Handover with Buffering for Distributed Mobility Management in Software Defined Mobile Networks

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Abstract: The rapidly-growing number of mobile subscribers has led to the creation of a large number of signalling messages. This makes it difficult to efficiently handle the mobility of subscribers in mobile cellular networks. The long-term evolution (LTE) architecture provides software-defined networking (SDN) to meet the requirements of 5G networks and to forward massive mobile data traffic. The SDN solution proposes separation of the control and data planes of a network. Centralized mobility management (CMM) is widely used in current mobile network technologies, such as 4G networks. One of the problems related to CMM is a single point of failure. To solve the problems of CMM and in order to provide for efficient mobility management, IETF has developed a solution called distributed mobility management (DMM), in which mobility is handled via the nearest mobility anchor. In this paper, we propose a DMM solution with handover operations for SDN-enabled mobile networks. The advantage of the proposed solution is that intra and inter handover procedures are defined with the data buffering and forwarding processes between base stations and mobility anchors. We adopt a simulation model to evaluate and compare the proposed solution with the existing solution in terms of handover latency, packet loss and handover failures.

Keywords: DMM, handover, LTE, SDN.

Introduction

The requirements of 5G networks have led to challenges for mobile network operators. These challenges include increasing the development speed of mobile networks and their

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technologies, such as increase in the number of mobile subscribers, signalling messages, and mobile traffic and integration of different technologies, social application data, and live video streaming (Cisco 2017). In addition, efficient management of the mobility of User Equipment (UE) is an important issue. Operators have been developing new solutions to improve network performance and manage it efficiently, such as Network Function Virtualization (NFV), Software-Defined Network (SDN), Distributed Mobility Management (DMM), cloud computing, and network clustering.

To meet the requirements of 5G networks, new paradigms, such as SDN, have been introduced by researchers and organizations for mobile network architecture (Ameigeiras 2015, Costa-Requena 2015, Kyung 2015). In SDN, control and data planes are separated using software such as the OpenFlow protocol (ONF 2012). The control plane is logically centralized by a software controller that can control OpenFlow-protocol-enabled network devices and their data routing/transmission processes to maintain low cost and high network performance. The software controller transforms the data plane into a virtual network over the physical network topology. The controller can configure the forwarding tables for OpenFlow-protocol-enabled network devices and monitor the performance of the data plane (ONF 2012).

In current LTE networks, centralized mobility management (CMM) is widely used to manage UE's mobility, to locate subscribers, and to control the data transmission paths. However, the primary problem of CMM is a single point of failure. Signalling data storms are one of the challenges in CMM. To solve the abovementioned problems, DMM is being developed by the Internet Engineering Task Force (IETF) (2016) to handle UE's mobility and manage mobile flows via the nearest anchor of the distributed mobility management entity (DMME) at the edge of a network.

The advantages of integrating SDN and DMM are that procedures and development are faster and redesigning is easier compared to CMM (Ernest 2013, Giust 2015). In Nguyen (2015), the authors propose hybrid mobility management, which is a combination of DMM and Proxy Mobile IPv6 (PMIPv6) (Perkins 2011). This method can reduce the handover latency of the DMM solution. The layer-2 handover procedures supported by the DMM solution are presented in Sanchez (2016). Local controllers are defined for the intra handovers in the area of mobility anchors, and regional controllers are defined for the inter handovers between different PDN gateways (P-GWs).

In this work, we propose a Handover with data Buffering and Forwarding (HoBF) to improve handover performance. In the proposed HoBF, the definition of intra handover is the same as the X2 handover in LTE networks. Inter handover is defined in the following two parts:

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(1) X2 handover with the data buffering and forwarding processes between base stations; (2) the serving and target mobility anchors exchange the information of a UE for data buffering/forwarding between DMMEs and for updating the transmission path via an SDN controller. In addition, we develop a simulation model for the proposed HoBF and the handover procedures in SDN/LTE networks.

The rest of the paper is organized as follows: Section II reviews related work and recent proposals. Section III describes our proposed HoBF considered in this study. The simulation setup and results are described in Section IV. In Section V, conclusions are presented.

Related Work

In the last few years, several studies have been carried out on adopting DMM in mobile networks. In Ernest (2013) and Giust (2015), the authors introduce the advantages of integrating SDN and DMM: i.e., faster procedures and development and easier redesign compared to CMM. Furthermore, in Nguyen (2015), the authors propose hybrid mobility management, which is a combination of DMM and PMIPv6. In Sanchez (2016), the authors propose a DMM solution with a local controller for intra handover and a regional controller for inter-domain handover.

Several researchers have proposed novel SDN-based DMM approaches (Nguyen 2016, Yang 2016, Ko 2017, Kukliński 2014). In Ko (2017), the authors propose an SDN-based approach for DMM that implements the location and handover management functions at a centralized SDN controller, while the packet-forwarding function is fully distributed at access routers. Therefore, SDN-based DMM can accomplish packet forwarding path optimization and provide significant benefits in terms of network and traffic management.

In Nguyen (2016), the authors introduce a method of using SDN-based DMM in 5G networks and compare the existing DMM proposals with the proposed SDN-based DMM. The authors placed their proposed DMM on top of an SDN controller as an application server. The result of this solution shows that complexity of the control plane decreases and becomes more scalable in terms of handover procedure delay and transmission delay.

In Valtulina (2014), the author introduces and evaluates a novel SDN/OpenFlow-based DMM approach that can be applied in virtualized LTE systems. In the proposed approach, the X2 interface is used for handover procedure between P-GWs, and network traffic can be seamlessly continued by a target P-GW. Simulation results show that the handover time is less than 150 ms. It can provide the requirement of LTE and LTE-A networks.

In Wang (2014), the author presents a survey result to improve the existing PMIPv6 mobility management protocol using DMM. In Giust (2014), the authors develop an analytic model of the handover latency of PMIPv6 and its distributed solution. They use the results obtained from analytic and experimental performance to evaluate the benefits of deploying a DMM solution. In Lee (2012), the authors present a novel protocol for IP mobility support. This protocol is referred to as a host-based DMM in the current mobile networks. In addition, they compare the performance of their protocol and Mobile IPv6 in terms of throughput and handover latency. Lee analyses and compares existing IPv6 mobility management protocols in Lee (2013), including the recently standardized PMIPv6 and fast PMIPv6. Lee and his co-authors analyse the performance of IPv6 mobility management protocols in terms of handover latency, handover blocking probability, and packet loss, and provide a few numerical results.

In Nguyen (2013), the author proposes a solution to improve existing PMIPv6 using a DMM-based inter-domain mobility scheme. This solution brings the mobility anchors near to the access network and provides mobility service to the nearby area of the gateway that genuinely requires continuous service. The partially distributed solution shows better performance than other solutions.

Handover management for Distributed Mobility Management

In this section, we describe the proposed HoBF for DMM in SDN-enabled mobile networks. When UE enters the service area of another P-GW, UE executes S1 handover procedure between serving and target P-GWs if the IP address is changed. During S1 handover, a two-level buffering scheme is used from serving cell to target cell and serving P-GW to target P-GW. The existing IETF solution uses the S1 handover of LTE networks with some changes only to enable the OpenFlow protocol.

The LTE network model for our solution is shown in Figure 1. As seen in the figure, base stations are connected to a nearby P-GW (S1 interface). These base stations are referred to as cluster eNodeBs in LTE networks. An eNodeB is connected to the nearest eNodeB through the X2 interface and logically connected to the management section of the network through the S1 interface. P-GWs are distributed for different areas of the network to control and operate the data plane and routing and transmission paths. An S-GW routes data between P-GWs and external networks.

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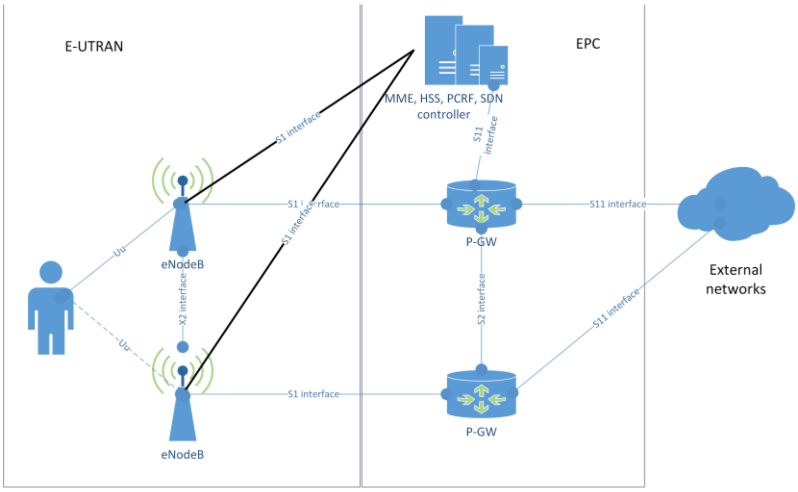

Figure 1. SDN enabled LTE network architecture with DMM solution

In the proposed HoBF, a P-GW can handle the mobility of UEs and manage the handover procedures instead of the CMM located in the management section of the Evolved Packet Core (EPC). A P-GW manages an IP address, which is referred to as the home address, for the UEs that establish a connection via eNodeBs. The UE does not change the IP address during the X2 handover of the LTE network when it moves to the target eNodeB (when the serving and target eNodeBs are attached to the same P-GW). This is referred to as intra mobility in the area of the P-GW. On the contrary, the IP address of the UE that moves to the target eNodeB of another P-GW changes during the S1 handover procedures. In other words, the UE enters the area of a different P-GW and executes the S1 handover procedures between neighbouring P-GWs.

After the handover procedures are performed successfully, the SDN controller configures the routing table between the serving and target P-GWs to provide a continuous session. Then, the SDN controller updates the routing table of the switches for a new path between the UE and external networks. Finally, the SDN controller releases radio resources and the old IP address based on the disconnection request by the serving P-GW. However, before this release process, two IP addresses (different P-GWs) can provide simultaneous connections for the UE, and data buffering and retransmission processes are performed between eNodeBs or P-GWs. The next subsection describes the two handover procedures.

Intra X2 Handover procedures

In this subsection, we describe the X2 handover procedures in the proposed HoBF. Network based X2 handover is executed at nearby eNodeBs when the UE moves to the attached P-GW; this is the same as in LTE networks (Nguyen 2016). Figure 2 shows the X2 handover procedure with the buffering and packet forwarding steps. During the handover procedure, the packets received at an old eNodeB are buffered and forwarded to new eNodeBs after the handover is successful.

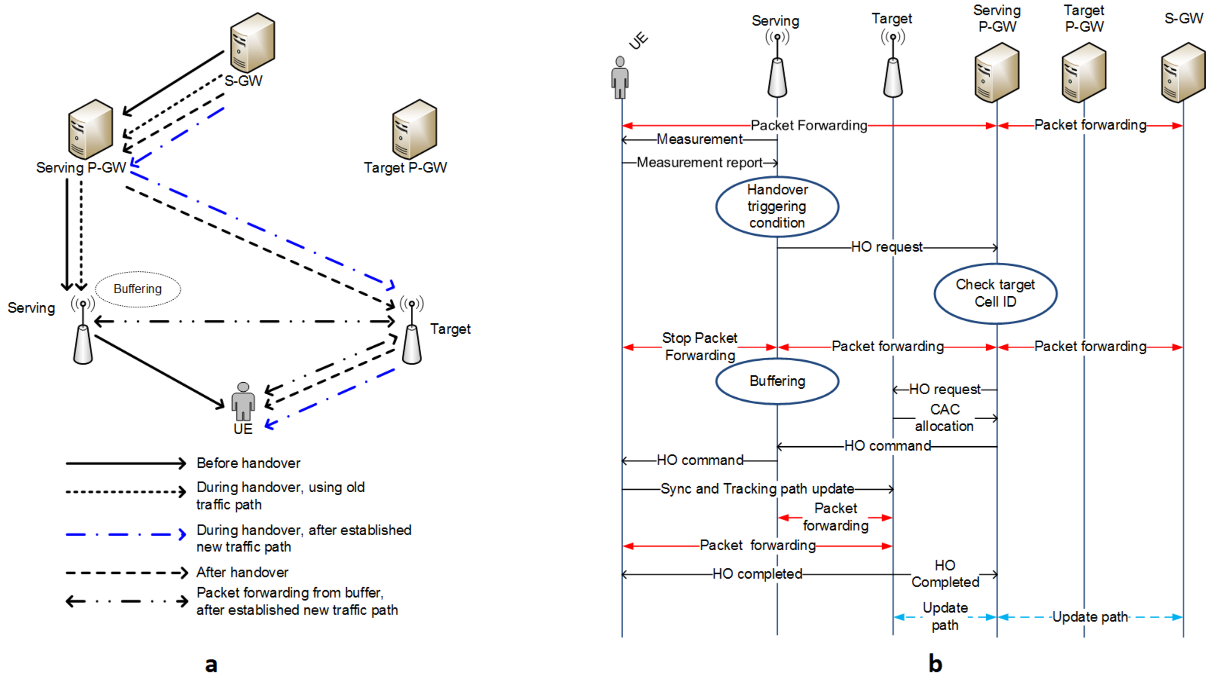

Figure 2. X2 Handover procedures: (a) handover procedures, (b) message flowchart

Figure 2a shows the UE's data traffic paths before handover, during handover with old and new path, after handover and packet forwarding from buffer to the target cell.

Figure 2b shows the messages of handover procedures between UE, serving cell, target cell, serving P-GW and target P-GW. First of all, the serving cell sends a measurement command (measurement) to UE in order to control the connection. UE replies with the measurement report for handover triggering. If handover is necessary, the serving cell sends the handover request (HO request) to the serving P-GW for the check-target-cell-ID process. The serving cell forwards to the target cell a HO request, if the target cell is attached to it (serving and target cells connected to same P-GW); if not, the serving P-GW sends the HO request to the target P-GW, and S1 handover begins.

After the target cell is allocated the radio resource for UE, the serving P-GW replies with the handover command (HO command) to the UE via the serving cell. Also, the serving cell has begun the buffering process. After UE is connected to the target cell, the buffered data is forwarded to UE via the target cell from the serving cell by the X2 interface. The S-GW updates UE's path to the new path.

Inter S1 Handover procedures

Network-based S1 handover is used for seamless mobility when the UE moves to the target eNodeB that is connected to a different P-GW. If handover is necessary, the serving P-GW sends a handover request to the target P-GW (see Figure 3b). Also, the serving cell and serving P-GW begin data buffering for UE.

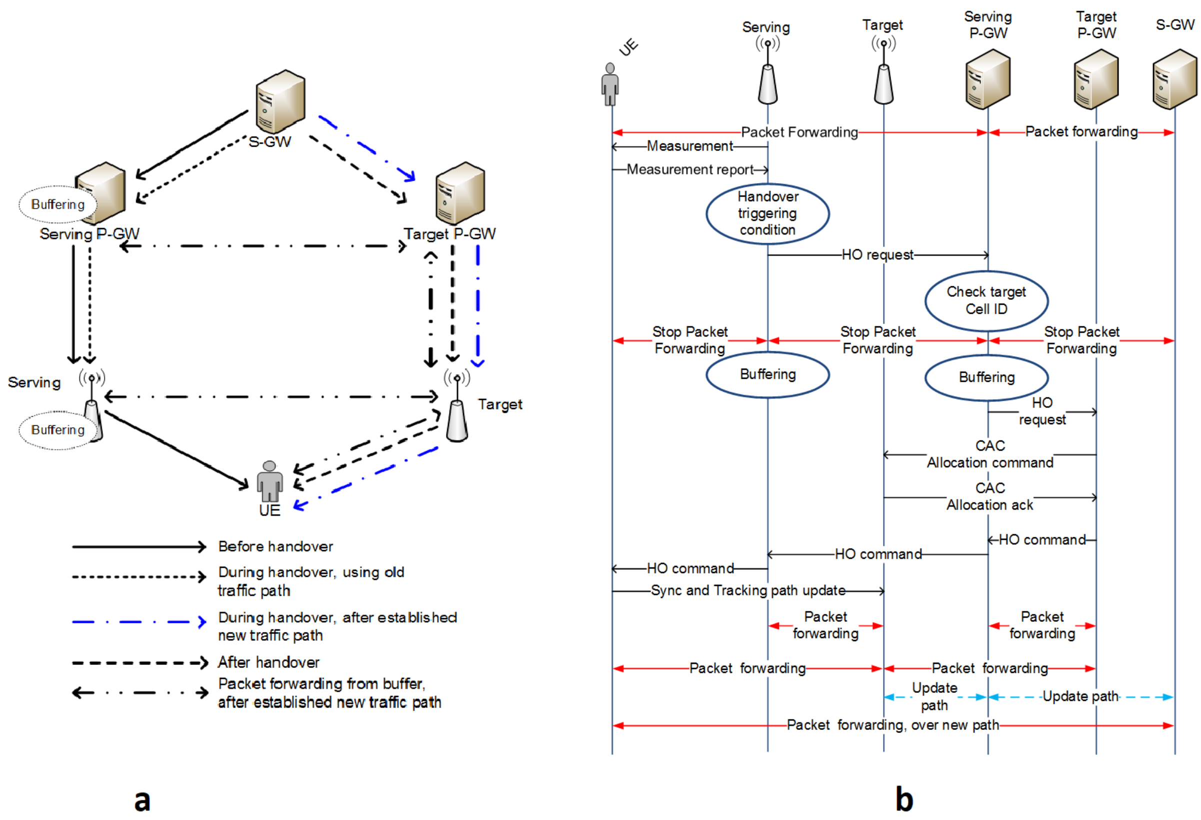

Figure 3. S1 Handover procedures: (a) handover procedures, (b) message flowchart

The target P-GW sends the radio resource allocation request to the target cell. If the target cell is accepted, the target P-GW sends the HO command to UE via serving P-GW and serving cell. After the handover procedure is successful, S-GW updates the data path to the UE. After the UE's connection is established to the target cell, the serving cell forwards the buffered data to UE via the target cell, and the serving P-GW begins data forwarding to UE via target P-GW and target cell.

Moreover, the serving eNodeB releases the radio resource when a 'handover complete' message is received from the target eNodeB. In addition, the target P-GW sends a release message to the serving P-GW. After this message is received, the serving P-GW releases the radio resources and IP address at the serving eNodeB.

Figure 3a shows the two-level data buffering and forwarding processes during S1 handover procedures. At the first level (between serving and target cells), the primary procedure is the same as X2 handover: i.e., a serving eNodeB buffers and forwards received packets to the target eNodeB during the handover procedure. Additionally, the serving P-GW stops packet transmission to the serving eNodeB when the handover procedure is started, and stores the packets received from external networks in its buffer. After the handover procedure is successful, the serving P-GW sends all packets (stored in the buffer and newly received from external networks) to the target P-GW.

For example, a UE establishes a connection to a VoIP Server via the serving P-GW and S-GW. As explained previously, the serving P-GW is a mobility anchor for this connection. When the UE moves to the target eNodeB that is connected to a different P-GW, the serving eNodeB sends a handover request to the target eNodeB via the serving and target P-GWs, if handover is necessary. The handover procedure (same as X2 handover) is used between the serving and target eNodeBs. In addition, the serving P-GW sends information about the UE to the target P-GW. This information contains the identifying information of the UE and all established connections with servers. If the handover procedure is successful, the target P-GW sends a request to the SDN controller for updating the routing table and checking/changing the information of the UE (location, tracking ID, IP address, etc.).

The SDN controller updates the routing table to OpenFlow switches for packet transmissions. Then, the packet transmissions of the connections of the UE use a new connection with the target eNodeB and can connect to external networks over the target P-GW. Note that the serving P-GW buffers the packets received from the S-GW and sends them to the target P-GW after the SDN controller completes an update process for the routing table. Additionally, the serving P-GW releases radio resources and the old IP address after the buffering and data forwarding processes are complete.

Simulation Results

This section presents the performance of proposed HoBF that is compared with that of the conventional mobility management of LTE networks in terms of total handover latency and the average values of packet loss in 50 simulation runs.

Simulation Setup

We simulated and verified the proposed HoBF using NS-3.17 with LENA (2017). For the simulation, we created a network topology that consisted of 18 eNodeBs, four P-GWs, and two S-GWs, as shown in Figure 4. Furthermore, the simulation model contained six L2 switches that supported OpenFlow protocol version 1.3 and the Ryu SDN controller. Table 1 lists the parameters used in the simulation; the values are based on LTE release 8 specifications. At the beginning of the simulation, 100 pedestrian users (UEs) with continuous VoIP services are randomly placed in the simulation area, and they are moved according to the random-walk model at speeds of 20 m/s, 40 m/s, 60 m/s, 80 m/s and 100 m/s. All users are registered to a nearby cell that is controlled by the S-GW and is connected to the P-GW. In this section, the Existing Handover (eHO) denotes the existing handover solution that is introduced by the IETF (2016).

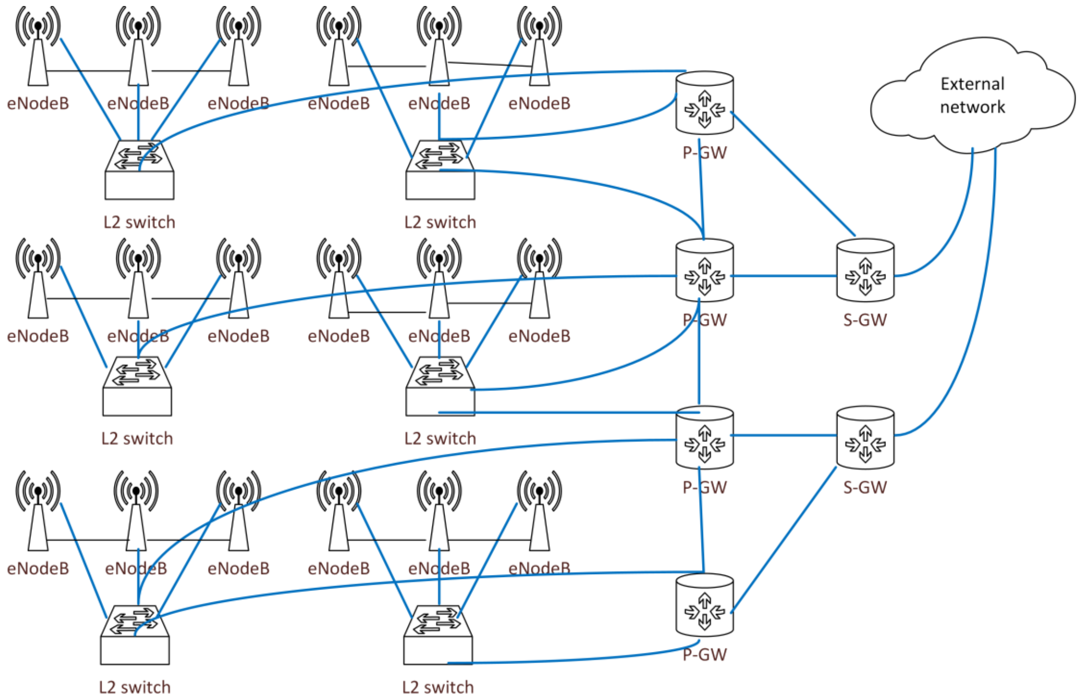

Figure 4. Simulation model with 18 eNodeBs, four P-GWs, two S-GWs

Table 1. Simulation parameters

Parameter	Value
Carrier frequency	*2.4 GHz*
Tx power of eNodeBs	*25 dBm, will change if cell radius is changed*
Hysteresis of Event A3	*-72 dBm, will change if cell radius is changed*
Time-to-trigger	*300 ms*
Pathloss model	*128.1+37.5 log10d*
Shadow fading deviation	*2 dB*
Cell radius	*0.5 km, 1 km, 1.5 km, 2 km, 2.5 km, 3 km*
Handover overlap area	*30% of cell radius*

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The Handover Latency

Handover latency is the time between last packet received from the serving eNodeB and the time of the first packet received from the target eNodeB. In other words, latency is the execution time of the handover procedure, when UE has disconnected from an old connection and is waiting for a new connection acceptance message from the target eNodeB. In LTE networks, an eNodeB can perform the handover latency, and there is no difference in the definition of handover latency for the handover types.

Table 2. Average Latency of S1 and X2 handovers

Cell Radius	Existing Handover (eHO)		Proposed HoBF	
	S1 handover	X2 handover	S1 handover	X2 handover
0.5 km	49.3 ms	20.7 ms	51.8 ms	14.18 ms
1 km	50.1 ms	21.4 ms	51.9 ms	14.28 ms
1.5 km	51.0 ms	22.1 ms	52.1 ms	14.29 ms
2 km	52.0 ms	23.6 ms	52.4 ms	14.36 ms
2.5 km	53.1 ms	23.7 ms	52.5 ms	14.40 ms
3 km	54.2 ms	23.8 ms	52.6 ms	14.41 ms

Table 2 shows the average values of the handover latency over the given traffic scenario in the eHO and proposed HoBF (50 simulation runs). The X2 handover latency of the proposed HoBF is shorter than that of the eHO. The S1 handover latency of the proposed HoBF is longer than that of the eHO because of the packet forwarding process between P-GWs. Also, the size of cell affects both handover types in the eHO solution. Our proposed HoBF can reduce the effect of cell radius. On the other hand, the little changed latency can support two-level buffering: (1) to queue packets that are stored in the buffer; and (2) to calculate a waiting time of packets at the serving P-GW and eNodeB. The performance and location of the SDN controller are affected (Valtulina 2014) by the change in OpenFlow routing table on L2 switches and routing path calculation processes.

The Packet loss

Packet loss is defined as the packets dropped or lost during the handover procedures (handover execution and completion). Lost packets are retransmitted between users and servers by the new path. The performance of the proposed HoBF and eHO can be compared in terms of average packet-loss ratio. Figure 5 shows the average packet-loss ratio for variation in cell radius. In the X2 handover case for the eHO, packet-loss ratio gradually decreases when cell radius increases. In addition, the figure shows a slight difference between the X2 and S1 handovers of the eHO because the packet buffering and forwarding processes are performed between P-GWs during the S1 handover procedures.

In the case of the proposed HoBF, there is no effect of cell radius because OpenFlow-enabled L2 switches directly forward packets to the target one controlled by the SDN controller. In other words, the packet loss of eHO is increased when the cell radius is increased. It is a deficiency of eHO in future networks that are heterogeneous and complex. Note that the buffer size of the switches is sufficient for forwarding a large number of packets.

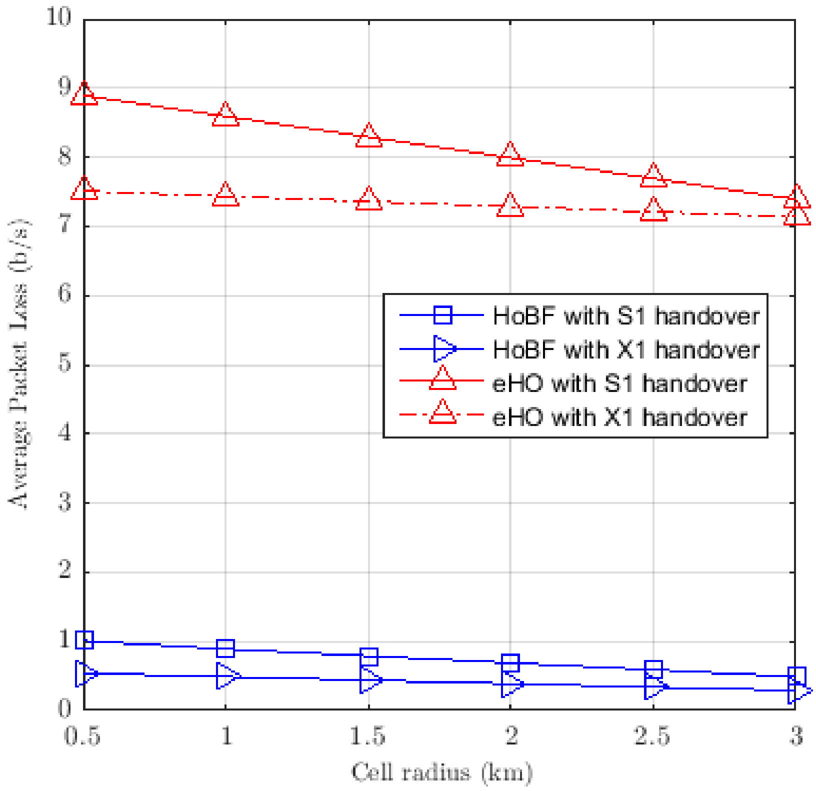

Figure 5. The effect of cell radius on the average packet loss

The Handover Failures

The measure of Handover Failures is defined as the ratio of the sum of dropped handovers, radio link failures (during handover procedures), and ping-pong handovers to the total number of handovers. The total number of handovers is the sum of all handovers that are triggered to the target cell. Figure 6 shows the ratio of handover failures for a number of handover scenarios. In the low-speed case, the proposed HoBF produces a failure ratio of 0.05%, compared with that of the eHO at 0.12%. Also, no Radio Link Failures (RLFs) and dropped handovers are observed, because many handovers are finished before RLF occurs and mobility anchors reduce the number of dropped handovers.

In the high-speed case, the difference between the eHO and HoBF is less visible. Here, the number of RLFs is affected because two-level buffering of messages is added to the handover procedures and affects the handover execution time.

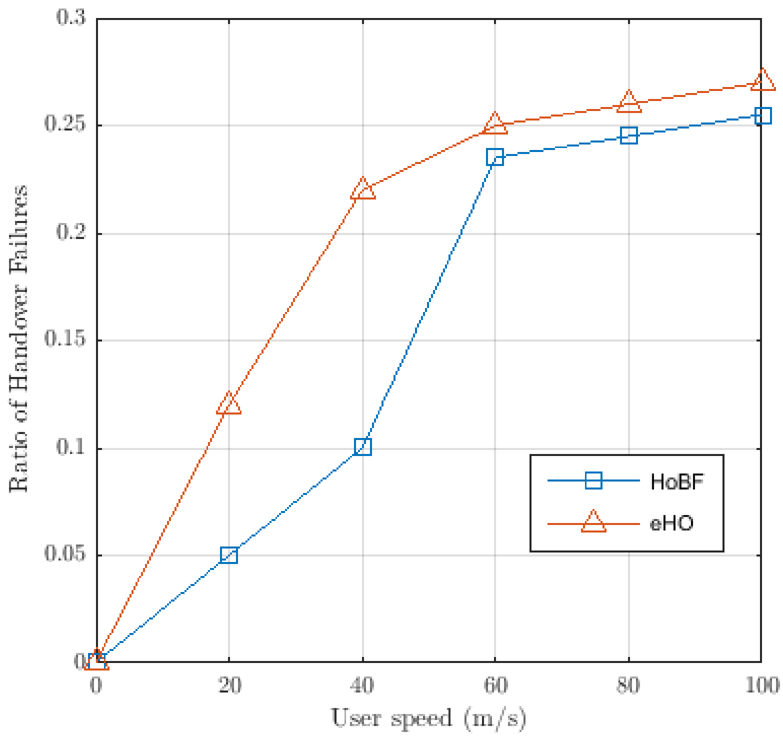

Figure 6. The impact of UE's speed on handover failure probability

Conclusion

This paper presents handover management for an SDN-based DMM solution in LTE networks. P-GWs are distributed close to the LTE radio access network to handle the mobility of users. Our proposal changes the handover procedures and defines two-level buffering in a DMM solution. The two levels of buffering in support of the handover procedure between different P-GWs are introduced in order to reduce the packet loss. We performed a simulation to compare the proposed HoBF with the eHO. From our simulation results, the advantages of our solution are the reduced values of X2 handover latency and packet loss when users are moving between eNodeBs or different P-GWs. Also, our proposed solution can reduce the effect of cell radius and improve the management of handover between the small cells and macrocells. Future work will focus on the implementation our solution for heterogeneous and complex networks.

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