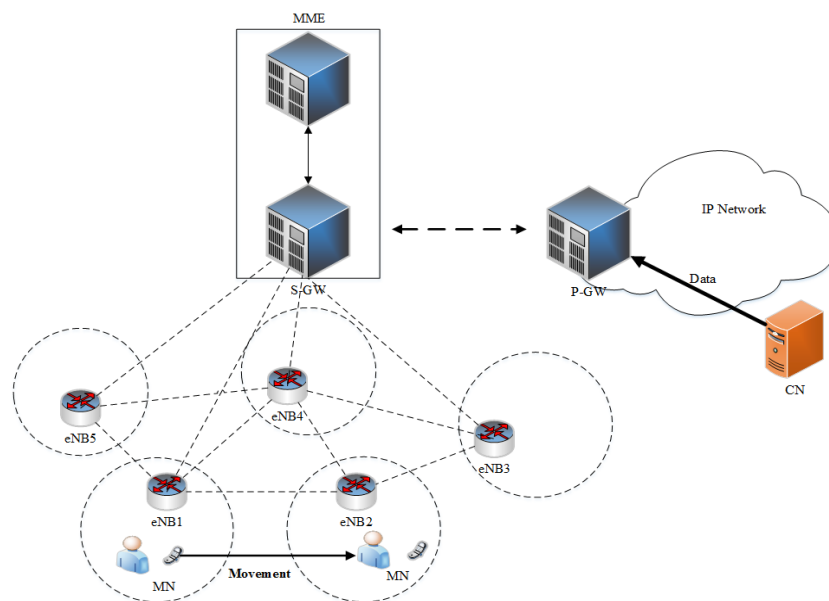


Figure 3. LTE/4G infrastructure (McLaurin *et al.*, 2018)



A major purpose of LTE is to improve the capacity of data transfer by using previously unused spectrum. This reduces data transfer cost and simplifies network architecture ([Campos, 2017](#)). The simplified network architecture means that every node connected in an LTE network will be at lesser cost than in a 3G network ([Jha & Saha, 2019](#)).

## Forecasting Analysis

Forecasting analysis is a tool for predicting certain conditions in the future. Many practical circumstances are predicted by forecasting analysis to help us make important decisions. For example, based on the data obtained by the forecasting of daily payments in retail stores, daily operational decisions in the stores can be executed ([Ma & Fildes, 2020](#)). In electric power systems, a model based on a higher-order Markov chain and the Gaussian mixture method has been developed for forecasting the power generated by photovoltaic systems ([Sanjari & Gooi, 2017](#)). A review of different forecasting models applied in telecommunication and ICT is given in Meade & Islam ([2015](#)).

Forecasting analysis in this paper is implemented in the form of a time series analysis ([Berk, 2015](#)) by use of a regression analysis as given in equation (1):

$$y = a + bx \quad (1)$$

where  $y$  the new prediction,  $a$  the actual prediction,  $b$  the direction coefficient of inclination and  $x$  the time period calculated through time deviation.

In order to determine the unknown coefficients,  $a$  and  $b$ , from the data, the moving average method is used. The method provides a simple calculation for smoothing historical data. Additionally, the method is useful to forecast when there is no trend and can work with different estimation methods for better analysis.

The method takes a set of observed values and then calculates the average amount from the set. The average value of the data amount is used to calculate the actual prediction  $a$ , as shown in equation (2):

$$a = \frac{\sum_{n=1}^N y_n}{N} \quad (2)$$

$y_n$  is the available data. It can be annual, monthly, or quarterly data. Meanwhile, the direction coefficient of inclination can be calculated with equation (3):

$$b = \frac{\sum_{n=1}^N x_n \sum_{n=1}^N y_n - N \sum_{n=1}^N x_n y_n}{(\sum_{n=1}^N x_n)^2 - N \sum_{n=1}^N x_n^2} \quad (3)$$

## Research Method

### Data analysis by using forecasting

Figure 4 shows the data analysis process by using forecasting method. This gives us the ability to do trend comparisons for each potential technology in Indonesia.

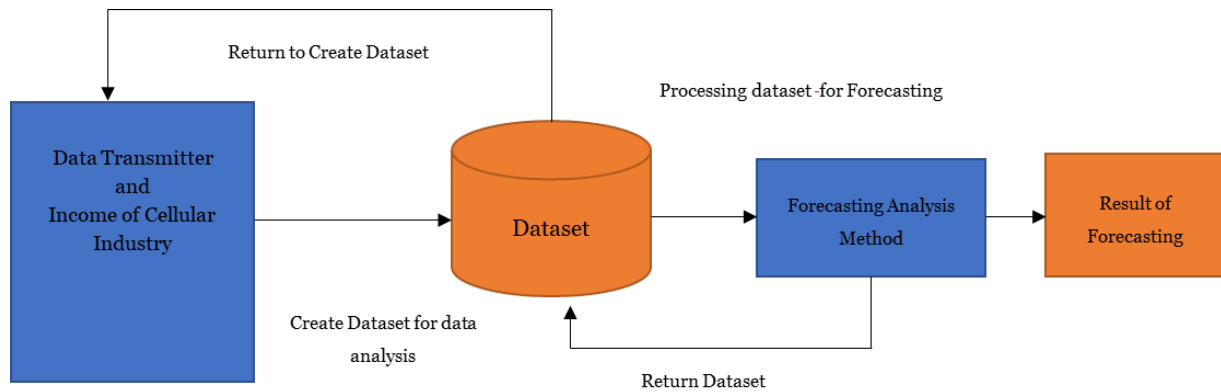


Figure 4. Dataset processing

### Data sources

The first sample data source for this research is in Table 1. The other data source used in this paper is the number of BTSs for each technology. Table 3 exhibits the number of BTSs in each quarter from Q3 2015 – Q2 2018.

Table 3. The number of BTS at the end of each quarter from Q3-2015 – Q2-2018 ([Kominfo, 2018](#))

| Period  | 2G Sites | Growth (%) | 3G Sites | Growth (%) | 4G Sites | Growth (%) |
|---------|----------|------------|----------|------------|----------|------------|
| Q3-2015 | 130,146  | -          | 110,482  | -          | 965      | -          |
| Q4-2015 | 129,847  | -0.23      | 114,300  | 3.46       | 5,600    | 480,31     |
| Q1-2016 | 130,624  | 0.60       | 118,858  | 3.99       | 10,269   | 83.38      |
| Q2-2016 | 131,794  | 0.90       | 138,095  | 16.18      | 12,040   | 17.25      |
| Q3-2016 | 132,469  | 0.51       | 148,639  | 7.63       | 20,935   | 73.88      |
| Q4-2016 | 132,579  | 0.08       | 158,702  | 6.77       | 24,997   | 19.40      |
| Q1-2017 | 128,374  | -3.17      | 162,334  | 2.29       | 42,318   | 69.29      |
| Q2-2017 | 132,903  | 3.53       | 170,007  | 4.73       | 54,701   | 29.26      |
| Q3-2017 | 132,865  | -0.03      | 174,796  | 2.82       | 61,291   | 12.05      |
| Q4-2017 | 132,496  | -0.28      | 175,708  | 0.52       | 72,045   | 17.55      |
| Q1-2018 | 132,405  | -0.07      | 178,492  | 1.58       | 83,646   | 16.1       |
| Q2-2018 | 123,663  | -6.60      | 161,769  | -9.37      | 96,449   | 15.31      |

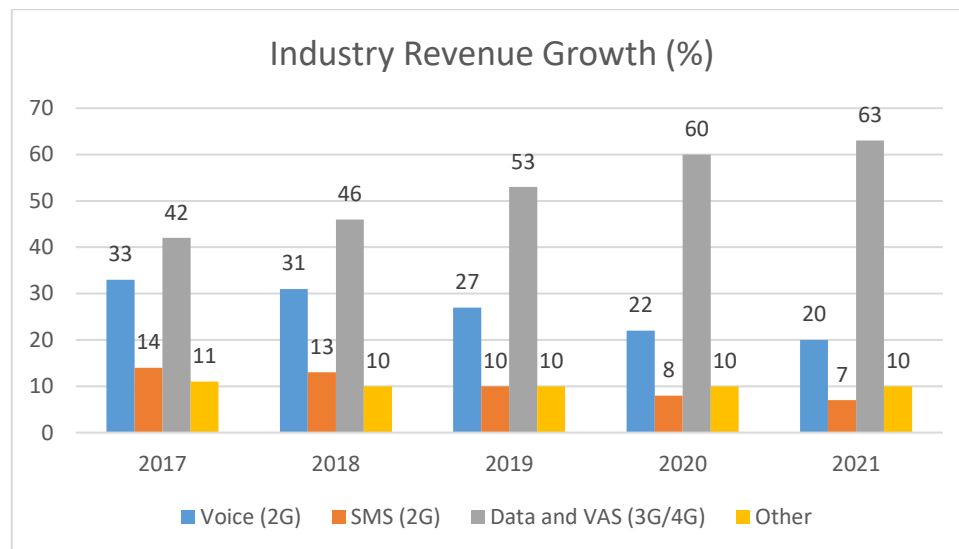
## Results and Discussion

### Analysis result of industry revenue growth

A predicted future trend for revenue growth was achieved by utilizing the data from Table 1 and equations (1) to (3). Table 4 depicts industry revenue growth. The data from Table 4 is shown graphically in Figure 5.

**Table 4. Trend of industry revenue growth**

| Technology           | Industry Revenue Growth (%) |      |      |      |      |
|----------------------|-----------------------------|------|------|------|------|
|                      | 2017                        | 2018 | 2019 | 2020 | 2021 |
| Voice (2G)           | 33                          | 31   | 27   | 22   | 20   |
| SMS (2G)             | 14                          | 13   | 10   | 8    | 7    |
| Data and VAS (3G/4G) | 42                          | 46   | 53   | 60   | 63   |
| Other                | 11                          | 10   | 10   | 10   | 10   |



**Figure 5. Industry revenue growth from 2017 to 2021**

Figure 5 shows the industry revenue growth among the three technologies from 2017 to 2021. There is a significant decrease in SMS revenue growth by 7 percentage points between 2017 and 2021. A significant reduction is also predicted for voice by 13 percentage points between 2017 and 2021. Meanwhile, there is a significant increment for data and VAS by 21 percentage points between 2017 and 2021.

### Analysis result of the number of BTS

Based on total operator requirements, positive and negative trends are found for the number of BTS of 2G, 3G and 4G technologies. Table 5 presents the forecast of the number of BTS. Figure 6 presents this result graphically.

Table 5. Trend of the number of BTS for 2G, 3G and 4G at each quarter in Indonesia

| Period  | 2G Sites | Growth (%) | 3G Sites | Growth (%) | 4G Sites | Growth (%) |
|---------|----------|------------|----------|------------|----------|------------|
| Q3-2018 | 131,103  | -          | 192,721  | -          | 99,394   | -          |
| Q4-2018 | 130,989  | -0.087     | 198,984  | 3.25       | 108,310  | 8.97       |
| Q1-2019 | 130,874  | -0.088     | 205,246  | 3.15       | 117,226  | 8.23       |
| Q2-2019 | 130,760  | -0.087     | 211,509  | 3.05       | 126,142  | 7.60       |
| Q3-2019 | 130,645  | -0.088     | 217,771  | 2.96       | 135,058  | 7.07       |
| Q4-2019 | 130,531  | -0.087     | 224,034  | 2.87       | 143,975  | 6.60       |
| Q1-2020 | 130,416  | -0.088     | 230,296  | 2.80       | 152,891  | 6.19       |
| Q2-2020 | 130,302  | -0.087     | 236,559  | 2.72       | 161,807  | 5.83       |
| Q3-2020 | 130,187  | -0.088     | 242,821  | 2.65       | 170,723  | 5.51       |
| Q4-2020 | 130,073  | -0.088     | 249,084  | 2.58       | 179,640  | 5.22       |
| Q1-2021 | 129,958  | -0.088     | 255,346  | 2.51       | 188,556  | 4.96       |
| Q2-2021 | 129,844  | -0.088     | 261,609  | 2.45       | 197,472  | 4.73       |
| Q3-2021 | 129,730  | -0.088     | 267,871  | 2.39       | 206,388  | 4.52       |
| Q4-2021 | 129,615  | -0.088     | 274,134  | 2.39       | 215,305  | 4.32       |

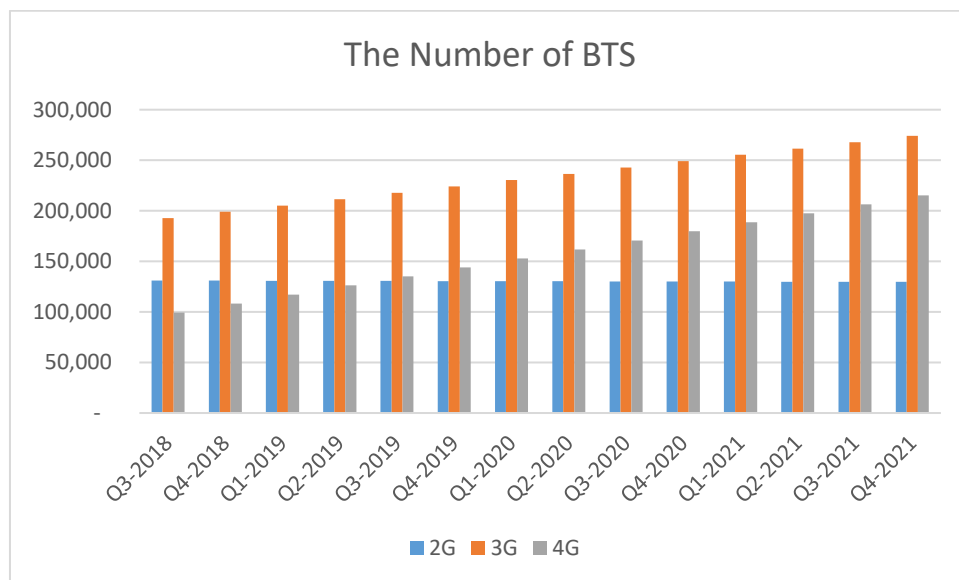


Figure 6. The number of BTS at the end of each quarter from Q3-2018 to Q4-2021

For 3G and 4G technologies, there is an uptrend from Q3-2018 to Q4-2021. For 3G sites, there is significant increment by 42.24% between Q3-2018 and Q4-2021. In addition, a positive trend also occurs for 4G sites, an increase of 116.62% between Q3-2018 and Q2-2021. Otherwise, 2G technology is on a downtrend from Q3-2018 to Q2-2021, declining 1.13% between Q3-2018 and Q2-2021. 2G technology is on a downtrend because it is entering a critical phase, where traffic and subscriber numbers continue to degrade while spectrum allocation for data services is made larger (Fadrian & Arifin, 2018).

## Discussion

In related forecasting, retailers use forecast analysis to support operational, tactical and strategic decisions ([Fildes, Ma & Kolassa, 2019](#)). Based on historical data for 2014-2017, retailers forecasted retail demand between 2018 and 2020 in online shares, with a positive trend during 2018-2020. In addition, forecasting customer flow by using third-party mobile payments is key for retailers in making daily operational decisions ([Ma & Fildes, 2020](#)). That research used many time series and a thousand stores from a variety of categories. The result was that a general solution for forecasting should be based on Gradient Boosting Regression Tree (GBRT). The same result on forecasting is found for the characteristics of 3G and 4G mobile broadband diffusion in India for 2016-2026 ([Jha & Saha, 2020](#)). For those reasons, we then do a comparative analysis of 2G, 3G and 4G technologies. The table below describes how revenue growth is affected by the number of BTS.

**Table 6. Relation table on revenue growth and the number of BTS**

| Period | 2G Sites | Revenue Growth of SMS (2G) | Revenue Growth of Voice (2G) | 3G Sites | 4G Sites | Revenue Growth of Data and Vas (3G/4G) |
|--------|----------|----------------------------|------------------------------|----------|----------|----------------------------------------|
| 2017   | 132,496  | 14                         | 33                           | 175,708  | 72,045   | 42                                     |
| 2018   | 130,989  | 13                         | 31                           | 198,984  | 108,310  | 46                                     |
| 2019   | 130,531  | 10                         | 27                           | 224,034  | 143,975  | 53                                     |
| 2020   | 130,073  | 8                          | 22                           | 249,084  | 179,640  | 60                                     |
| 2021   | 129,615  | 7                          | 20                           | 274,134  | 215,305  | 63                                     |

The table suggests that a reduction of 2G sites by 2.17% will decrease revenue growth of SMS by 7 percentage points and of voice by 13 percentage points during 2017-2021. Otherwise, increasing 3G sites by 56.02% and 4G sites by 198.85% will increase revenue growth of data and VAS by 21 percentage points for the same period. Reduction or addition of sites will affect the number of subscribers that can join a cellular network for revenue generation ([Fadrian & Arifin, 2018](#)). The effect of the number of BTS on revenue growth can be discussed in terms of maturity. Companies do not continue to add base station endlessly. As they add new base stations in lower value regions with smaller numbers of subscribers, this affects revenue growth.

Previous mobile technology (2G, 3G and 4G) was mainly for carrying human-to-human traffic with a limited number of services types. The next generation, 5G, will have a much higher number of service, traffic and user types ([Akkari & Dimitrou, 2019](#)). The authors concur that 5G will be the future of mobile technology.

## Conclusions

This research has shown the application of moving averages for forecasting analysis. We have compared revenue growth and the number of BTS for each generation of mobile technology in Indonesia. We have noted that a reduction or addition of sites will impact on the number of subscribers that can join a mobile network for generating income. This relationship helps to explain the positive trend that customers in Indonesia tend to use data rather than voice and SMS.

## Limitation and Future Research

This research only compares the three mobile telecommunication technologies for the number of BTS and revenue growth. A limitation of the study is that it does not take account of the large area of Indonesia. Future research will be needed to plan for the 2G switch-off in Indonesia.

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## The NBN Futures Forum

### Learning from International Experience

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**Abstract:** On 25 February 2020, TelSoc hosted the third NBN Futures Forum in Melbourne on the theme of learning from international experience for Australia's National Broadband Network. Three speakers discussed various aspects of the topic, including comparisons via league tables, the experience in New Zealand, and the need for good broadband to participate in the global economy. Discussion following the speeches brought out a need to understand the range of demands for broadband from a variety of end users and industrial applications.

**Keywords:** NBN, public policy

### Introduction

The NBN Futures Project ([Holmes & Campbell, 2019](#)) has been organizing a series of public forums under the title NBN Futures to encourage debate, and potentially to build consensus, about the future of Australia's National Broadband Network (NBN) now that the initial rollout is nearing completion. The forums are hosted by TelSoc (the Telecommunications Association Inc, publisher of this *Journal*). The first forum was held in July 2019 and is summarized in Campbell & Milner ([2019](#)); the second, held on 22 October 2019, is summarized in Campbell ([2019](#)).

The third forum, held on 25 February 2020 in Melbourne and online, had the theme of "Learning from International Experience". Three speakers addressed various aspects of this theme in short presentations of no longer than 15 minutes. Discussion from the audience and online followed.

### The NBN Futures Forum

After some opening remarks by Mr John Burke, who chaired the event, the three speakers were invited to address the theme of "learning from international experience".

## Richard Ferrers: International comparisons

Dr Richard Ferrers is with the Australian Research Data Commons, which promotes data science as a new technology for research and which could be described as a “sister project” of the NBN. He addressed the topic of comparing Australia’s NBN to projects in other countries with a view to maximizing the value of the NBN. He aimed to broaden the discussion of “value” of the NBN beyond simple comparisons of download speeds.

He noted first that the Broadband Commission (a joint initiative of the ITU and UNESCO) had proposed seven targets to be achieved by 2025, with the aim of promoting “meaningful universal connectivity”. “Broadband” was assumed but none of the targets mentioned download speed specifically. The first target was that, by 2025, all countries should have a funded national broadband plan or strategy. Other targets emphasized affordability, widespread availability, access to digital financial services and the connection of SMEs. For end users, there should be development of a minimum level of digital skills and gender equality across all targets.

Nevertheless, speed and availability had been important and there had been substantial progress in the period 2009 to 2019. Dr Ferrers noted that, in 2009, an average dialup user would download 100 MB per month, while a broadband user would download, on average, 6 GB per month. In 2019, the average user downloads 250 GB per month. Despite this progress, Australia remains at the low end of comparable countries. OECD figures from 2018 showed Australia second last and, if all other countries remained unchanged, the completion of the initial rollout of the NBN would promote Australia only to the middle of the pack in terms of speeds actually being used. A key issue is that few, if any, Australians purchase download speeds above 100 Mbps.

Narrowing the focus to Australia’s major trading partners, fixed-line broadband coverage in Australia of 90% was exceeded by all except the United States, but Australia’s average download speed of at least 50 Mbps was exceeded only by the USA and Republic of Korea (and, perhaps, marginally by New Zealand).

Focussing then on some examples, Dr Ferrers considered the policies and outcomes in South Korea, China and Thailand. In South Korea, the plan has been to provide 99% coverage of FTTH, with 50% coverage to 10 Gbps download speed by 2022. He pointed out that the access technology was a “multi-technology mix”, like Australia’s NBN: HFC access has declined only slightly since 2007 and still provides about 4 million accesses, while FTTH has risen rapidly.

In China, the broadband strategy from 2013 envisaged broadband coverage of urban and rural areas by 2020. About 70% of households now have broadband access of 50 Mbps download

speed or more. About 50% of urban home users have 100 Mbps and some home users in developed cities have 1 Gbps. At the end of 2017, about 84% of users were on fibre access. A clear contrast with Australia is that there is a high proportion of users on 100 Mbps or greater in China. This suggests that NBN Co should pay more attention to high-speed usage.

In Thailand, 39% of its 18 million households have fibre access, including users on 1 Gbps. One provider, True, has recently reduced its price for 1 Gbps access to \$140 per month (from \$499 per month). This is leading to a steep increase in average download speeds in Thailand.

In comparison with all its major trading partners, Australia lags all countries except India in average download access speeds, according to Ookla data, and improved only slowly from 2018 to 2019.

Dr Ferrers noted, however, that there was significant potential in the NBN to improve average download speeds. The first NBN services at Gigabit-per-second speeds should be offered from May 2020 and about half the accesses – those based on FTTP, HFC and FTTC – could potentially have access to such services. A small proportionate take-up of Gigabit-per-second services could improve Australia's ranking in terms of average access speed and a 20% take-up would put Australia ahead of all OECD countries (assuming no improvement in other countries). While the emphasis had been on availability and coverage, there were other values to be considered for the NBN, including affordability, reliability, usability and gender equality.

In summing up, Dr Ferrers made five recommendations for improving the value of the NBN:

1. Provide affordable Gigabit-per-second services (from May 2020);
2. Emphasise upgrades after the initial rollout is complete;
3. Focus on usage, rather than availability, after the initial rollout;
4. Plan for and measure customer satisfaction;
5. Plan for and measure the NBN performance in comparison with international league tables, including with major trading partners.

Dr Ferrers has expanded on his presentation in a more detailed article, published elsewhere in this issue ([Ferrers, 2020](#)).

## Murray Milner: the New Zealand experience

Dr Murray Milner, who was a director of Crown Fibre Holdings in New Zealand for 10 years, addressed the issue of what could be learnt from the New Zealand experience. He noted first that there were three broadband programs: the Ultra-fast Broadband (UFB) program for FTTP; several Rural Broadband Initiatives; and a Mobile Blackspot Fund. These programs will together give 99.8% of New Zealanders access to enhanced broadband by the end of 2023.

These programs had benefited from strong cross-party political alignment, leading to stable policy formation from 2006 onwards. The initial target of FTTN to 80% of premises was replaced in 2009 by UFB and the UFB and other programs have continued or been enhanced since the current government came to power in 2017.

The UFB program was based on a set of commercial principles that provided for wholesale access provision of FTTP and competitive retail service provision. The government would support only fibre access to the property boundary, deemed to be “common fibre access infrastructure”. Thirty-three candidate areas were identified in which it was estimated fibre to the property boundary could be provisioned for no more than NZD 1,500 per premises passed (in 2010 dollars). Government support would be capped at this level and the wholesaler, selected by tender, for each area would enter into a public-private partnership or would be granted an interest-free loan. Each wholesale provider would also have to meet strict contractual obligations on its rollout schedule. Existing broadband access would continue to operate and there would be no forced migration to UFB.

In the event, four wholesale service providers were supported, with the largest, Chorus, covering 24 of the 33 areas. All premises in these areas were to be passed by the end of 2019 (achieved in November 2019), with 95% of priority premises passed by the end of 2015. Take-up of FTTP has been around 55%. The result has been a steady increase in FTTP connections replacing FTTN. At the end 2019, FTTN accounts for only 30% of broadband accesses.

While the UFB had been a success, it was not always smoothly achieved. Dr Milner suggested that the problems encountered with the UFB rollout fell into three categories: resourcing, cost and connections. The resourcing issues involved the ramp-up and health and safety practices of the field workforce. The cost issues, especially for Chorus, involved bringing the cost per premises passed down to the level of support provided by the government. Chorus had suffered severe debt issues in 2016 as the costs were being reduced. The connection issues arose from the variety of premises to be served, from single houses to multi-dwelling buildings. There could be provisioning delays, leading to customer and retail provider dissatisfaction.

When Ultrafast Fibre, a wholesale provider for the UFB, bought out the government’s portion of its public-private partnership in 2016, the government recycled its windfall into an extension of the UFB program. With the government support increased to be no more than NZD 2,000 per premises passed, it was possible to extend the UFB program to 87% of New Zealand premises, covering over 400 cities and towns, to be completed in 2022.

For the remaining 13%, Dr Milner reported on a number of government programs. A first rural broadband initiative ending in 2013 provided a grant to Vodafone (selected by tender) to enhance its coverage in rural areas. A second rural broadband initiative, ongoing to 2023, will

see further government support of NZD 180M. There are also a Mobile Blackspot Fund and support for services to marae (Māori meeting places) with funding to 2023.

The outcome of all these programs is that, by the end of 2023, 99.8% of premises will have been provided with enhanced broadband (at least 50 Mbps downstream). Government support has been NZD 2.1B, with over NZD 1.0B of capital from the UFB program due to be returned by 2036. In the UFB areas, take-up has been about 55%, with 10% take-up of 1 Gbps downstream service. Higher speed services at 2, 4 and 8 Gbps are being introduced in 2020.

Dr Milner has provided a more detailed account, published elsewhere in this *Journal* ([Milner, 2020](#)).

### Jim Holmes: international experience

Dr Jim Holmes based his remarks on his experience as an international consultant working on national broadband plans or action plans in 10-12 countries. He took issue with the idea, promulgated by the Vertigan committee ([Vertigan, 2014](#)), that one could estimate a cap on access speed and individual or household requirements for the next 10 or 20 years. This, he maintained, was putting a cap on people's capacity to participate in the digital economy if it meant that services were planned to this limit. Household requirements were not just a matter of streaming video but, rather, access to processes and systems that will be required for full social and economic inclusion at any location.

Dr Holmes had many examples of where limited access to broadband had undesirable effects. For example, he noted that it may not be possible to attract or retain staff in regional and remote areas without good broadband and this affects all business, not just industries linked to broadband.

He noted also that business systems are often designed around the broadband capabilities common in Europe or the US. He cited examples where primary producers without satisfactory broadband had sent data via people flying to the US or via competitors in better served areas in order to enter data into market systems. Clearly these workarounds were costly and unsustainable. Participation in the modern online economy required good broadband access.

In commenting on the previous speeches, Dr Holmes noted, firstly, that he was somewhat sceptical of the quality of inputs to international league tables. He suggested that the inputs from some countries were not always well based. From the New Zealand experience, he felt the key learning was that bipartisanship was critical to provide commitment to long-term policy and continuity.

For Australia, Dr Holmes remarked that broadband was no longer a “blank canvas”: the need now is to influence what Australia should do from now on. He suggested that there were two key actions to be undertaken: make long-term plans for long-term infrastructure and long-term investment; promote usage of broadband and ensure there are no functional capacity constraints.

## Questions and discussion

Questions and discussion from those attending in person and online followed the speeches.

*For new broadband services, what level of asymmetry between download and upload speeds can be expected?*

Dr Milner believed that the less asymmetry in the provision of broadband services the better the performance experienced by users for most applications. While symmetry is always best, asymmetry of 2:1 or even up to 5:1 is satisfactory for most applications and these are the ratios typical for most UFB products provided in the New Zealand market. Symmetric products are also available at a small premium.

Dr Ferrers suggested that NBN Co has been trying to optimize revenue by providing more download capacity at the expense of upload capacity.

*Can fixed wireless access stimulate demand for fibre access?* Explanatory comment from the questioner: *Fixed wireless access as a competitor to fibre can have an impact especially in areas not yet served by fibre or where fibre is foreshadowed. Spark has been promoting this option, especially for one-person premises. Spark moves high usage premises onto UFB in order to meet performance standards.*

Dr Milner remarked that the current take-up of UFB is at the maximum level that can be supported by the wholesale service providers.

*Can Jim Holmes clarify his comments about forecasts of usage? The Vertigan report did use data on actual usage to estimate demand.*

Dr Holmes suggested that current usage was constrained by current availability of broadband. There was a need to promote usage of broadband for access, for example, to government services. It would be wrong to maintain constrained views of usage without a scalable future, as usage will continue to increase.

*There has been an emphasis on internet and broadband speeds, but speed can be quoted in a number of ways: the maximum that can be provided; the subscription speed; the actual throughput. What measure is best for comparison?*



Dr Ferrers suggested that, for value comparisons, the key question is “what experience am I getting?” However, the headline speed is usually used for comparisons. The OECD measures what customers are sold. Ookla is measuring actual performance.

Dr Milner noted that in New Zealand the speeds sold on fibre are guaranteed to be  $\pm 5\%$  at all times. FTTN and fixed wireless access both suffer from severely degraded periods.

A follow-up comment from the questioner: *It is difficult to compare between countries. Ookla tests may be unrepresentative because customers test either when they are suffering unreliable performance or when they wish to boast about the speed they are getting. Akamai figures may be more reliable because they are measurements of actual web browsing. In any case, the technology capability may be much more than what is sold.*

*There are many accesses in China at 100 Mbps or greater but not in Australia. What differences are there between Chinese and Australian end-users?*

Dr Ferrers suggested it might be a good idea to ask Chinese students in Australia. In any case, he suggested there was not much published data. It is possible that in some parts of China users are being moved to higher rates without any other change. It was not clear that the average Chinese user changed his or her online behaviour as a result.

Dr Holmes believed it was necessary to look at a whole range of users, not just typical households. For example, work time at home is common in the global economy and will become more so as the distinctions between being at work and not being at work break down further.

*How important is working from home in broadband provision?*

Dr Holmes maintained that working from home, or from any location, will be increasingly important. He suggested that there was a general need to understand the demand side of broadband access, not just the supply side.

*What other uses will affect the demand for broadband access?* Explanatory comment from the questioner: *Big data is coming. There will be new infrastructure needed for instrumenting all highways and traffic lights, etc. 5G is emerging and will need backhaul infrastructure. The industrial demand for broadband will be enormous.*

Dr Milner reported that more and more roadside devices in New Zealand are being connected by fibre. The UFB program had included these devices. Also, 5G backhaul and fronthaul will be provided on fibre.

Dr Ferrers remarked that NBN Co will be supplying fibre connections to elevators for the emergency telephones. The NBN can handle large traffic volumes.

*There has been a lot of research on internet usage in the past but less so now. Who has the political and social clout to promote the study of usage and develop policy in this area?*

Dr Holmes suggested that the NBN Futures group would be working on this issue as part of a long-term plan or framework for broadband development. He noted that because of the technological diversity of the NBN there may be different user behaviours to work around the limitations of the NBN in some areas.

## Conclusion

This was the third of a planned series of forums on the topic of the future of the NBN. Much emphasis to date in the development of the NBN has been on availability and download speed. While the NBN is making a step-change improvement in both broadband availability and speed, the international comparisons show that Australia has not yet fully addressed the availability issue. Most of Australia's major trading partners have wider availability of broadband (up to 99%) and in New Zealand there are well funded programs to provide enhanced broadband to the 13% of premises not covered by the UFB fibre rollout. Experience suggests that the ability to retain workers depends on good broadband access to the international digital economy and that workarounds to cope with poor broadband access are expensive and inefficient.

On access speed, Australia's NBN will provide 50 Mbps downstream as a minimum for most premises and few services above 100 Mbps. The international comparisons suggest that this is a minimal capability today. There are many countries in which speeds above 100 Mbps are common. There is a clear desire and willingness to pay for higher speed access – in New Zealand, about 10% of the current take-up of fibre access is for 1 Gbps service. If the NBN were to provide a substantially higher proportion of accesses above 100 Mbps, it would significantly improve Australia's "league table" broadband standing.

There is a clear need to understand in more detail the range of users and uses of the NBN, that is, the demand for broadband access and the drivers for this demand. Looking at "typical households" will be insufficient: working from home is becoming more common and demands for bandwidth by all applications continue to grow. Commercial demands in the era of "big data" will also grow. At the moment, it appears there is little published data on drivers of increased demand and changes in end-user behaviour.

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# The Telephony Engineering History of Western Australia from 1887 to 1987

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Simon Moorhead

Ericsson Australia and New Zealand

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**Abstract:** A historic paper from 1991 which details the development of the public telephone system of Western Australia between 1887 and 1987.

**Keywords:** Telecommunications, History, Western Australia

## Introduction

The historic paper ([Moynihan, 1991](#)) details the development of the public telephone system in Western Australia over the century between 1887 and 1987, through interpretation of contemporary material, photographs and other written records.

The paper divides the timeline of development into five periods: namely, the Colonial System 1887-1900, Federation, Between the Wars 1914-1945, Post-war 1945-1973 and Telecom 1973-1987.

The author has undertaken significant research of written records and quotes a number of interesting sources including the West Australian newspapers the *Inquirer*, *The Western Australian Times*, the *Herald* (Fremantle) and *The West Australian*. He also quotes from the Proceedings of the Western Australian Legislative Council and various Commonwealth Reports after Federation. Towards the end of the paper he quotes from more contemporary sources such as Telecom (now Telstra) publications and Engineering Heritage Conferences and papers.

It would seem that, despite Federation, Western Australia developed its public telephone system relatively independent of the Eastern States and was required to satisfy the unique requirements of a geographically large State. The author has also provided a selection of fascinating black and white photographs which are relevant to the subject matter.

## Reference

Moynihan, J. F. (1991). Interpreting the Engineering History of Telephony in Western Australia, 1887-1987, *Telecommunication Journal of Australia*, 41(3), 55-65.



## The Historic Paper

# Interpreting the Engineering History of Telephony in Western Australia, 1887-1987<sup>1</sup>

J. F. Moynihan, Telecom Australia

The paper is a case study on how the development of the public telephone system of Western Australia during its first 100 years is interpreted mainly through written material, photographs and other such "paper" records.

## INTRODUCTION

A fair proportion of engineering heritage matters deal with activity of which some sort of physical evidence remains, e.g., bridges. With communication engineering and allied fields such as electronics the working life of plant is relatively brief due to technological changes. Also as the plant is small and easily disposed of, few artefacts remain. Thus it is necessary to seek out the engineering heritage of communications from written material, photographs and other such "paper" records. This paper is a case study assembled in that matter.

Like other Australian colonies Western Australia was early in trialling use of the telephone. However, it was the last colony to open a public telephone exchange, in 1887.

Growth of the system was relatively slow. The State's first automatic exchange was opened in 1914, but it was 1930 before the second was commissioned. 1930 also saw the introduction of telephone working between Perth and the eastern states.

Post-war pressures caused the growth pattern to change. The era of greatest change was post-1960 with, for example, trunk telephone working reaching the far north and the first coaxial cables and microwave systems in the State being commissioned. The beginnings of a wideband network in the 1960s gradually spread throughout the State, culminating in the opening of the Kimberley Microwave System in 1983 and the introduction of optical fibre cable in 1986.

At the same time changes were taking place with switching equipment. After a few crossbar exchanges were installed, subscriber trunk dialling (STD) was introduced in 1966. Subsequently ARF crossbar was upgraded to ARE-11 processor working and, in turn, digital AXE exchanges have become the norm in recent years.



Connie Letch, Perth's first telephonist.

## THE COLONIAL SYSTEM 1887-1900

Alexander Graham Bell made his first successful telephone call on 10 March 1876. Ann Moyal says 'It is not clear who deserves priority for creating the first successful telephone in Australia' (1). She lists W. J. Thomas of Geelong as making a home made instrument in 1877 and other people in the remaining Australian colonies as making successful calls in 1878.

The *Inquirer* of Wednesday, 13 March 1878 noted 'The first trial of telephones in the Colony took place on Saturday between the Perth and Fremantle telegraph offices' (2). Thus the first telephone

<sup>1</sup> This paper was originally delivered at Perth on 3 December 1990 to a conference on Interpreting Engineering Heritage sponsored by the Institution of Engineers, Australia in association with the National Trust of Australia and the Western Australian Maritime Museum. It is reproduced here with the kind permission of the Institution of Engineers, Australia.



connection in Western Australia was established on 9 March 1878. Later that year a telephone line was constructed from Government House to the nearby Colonial Secretary's office. This was no doubt at the behest of Governor Ord, a former Major-General of Royal Engineers who was keen on instant communication (3).

Telephone exchanges were established in the eastern colonies from 1880 and visitors from Perth noted how popular the service was with both businessmen and public alike. On 22 March 1882 Lord Gifford VC, Colonial Secretary wrote to James Fleming, Superintendent of Telegraphs and an Associate Member of the Institute of Telegraph Engineers, London, asking in effect for a scheme for a telephone system at Perth and Fremantle to be prepared for the consideration of Governor Robinson (Ord's successor). Fleming, an ex-convict of notable talent, had, in 1870, produced a similar document from which WA's telegraph system was developed.

Fleming replied on 5 April 1882. He began 'By an ingenious application of a recent discovery, know as the "Telephone Exchange" a new means of communication has been introduced successfully . . .'. He later referred to 'This excellent means of communicating . . .'. Assuming a total of 30 subscribers at Perth and Fremantle he estimated an establishment cost of 1300 pounds with an annual cost of 453 pounds. Gifford forwarded Fleming's memo to Robinson who marked the papers on 29 July 1882, "So do I (agree), provided a sufficient number of guaranteed subscribers can be found to protect the Government from loss" (4). Gifford then forwarded a circular to potential subscribers, naming an annual rental of 8 pounds with no charge for individual calls, plus an extra 4 pounds per annum to be allowed to talk from Perth to Fremantle and vice versa. 45 replies were received and only 21 were favourable. The scheme had foundered for want of public support! (5) However, the next year 2000 pounds was placed on the estimates for the Perth and Fremantle telephone exchange system.

Following Fleming's untimely death, William John Hancock (later Hon. DSc, MICE, MIEE) was appointed Superintendent of Telephones in the Works and Railway Department in January 1886. 22 years of age he had, among other things, worked on the telephone and electrical supply system of his native Dublin (6). Hancock's annual salary of 100 pounds was paid from the Eastern Railway vote.

Hancock placed an order for 50 telephones 'of American design' on the Crown Agents for the Colonies, London. These instruments, with Blake transmitters and Bell receivers, ex the Western Electric Works at Antwerp, Belgium, arrived per SS **Cumbria** in May 1887. There are no extant papers on the actual switchboards, but giving his Presidential address to the

Western Australian Institution of Engineers in 1917 Hancock described them as being two 50 line units manufactured by the Western Electric Company of USA (6).

A contract was let to Mr H. Roche to erect poles and crossarms in Perth for 130 pounds. In late October the **Inquirer** noted that poles and wires were going up in Perth, and that the Perth and Fremantle telephone system should be in operation 'in about a month's time'. It was noted also that the Perth Telephone Exchange would be in 'a small cottage next to the Working Mens Institute'. Tenders had also been accepted for work to be carried out on this cottage in order to fit it out as a telephone exchange.

The Working Men's Institute then stood in Wellington St on the site now occupied by the Barrack Street Bridge. Thus Perth's first telephone exchange was at the present north-east corner of Wellington and Barrack Streets, i.e., a site now immediately next to the Barrack Street bridge and occupied by an advertising hoarding.

No official files on opening of the Perth and Fremantle telephone exchanges have survived, and opening of the Perth exchange was not mentioned in any newspapers. (Researching newspapers of the time is confused by the fact that a racehorse called 'Telephone' was much in the news). Later annual reports of the Post and Telegraph Department gave the dates as Perth, 1 December 1887, and Fremantle, 1 January 1888, and sometimes 1 February 1888.

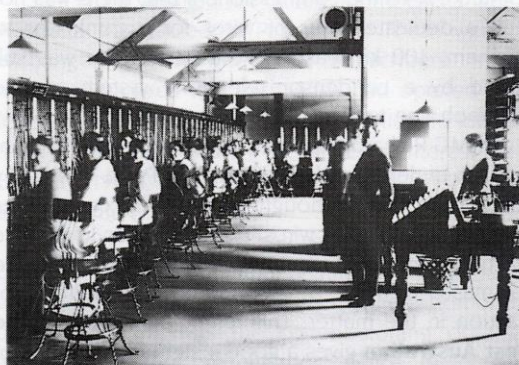
The first two telephonists at Perth were Misses Connie Letch and Ada Woodbridge. Miss Letch (later Mrs Carter) preserved her letter of appointment from J. Arthur Wright, Director of Public Works. Dated 28 November 1887 it read in part (7):

'Referring to your letter of the 14th instant I have now to inform you that your application for the appointment of Lady Telephonist at the Perth Telephone Exchange is approved commencing from 1st December next, at the rate of 12 shillings per week . . .'

This document fixes the date of opening of the Perth exchange. As to Fremantle the **Inquirer** noted early in January 1888 that poles were up but no wires were strung. In mid-January it stated the exchange should be completed within a week. On Wednesday 1 February 1888 it stated briefly 'The Fremantle Telephone Exchange was opened on Monday last'. Thus the Fremantle exchange was opened to the public on 23 January 1888. This writer has puzzled for some time of the significance of later official reports naming the opening as 1 January 1888. It seems likely that this was when the switchboard installation was completed and speech with Perth was first possible, although no subscribers were then connected at Fremantle. The Fremantle telephone switchboard was situated in a room in the Town Hall, opened only a few months



earlier. The first telephonists at Fremantle were Misses R. Chamberlain and E. Crake.



*Perth Manual Exchange, 1912.*

The annual rental was 15 pounds for a service within half a mile radius of the exchange, plus 25 shillings for every extra quarter of a mile. There was no extra charge for Perth — Fremantle calls. Hours were 8 a.m. to 6 p.m., except Sundays and holidays when the exchanges closed.

The first list (directory) of subscribers has not survived, however, list number two published February 1888 is extant. This lists 44 subscribers at Perth and 26 at Fremantle, a total of 70, including 17 government departments. Switch number 1 was allocated to Government House.

On 1 January 1890 the telephone system was transferred to the Post & Telegraph Department. In his report for 1890 Postmaster-General R. A. Sholl (Chief Officer of the P & T Department) noted: 'thus the two similar services (telegraph and telephone) have been amalgamated, and (this) will no doubt prove beneficial to the public'. Sholl further noted that his department had also taken charge of the 'Railway Telephone System'. Hancock's annual salary then rose to 325 pounds.

The small exchange in Wellington Street Perth was soon in need of extension and a new switchboard was ordered from the Western Electric Coy of Chicago. When it arrived the board was fitted into a large room at the top of the then GPO building on the north-east corner of Barrack Street and St George's Terrace and placed in service in June 1892. In reporting this, Hancock also noted that, after experience with various telephone instruments, he had adopted as a standard the French Berthon-Ader instrument. He further noted that the number of trunks to Fremantle was to be increased, by one, to five.

William Hancock left the P & T Department in mid-1893 to take leave in England. On his return in 1894, he was appointed Government Electrician and Electrical Engineer in the Public Works Department, a position he held until retirement in 1921. He had wide

ranging interests and held the honorary position of Chief Radiographer at Royal Perth Hospital from 1898 to 1920 (6, 8).

Edward Snook succeeded Hancock as Superintendent of Telephones & Telegraphs, a designation which was changed to Chief Inspector of Telegraphs in 1894.

The State's first telephone cable was an aerial cable, strung from Perth to Fremantle in 1897. This had 24 pairs paper insulated cotton wrapped in a lead sheath covered with tarred hemp.

In February 1900 a single circuit submarine telephone cable was laid from Cottesloe to Rottnest Island. This cable was another first for WA. An exchange was opened on the island a few weeks later.

In his final report before federation, PMG Sholl listed 11 telephone exchanges in WA and their opening dates, viz., Perth 1887; Fremantle, 1888; North Fremantle, Geraldton and Albany, 1895; Guildford 1896; Coolgardie, Kalgoorlie and Boulder, 1897; Cottesloe, 1898; Northam, 1900. (Rottnest exchange, at that time serving State Government organisations only, was not listed). Between them there were 2,445 subscribers (9).

## FEDERATION

The Federal Postmaster-General's Department (PMG) was formed on 1 March 1901. In May 1901 a Departmental Electrical Committee, chaired by Sir Charles Todd of Adelaide, conducted an inquiry into the existing systems of telegraphy and telephony in Australia. WA's Manager and Electrician George Stevens report to, and examination by, committee members is the first full word picture of WA's telecommunication system that is extant. There is too much detail to go into here, but some points of interest are: (a) there were no underground circuits in WA; (b) ways of undergrounding were being considered; (c) the Ericsson telephone instrument was now standard; (d) there were no slot-machine public telephones; (e) Perth and Fremantle had a mixture of metallic (2 wire) and single wire (earth return) circuits for subscribers. Kalgoorlie, Coolgardie, Boulder and Northam were all metallic, other exchanges were earth return. (10)

Telephone regulations were initially published by the Commonwealth in 1902. These stated, *inter alia*, that charges for telephone services 'shall be those for the time being in force in respective States'. Thus the WA annual charges, in force since 1896 remained i.e., 7 pounds for commercial subscribers for one mile plus 1 pound for each additional mile. The corresponding charges for a domestic service were 5 pounds and 1 pound respectively. There was also a range of annual trunk charges for calls between metropolitan exchanges e.g., Perth — Fremantle was 3 pounds.

The federal postal authorities and a number of WA businessmen were not satisfied with the performance of the telegraph service between WA and other States.



INTERPRETING THE ENGINEERING HISTORY OF TELEPHONY IN WESTERN AUSTRALIA, 1887-1987

Apparently there were other aspects of the WA Post Office administration that were considered unsatisfactory. Early in 1905 Mr E. J. Young Telegraph Manager, NSW visited WA. He examined the workings of both the WA telephone and telegraph systems and filed an adverse report. (11) Subsequently a full enquiry on the report was conducted. This led to a further adverse report.

George Stevens, whose designation had been changed to Electrical Engineer in 1904, was demoted to the position of Controller of Stores and Edward Snook was also demoted; to Postmaster, Bunbury. (In the final event these demotions were cancelled). Stevens claimed, in effect, that he was *persona non grata* in the federal post office because of three matters: firstly he opposed the indiscriminate use of condenser telephones because of their adverse effect on the service of telegraph lines to which these were attached; secondly he considered more telephonists were required at Perth exchange and, thirdly, his proposal to spend 3,300 pounds on the erection of an extra Perth—Coolgardie telegraph line was considered wasteful. Stevens, with the backing of Sir John Forrest, claimed his right to superannuation under a WA State Act and this was finally granted. Presumably Edward Snook chose a similar fate as he and Stevens were initially gazetted as retiring in February 1906, this being later amended to May 1906, possibly because of Stevens' protests (12, 13).

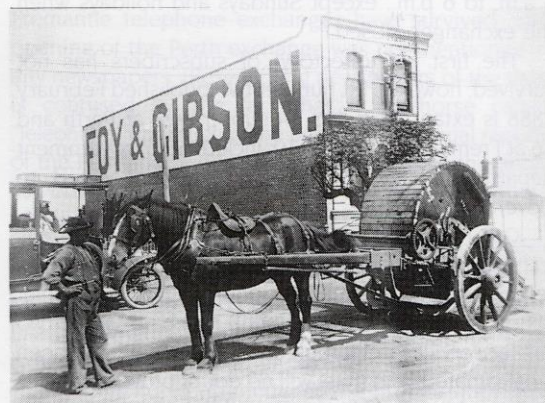
The most surprising aspect of the situation was still to come; three Sydney men were transferred to Perth — Young to act to six months as Deputy Postmaster-General (DPMG) for WA while Richard Hardman was on furlough, A. A. Dircks and P. DeGruchy to take up permanently as Electrical Engineer and Superintendent of Telegraphs respectively.

Undergrounding of telephone wires had been under consideration at least since 1898. The beginning of undergrounding was the laying of a Perth-Fremantle 26 pair, probably 1.27 mm diameter (40 pounds per mile) paper insulated, copper conductor, lead-sheathed cable in 1906. Lack of experience is evident as the conductor joints gave trouble and a number had to be remade. Also contract plumbers were brought in to plumb lead sleeves to the cable sheath at these joints (14).

In 1908 a Royal Commission was set up to look into administration of the Postal Service. The commissioners took evidence in Perth and Kalgoorlie in January-February 1909. (15) Perhaps the most interesting evidence, as far as this paper is concerned, was given by Alex Dircks, still WA's Electrical Engineer. We see, through his evidence, a hard-working man with many demands on his time. His support staff were similarly placed as most construction work was done by contract or temporary labour. Few courses were open for his staff to better themselves. Public Service rules were

restrictive in staff matters also both PMG Headquarters Melbourne and the Treasury were parsimonious. Dircks pointed out to the commissioners that there was not even a dedicated pair of wires for a trunk line to Northam, 100 km east of Perth. The town was still served by a condenser telephone system on the telegraph line to Perth.

DPMG Richard Hardman advised the commissioners that undergrounding of wires in Perth was badly needed. He said he thought that in some cases poles were being held up by wires. This brought an immediate reaction from the Perth City Council who wrote to the Postmaster-General at Melbourne complaining of inaction in the matter. This letter, published in **The West Australian** gives a good insight into the lack of progress in undergrounding to that time. The PMG had promised early in 1906 that work would start soon; plans were drawn up in mid-1906 and funds allocated; March 1907, the DPMG stated work would start in a week or so; July 1907, work held up for want of quality conduits; February 1908, DPMG says work will start. (16)



Horse drawn cable jinker, 1913.

Alex Dircks' evidence to the commissioners, together with the above letter more or less completes the undergrounding picture. A fair amount of time was taken in trying to get suitable conduits manufactured in Perth, all to no avail. Finally conduits were brought from Adelaide to get continuous work under way early in 1909 (there had been a short trial section laid in George Street from St George's Terrace to Hay Street late in 1908, but whether this was using the best available WA conduits or the SA conduits is not clear). By mid-1909 conduits had been laid from the GPO to Roe St in the north and Victoria Avenue in the east, together with a short section at the western end of St George's Terrace.

No records have survived as to the commissioning of cables to supersede the overhead wires, but this apparently got under way early in the 1910s. In Perth the wires themselves were taken down gradually during the Great War years. Concurrent with work in Perth,



undergrounding was going on in Fremantle, Kalgoorlie and Boulder.

In 1910 a detailed list of telephone exchanges in Australia was tabled in Parliament. There were 42 exchanges in WA with 5431 subscribers. In the metropolitan area two exchanges had opened since federation – South Perth (1902) and Midland Junction (1907). Some new country exchanges of interest are – Bunbury (1903), York (1906), Katanning (1907), Narrogin and Broome (1908). (17)

In 1906 a decision had been taken to install common battery (CB) manual equipment in the larger exchanges of Australia. The only manifestation of this decision in WA was the commissioning of a CB exchange in the present post office building at Fremantle, in May 1911. About half of the 650 subscribers were initially connected to the new board, the other half had to wait completion of undergrounding works before changeover took place.

Also, in that year, the first long distance telephone trunk line in the State was constructed between Perth and Bunbury, being commissioned on 2 November 1911. Two years later a similar line was completed to Albany.

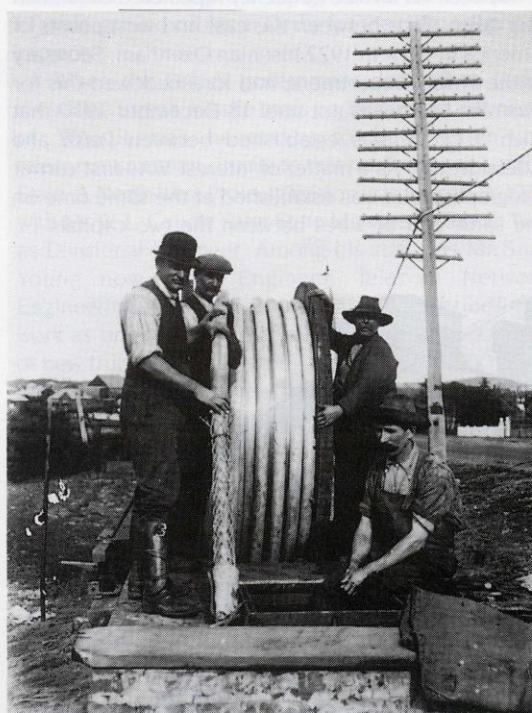
### BETWEEN THE WARS 1914-1945

Central Exchange, Perth, was still in the GPO and being extended as necessary. As outlined in reference 18, three lots of tenders were called before it was decided to have an American contractor install an automatic exchange, in lieu of CB, at the present Central Exchange site in Murray St near Milligan St (the undergrounding of wires started in 1909 had assumed this site as the city's copper centre). The exchange performed poorly at cutover in September 1914, subscribers being rebated one half of their rental charge for the first two weeks of operation. It was August 1915 before the problems were sorted out and the installing company's engineer, Harry Janes, was able to leave WA.



Overhead wires, Perth Town Hall corner, just prior to dismantling, 1915.

The WA colonial Post Office did not boast any drafting staff so no drawings of telephones or telegraph works were produced. It appears to have been about 1907 or 1908 before the PMG Engineering Branch in WA began to produce drawings. The earliest telephone-only circuit map of the State that has survived is dated 1915. The extremes of connections to Perth were Bunbury, Bridgetown, Albany in the south, Mingenew and Bolgart in the north. In the east, connections were made to Kalgoorlie on Sundays by taking two telegraph lines out of service and connecting them as a temporary telephone circuit.



Laying cable Perth-Fremantle, 1916.

A composite telephone/telegraph circuit map of WA for 1921 has survived. This shows that telephone and/or telegraph lines had reached all then settled parts of the State. There was a multi-office telephone trunk to Geraldton, for example, although as the DPMG was to say a few years later that this could not be considered suitable for commercial speech to Perth. In the Pilbara and Kimberleys condenser phone connections to telegraph lines are much in evidence, similarly north of Kalgoorlie as far as Wiluna and Laverton.

As the 1920s progressed Geraldton and Kalgoorlie citizens continually pressed for a better telephone connection with Perth. Electronics first came to WA telephony with the commissioning of a voice frequency (VF) telephone repeater at Merredin, half way between Perth and Kalgoorlie. This boosted speech between the two places and was commissioned in January 1927.



## INTERPRETING THE ENGINEERING HISTORY OF TELEPHONY IN WESTERN AUSTRALIA, 1887-1987

WA's first carrier frequency telephone system was a single-circuit installation between Perth and Geraldton, placed in service in October 1928. (19) A similar system was connected on the Perth-Albany line in 1929.

Although moves began as early as 1922 to have Cottesloe exchange automated, it was January 1930 before this came to pass, thus becoming only the second automatic exchange in WA. In May of that year, ranks of bi-motional selectors were added to Fremantle exchange to enable direct indialling, local calls still being handled manually.

Speech via a voice frequency repeater circuit had first taken place between the east and west coasts of America in 1915. In 1922 Justinian Oxenham, Secretary of the PMG's Department, had foreshadowed this for Australia but it was not until 18 December 1930 that such a circuit was established between Perth and Adelaide. (20) As a matter of interest WA's first carrier telegraph circuit was established at the same time on the same pair of wires between the two capitals.



Central Exchange Perth, 1937.

Automatic exchanges for country centres in Australia had been mooted since the 1920s. In 1930 a list of such proposed exchanges for all States was produced listing the following as a possible site for WA's first Rural Automatic Exchanges (RAX) — Darlington, North Beach, Mundaring, Dardanup or Burekup. (21) However, the depression intervened and, except in NSW and Victoria, it was 1935 before RAXs were commissioned in other States. WA's initial unit was placed in service at Brunswick Junction on 7 July 1935.

Within a few weeks RAXs were also cutover at Broomehill and Dowerin.

Since federation Rottneest exchange had remained in WA Government hands. With war imminent the Defence Department contributed towards the PMG laying a new submarine cable to the island late in 1935. A PMG exchange was opened on the island on 1 April 1936. Thus the last pre-federation telephone exchange in Australia passed to the PMG's control. (3)

## Western Australian Transcontinental TELEPHONE SERVICE

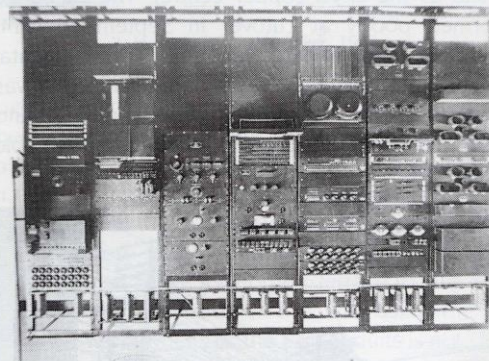
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| ADELAIDE - - | 12 0                          | 9 0                                                   | 6 0                           |
| MELBOURNE -  | 14 0                          | 10 6                                                  | 7 0                           |
| SYDNEY - - - | 17 0                          | 12 9                                                  | 8 6                           |
| BRISBANE - - | 18 0                          | 13 6                                                  | 9 0                           |

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Cost of calls from WA to the Eastern States, 1930.

Moves had been afoot since 1926 to have automatic exchanges established at Maylands and Victoria Park. These were finally established in May 1936. Later that year the first three-circuit carrier telephone system was introduced between Kalgoorlie and the new metropolitan carrier terminal of Victoria Park (previously trunk, VF and carrier circuits terminated in Central Exchange, Perth, some of these terminals remaining there until the mid-1940s). In 1937, a similar system was fitted between Victoria Park and Geraldton.



A view of the equipment panels at Rawlinna, on the east-west route, 1930. From left — first four panels, carrier telegraph; fifth panel, test equipment; sixth panel, miscellaneous equipment; seventh panel, voice frequency repeater panel.

Nedlands automatic exchange was commissioned in 1937 and two years later Subiaco became the first 2000 type step-by-step exchange in WA. The next two automatic exchanges were Fremantle and South Perth, both commissioned in 1941.



The metropolitan manual trunk exchange had been transferred to the then new Central Exchange building late in 1913. As time went on, it was obvious that this would have to be moved. In the late 1930s Victoria Park was favoured but finally it was decided to relocate to the GPO Perth (opened at its present location in Forrest Place in 1923). A "new" manual trunk centre was commissioned there on 14 December 1941. The equipment was actually second-hand units from Melbourne. (22)

### POST-WAR 1945-1975

At the end of the World War WA, like all other Australia States, had a number of applicants awaiting telephone service. Equipment was of course scarce but as it slowly became available extra exchanges were opened, open wire trunk routes were expanded to the major centres and new routes run to developing areas. Single and three-circuit carrier telephone systems were installed to expand the trunk telephone service, and by 1953 there were over one hundred such carrier systems in service in WA. (23)

Automatic exchange buildings were also being erected, these included Mount Hawthorn (commissioned 1949) and Bulwer (1955), the last two exchanges to have subscribers transferred from Perth's Central Exchange's original service area in 1914. A notable occurrence took place when the City Beach exchange was automated on 30 September 1953. At that time Perth became the first Australian capital city to have an all-automatic telephone system.



A line party at Zanthus during the 1942 upgrade of the east-west pole route.

Three-circuit carrier systems were proving inadequate so the Australian Post Office (APO), as the PMG's Department now called itself, introduced 12-circuit systems post war. WA's first two systems went into service simultaneously, Perth — Kalgoorlie, and Kalgoorlie — Port Augusta in February 1954. Initially, six circuits were through-connected at Kalgoorlie to increase east-west circuits. (20)

Shockley *et al.* had produced their first transistor at the Bell Telephone Laboratories in 1947, but it was

some years later before a commercial fully transistorised carrier telephone system was placed in operation in WA. This was a Mullard rural carrier system established between Merredin and Nungarin in December 1959. (24)

Trunk telephone working had reached Meekathara in 1935 and Carnarvon in 1938. These remained the northernmost points served with telephony until a radio-telephone circuit was established to Derby in 1959 (Broome had been telephonically joined to Derby by an open-wire pair of copper wires in 1952). This was the final outcome of planning begun in the 1940s. (25) This writer was the project engineer for the installation of underground cables in Derby for the radio-telephone project.

When the British government decided to target their Blue Streak missile trials on Talgarno in the north of WA, it was necessary to build open-wire telecommunication circuits to that northern point of the State. A North-West Project Division was formed in 1958 with Mr W. L. Caudle (later State Manager, Telecom WA) as Divisional Engineer. Among his staff was Mr S. A. Young now Chief Engineer, Telecom Network Engineering, WA Region. Ann Moyal describes this work as 'an enterprise that involved building 500 miles of new trunk lines, and stringing wire over 1,000 miles across the northern reaches of the State. ... The common factor (of the project) was improvisation and endurance, and ... the need to find novel solutions to a telecommunication connection that required the highest reliability ...' (26)

In the event Britain terminated the Blue Streak project before its completion. However, the APO continued building the northern route. Open wire telephony thus reached Port Hedland in 1962, Broome and Derby in 1965, and Wyndham, in the far north-east of WA, in February 1968.

In 1959 the APO took a decision to introduce L M Ericsson crossbar exchanges into the telephone network. Subsequently, ARF102 exchanges were commissioned in all mainland States in 1963. This writer was the project engineer for the installation of WA's first such exchange, opened at Scarborough on 7 November 1963.

The demand for extra trunk circuits continued in all directions. Extra wires were added to the east-west route in 1958 and 1965. A four-tube coaxial cable, installed by the ditching method, was laid to Bunbury and placed in service in 1965. (27)

Multimetreing, a forerunner of subscriber trunk dialling (STD) had been introduced on calls from Rockingham, Safety Bay and Medina to Perth in 1958 using step-by-step equipment. With the spread of crossbar exchanges in the 1960s, full STD was initially introduced from 15 Perth exchanges to 11 country exchanges including Pinjarra, Bunbury and Northam, in October 1966. (28)



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With the introduction of iron-ore mining in the Pilbara and also because of general expansion in the State a four-tube coaxial cable was laid from Perth to Carnarvon by the, then, new direct plough method in 1967/68. (29) The Supervising Engineer for this project was Mr A. D. Pettersson, later Telecom WA's first Chief State Engineer in 1975. The project engineer was Mr J. A. Huston who, in 1983, succeeded Mr Pettersson as Chief State Engineer and was later State Manager, Telecom, South Australia. (29)

Initially it was planned to extend the broadband route from Carnarvon to Port Hedland by radio, but finally a four-tube coaxial cable was laid between these two towns, and commissioned in 1971. This Perth—Carnarvon—Port Hedland route was served by a 12 MHz carrier system. While these coaxial cables were being installed microwave radio systems were being established also. The notable systems were: Perth—Northam, 1966, supplemented by a four-tube coaxial cable, 1974; Perth—Katanning—Narrogin 1969, later extended to Albany in 1974; Bunbury—Bridgetown, 1972 and Northam—York, 1975.

The lack of east-west circuits remained a constant problem to the APO. Finally, in 1966 a \$10 million contract was let to GEC (Australia) Pty Ltd for the provision of a 2 GHz microwave radio system between Northam and Port Pirie. This project ran late so 24 INTELSAT III satellite circuits were used to temporarily relieve the pressure of traffic from November 1969 until the microwave system was commissioned on 9 July 1970. This then gave WA access to the national STD grid. (20, 30)

The State's first ARM crossbar trunk exchange was placed in service at Pier exchange in 1968. The APO subsequently developed the two-wire ARF Minor Trunk Switching Centres (MSC) as an alternative to the costly ARM exchanges. Busselton, commissioned in 1970, was the first MSC.

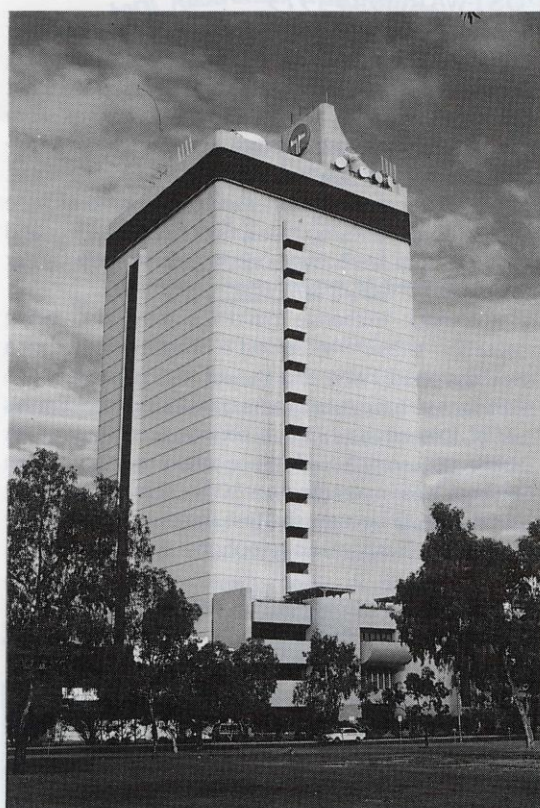
### TELECOM 1975-1987

On 1 July 1975, the Postmaster-General's Department ceased to exist and Telecom Australia became responsible for Australia's public telecommunication system.

Solar power first came to Telecom WA in a small way. The initial installations were carried out at minor open-wire repeaters at Roy Hill and Kumarina in the Pilbara in April 1976. This was the beginning of a flood of installations of all sorts in WA, drawing power from solar panels.

Perhaps the most notable happening in WA's telephone history of the 1970s was the opening of the Wellington telecommunication building in Perth in 1978. This multi-storey earthquake resistant structure will provide for WA's major telecommunications requirements well into the twenty-first century.

WA's first digital telephone system was a 30-circuit pulse code modulation (PCM) system between Pinjarra, Mandurah and Mandurah South, commissioned early in 1979. In that same year, the State's first ARE-11 processor controlled crossbar local exchange was cutover at Bulwer. The next year saw the introduction of a stored program controlled (SPC) trunk exchange in the Wellington Building. After nearly 40 years of service in the GPO, the manual national trunk exchange closed there on 16 September 1981, to be relocated at Wellington.



*Wellington exchange building, opened 1978.*

As the 1960s and 1970s had progressed, wideband telecommunications routes had spread throughout the southern half of the State and the Pilbara. From a date that is not recorded, but about 1967, 'tails' from these routes had spread to many centres in the form of the single quad cable (SQC). This cable, with four conductors, was designed to carry up to two supergroups, i.e., 120 circuits. Thus it was that most of WA's larger open-wire trunk routes fell into disuse in a relatively short time. The exception was the Kimberleys. Broome and Derby were served by four wires from the Pilbara, thence two wires via Fitzroy Crossing and Halls Creek to Wyndham. In the late 1970s a decision was taken to install the 6.7 GHz Kimberley Microwave Radio System (KMS). This was to stretch



from Port Hedland via Broome and Derby, Fitzroy Crossing and Halls Creek to Kununurra. A 60-circuit 'tail' system would serve Wyndham from Kununurra.

Construction work in the KMS began in mid-1981 and the Port Hedland—Broome—Derby section was opened on 4 November 1982. The section to Derby and Halls Creek was brought into service on 11 July 1983. The overall system, complete to Kununurra, was opened on 11 September 1983. It was completed ahead of its original target date of late 1983, and also within budget at a cost of \$21 million. Before leaving this subject it is of interest to note use of the superseded single pair of wires that had run through the Kimberleys. This supported a physical circuit, a three-circuit carrier system as well as a 12-circuit and also a high frequency 12-circuit carrier system. In the Derby—Fitzroy Crossing length for example the route had carried 153 circuits as follows: telephony circuits — 3.4 kHz, 8; 2.0 kHz 22; voice frequency telegraph circuits — 125 kHz, 122; and one 10 kHz radio relay programme line.

Kununurra and Katherine (NT) were linked in October 1987 thus giving a telephone "Highway One" around Australia.

In the switching field Telecom had taken a decision in 1977 to install L M Ericsson's electronic AXE exchanges. The pilot installation in Australia was commissioned at Endeavour Hills near Melbourne in 1981. WA's first installation was brought into service at Cannington on 29 September 1983.

A major milestone event in WA's telecommunication history took place on 13 April 1985. At the tiny settlement on Tenindewa, 75 km east of Geraldton, the State's last manual switchboard was replaced by an automatic exchange. However, a number of individual manual telephone services still remained in various parts of the State connected to Telecom's Manual Assistance Centres.

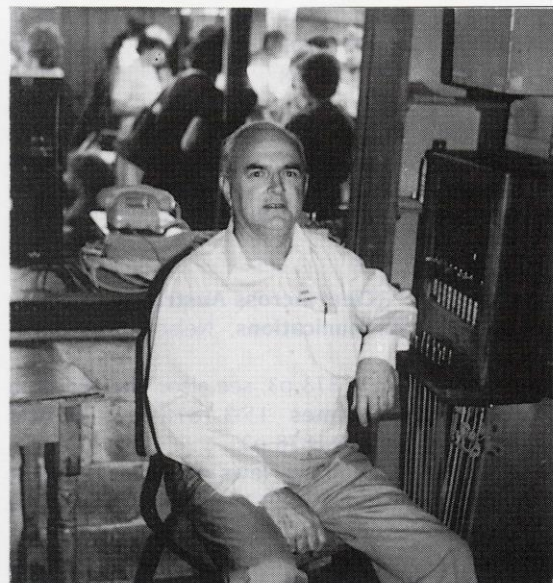
In the 1970s Telecom's Research Laboratories had developed the concept of the Digital Radio Concentrator System (DRCS) to serve sparsely populated areas. Final manufacture of DRCS was carried out by the Nippon Electric Coy of Japan. Communications Minister, Michael Duffy opened WA's first system, in the Meekatharra—Mt Magnet area on 19 June 1985.

Late 1985 saw the completion of a 140 megabit/second digital link around Australia from Perth to Brisbane. This is a sign of the times in that the future of telephony is in digital working. As the introduction of machine telegraphy into Australia in 1925 sounded the distant death knell of morse code key telegraphy in 1963, so the introduction, in recent years, of digital telephone working heralds the end of analogue working some time in the future.

Australia's first satellite, AUSSAT 1, was launched in August 1985 and was operational by October 1985.

Telecom announced the ITERRA service, that is telecommunication service available anywhere in Australia via AUSSAT and a local earth station. In WA the first earth station was established in December 1985 at Telfer, a goldmine in the Great Sandy Desert about 200 km east of Marble Bar.

The gun that signalled Australia II's win in the America's Cup in 1983 also signalled to Western Australia the need to get ready for a defence round off Fremantle in the summer of 1986/1987. After studying the situation, Telecom was able to meet almost all the communication needs by advancing major works by one or two years. The example of greatest interest was installation of the State's first optical fibre cable, between Wellington and Fremantle via exchanges at South Perth, Manning, Bateman and Hilton. The laying of this multi-mode cable completed in April 1985, was about one year ahead of the originally planned date. After the installation of transmission equipment the whole system was commissioned in mid-June 1986.



The author next to WA's last manual switchboard — at Tenindewa, 1985.

In April 1987 laying of an optic fibre cable between Perth and Adelaide was begun. This task was completed with commissioning of the cable on 5 December 1989.

## CONCLUSION

In the 100 years since telephone working was introduced to the public in WA, there have been many changes. Most of these have been in the last few decades as technology progressed and commercial use of these advances was made possible. Western Australia, the largest State in the nation, is well served by Telecom, and this includes the most important aspect of all — Telecom staff: engineers; draftsmen;



technicians, linemen, telephonists, administrative staff and many others have worked together over the years to make this feat possible.

### ACKNOWLEDGEMENTS

The author acknowledges those many of his colleagues in Telecom who have been generous with their information and time, to make preparation of this paper possible. The librarians and staff of Battye Library and the WA State Reference Library were, as always, most helpful.

### APPENDIX

Major Telephone Statistics for Western Australia:

| YEAR  | NO OF EXCHANGES | NO OF SERVICES |
|-------|-----------------|----------------|
| 1890  | 2               | 106            |
| 1900  | 11              | 2445           |
| 1910  | 42              | 5431           |
| *1920 | 115             | 9905           |
| *1930 | 646             | 21258          |
| 1940  | 635             | 27365          |
| 1950  | 701             | 47743          |
| 1960  | 768             | 91849          |
| 1970  | 744             | 199558         |
| 1980  | 686             | 424736         |
| 1987  | 612             | 605210         |

\*In the 1920s the definition of 'telephone exchange' was changed to include a large number of installations previously classified as 'telephone stations'.

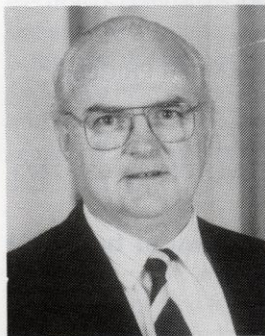
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*The Cost of a Basic Telephone Service in Australian Capital Cities, 1901-1990*. This was published by Telecom in 1990.

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