New Approach for Mobility Management in Openflow/Software-Defined Networks

N. Omheni[1], F. Zarai[1], B. Sadoun[2] and M. S. Obaidat[3,*]
[1]*New Technologies and Telecommunications Systems Research Unit, ENET'COM, Tunisia*
[2]*College of Engineering, Al-Balqa Applied University, Jordan, ECE Department,*
Nazarbayev University, Astana, Kazakhstan
[3]*Kazakhstan and King Abdullah II School of Information Technology, University of Jordan, Jordan*

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Abstract: The Software-Defined Networking (SDN) paradigm predicts that the evolution of cellular and wireless networks will bring a considerable increase of two factors, the densification of the Radio Access Network (RAN) part and the progressive demand for traffic. This rapid evolution has led to the emergence of extremely complicated systems, where a large number of logic modules must interact to lead to the desired behavior and the desired quality of service. The key advantage of SDNs is the simplicity of networking and the deployment of new mechanisms and applications. Furthermore, the programmable aspect on the traffic and devices in SDNs makes them more efficient and flexible than traditional networks. In this context, Distributed Mobility Management (DMM) has been recently presented as a new trend to solve the issues of the today's mobility management protocols. In this paper, we propose a partially distributed Mobility Management for OpenFlow/SDN networks. According to simulation results, our approach guarantees a significant reduction of the number of handover and the signaling cost.

1 INTRODUCTION

We are witnessing in recent years to an explosion of mobile communications, together with an exponential usage of Internet for all kinds of applications. It is expected that by the year 2020, more than 50 billion smart devices around the world should be connected and the annual revenues of this new market will exceed US $8.9 trillion (IoT, 2016). In this evolved context, a wide range of wireless technologies has gradually emerged indicating a great diversity in communication needs in various application domains and new standards have regularly been proposed. Moreover, the massive volume of traffic and the evolutionary aspect of the size of such systems make any study carried out on these networks a very difficult task. Thus, both mobile operators, industry and research communities are trying to discover innovative solutions and mechanisms to improve their network efficiency and performance as well as to moderate the costs of new service deployment and network operation maintenance.

Software-Defined Networking (SDN) and Network Function Virtualization (NFV) are two important recent innovations that are expected to offer such solutions. SDN is a new paradigm for programmable networking and is adopted extensively in enterprise networks and data centers. (Ahn, 2017). Figure 1 depicts the SDN network. In such network, control and data forwarding functions are managed separately in order to permit centralized and programmable network control (Kreutz, 2015).

The major components of the SDN architecture comprise a data plane involving network resources for data forwarding, a control plane including SDN controllers permitting a centralized control of network resources, and a management applications to program network operations over a controller. The interface between the data and the control forwarding plans is called the southbound interface while the

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[*] Fellow of IEEE and Fellow of SCS.

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control-application interface is called the northbound interface.

Mobility management plays a crucial role in such environments, where mobiles can easily experience numerous handovers during the same connectivity session. Consequently, there is a real need to propose novel mobility management approaches.

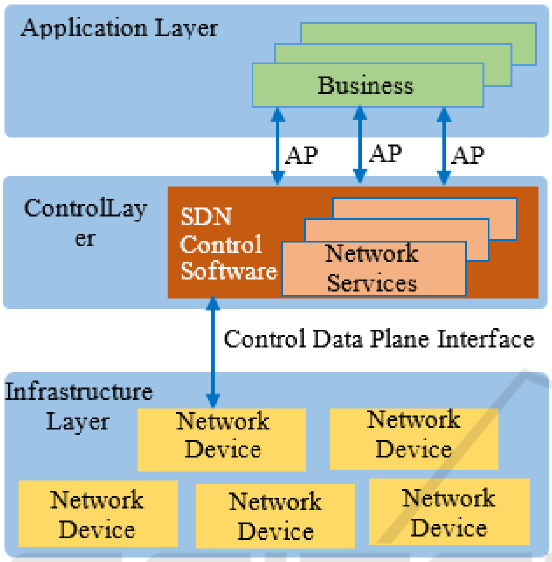

Figure 1: Overall main components of SDN architecture.

Mobility management approaches have to be distributed to provide better reliability and avoid any network bottleneck or single point of failure.

Here the DMM paradigm presents most of the above-mentioned features, and specifically accounts for distributed IP flow mobility managed via distributed anchoring by separating data and control planes to address the limitations of current centralized mobility management such as scalability, reliability and sub-optimal routing (Liu, 2014).

Several DMM-oriented solutions have been proposed in the literature as, for example, the Distributed Mobility Anchoring (DMA) (Seite, 2013), Double NAT (D-NAT) (Liebsc, 2011), Inter-domain DMM, and Local IP Access (LIPA)/Selected IP Traffic Offload (SIPTO) (3GPP, 2015). OpenFlow-based SDN architecture is another candidate solution that supports DMM features and outperforms existing solutions. Advantages provided by OpenFlow, as the most joint communication protocol used in SDN approach, would be an enabler to reach the forwarding plane of OpenFlow switches through the network and reconfigure it in line with the necessities of applications and network services (The OpenFlow, 2017).

In this paper, we present a new SDN/OpenFlow based partially DMM. First, we introduce the proposed architecture components. Then, we describe our suggested mobility management procedures for SDN/OpenFlow composed by two stages: (a) preparation and registration stage and (b) handover execution. Our approach belongs to the category of partially distributed mobility management. The SDN Controller handles the control plane in a centralized way. While, the DMM-ARs (Distributed Mobility management-Access Routers) manage the data plane in a distributed manner.

The rest of this paper is organized as follows. Section 2 presents the related work. In section 3, the new Software Defined Networking (SDN)/OpenFlow based partially DMM is detailed.OpenFlow operations, which are executed in the DMM-AR are detailed in section 4. Performance evaluation is discussed in Section 5. Finally, Section 6 concludes the paper.

2 RELATED WORK

2.1 Software-Defined Networking (SDN)

In this section, we discuss different projects dealing with wireless and cellular networks that integrate SDN paradigm. In SoftCell (Jin, 2013), SDN principles are incorporated in LTE (Long Term Evolution) core networks. The aim of this framework is to build simple programmable core switches inside mobile network while the most of functionalities are pushed to access switches in the radio access network. This division between access and other core switches creates real scalability.

Contrary to SoftCell, which is interested in the dimensioning of the core network, SoftRAN project makes use of SDN functionalities to remodel the LTE radio access network (Gudipati, 2013). In traditional radio access networks, interference and handovers are handled using distributed protocols. While this concept is acceptable in light networks, in ultra-dense environment it leads to bad performance in terms of interferences and latencies. In SoftRAN, the entire LTE network is controlled in a centralized manner. All e-Node B co-located in a geographical area are managed as a virtual big-base station. Radio resources are abstracted out as three-dimensional grid of space, time and frequency slots. Periodically, all radio interfaces send information about local network state to SDN controller. The latter determines the way to assign radio resources block and transmit power for each radio element.

Work in (Tomovic, 2017) was recently published. The authors proposed a new architecture for IoT (Internet of Thing) combining the two evolving technologies: Fog computing and SDN. Their goal was to support a high level of scalability, real-time data delivery and mobility. Fog computing policy is considered as the suitable platform for IoT thanks to its capability to reduce latency for services that need fast analysis and decision-making. While, SDN is used due to its centralized aspect to manage control plane, which permits the execution of sophisticated techniques for resource management and traffic control.

In (Ahmad, 2016), authors proposed a new solution in the form of Software-Defined Mobile Networks (SDMN) including SDN, NFV (Network Function Virtualization) and cloud technologies. The goal is to answer the issues confronted by current mobile network architectures in integrating diverse services.

Authors in (Knaesel, 2013) proposed an OpenFlow based IEEE 802.21 Media Independent Handover (MIH) to perform link connectivity establishment in SDN. Nevertheless, 3GPP or ETSI NFV architectures are not considered in their framework. In this work, a MIH-enabled Evolved Packet System was proposed to offer seamless handovers between 3GPP and non-3GPP wireless technologies. However, their work does not consider programmable or virtualized mobile concepts.

2.2 Distributed Mobility Management (DMM)

There are already many works that have treated Distributed Mobility Management in the context of SDN. In (Chen, 2016), a mobility management approach called Mobility SDN (M-SDN) was proposed to decrease the traffic pause time produced by a host-initiated layer-2 handover. The key idea of this work is that the handover preparation is performed in parallel with layer-2 handover and active flows are sent to each potential handover target. In (Costa, 2013), the authors considered the 5G as an application group and suggested that mobility management can be treated as a service on top of the SDN controller. In (Hampel, 2013), the authors focused on forwarding data across networking layers and discussed how to relate SDN to the Telecom domain. Authors of (Jeon, 2013) presented a new architecture for SDN based mobile networking with two kinds of controller model: hierarchical and single controller. In (Nguyen, 2016), authors proposed a new DMM solution in the context of 5G networks based on SDN architecture called S-DMM. In their proposed architecture, DMM is delivered as a service deployed on top of SDN controller. Mobile Access Routers (MAR) are considered as a simple forwarding hardware and do not necessitate any mobility-related module. The centralized control controller permits the operators to control the network at a reduced complexity level.

In the rest of this subsection, we describe briefly three main types of DMM solutions, which have been published as extensions or improvements of already published standards.

The first type of solutions is known as PMIPv6-based DMM solution. It is based on amelioration of classical IP mobility protocols and mainly PMIPv6 (Proxy Mobile IPv6). This protocol manages mobility in a centralized way where the Local Mobility Anchor (LMA) in the core network creates bidirectional tunnels to Mobile Access Gateways (MAGs) fixed in the radio access networks. More details about this protocol can be founded in (Bernardos, 2014).

The second family of solutions is inspired by the SDN context and named SDN-based DMM. In SDN, network control and data forwarding functions are managed separately to permit centralized and programmable network control. With this paradigm, network administrators are able to program the comportment of the traffic and the network in a centralized manner.

The last category of solutions is the routing-based DMM. The main idea of this kind of solutions is to eliminate any anchor point from the network architecture; permitting all nodes in the network to re-establish a new routing map when terminals change their location. This family of solutions belongs to the IP routing protocols.

3 SDN-BASED PARTIALLY DISTRIBUTED MM (S-PDMM)

3.1 Proposed Architecture Components

In this section, we introduce in detail the proposed system model for SDN-based partially distributed MM and we describe the suggested mobility management procedures. The proposed architecture is shown in Figure 2. Our SDN mobility management architecture relies on three main levels:

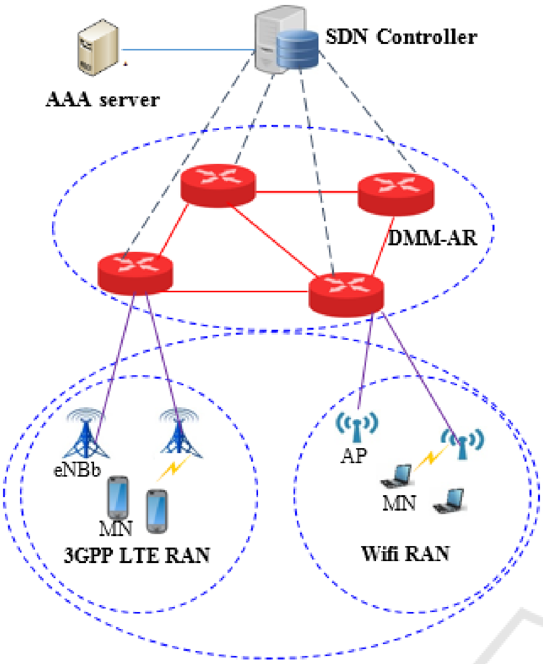

Figure 2: Proposed architecture.

the RANs (Radio Access Networks), the DMM-AR and the SDN Controller. The proposed architecture is shown in Figure 2. Our SDN mobility management architecture relies on three main levels: the RANs (Radio Access Networks), the DMM-AR and the SDN Controller.

The first level is composed of SDN enabled WiFi access points and 3GPP LTE radio access network. RANs are the heterogeneous access networks, which include different access technologies such as WiFi and LTE.

These radio access networks can be programmable and under the supervision of SDN Controller in the core network.

The DMM-AR is an access router which not only delivers connectivity to the RANs (default gateway), it is also boosted with some specific DMM functionalities. DMM-ARs act as OpenFlow switches (OFS) and communicates with the SDN controller with the southbound Application Program Interfaces (APIs) to achieve the packet processing and forwarding feature. The SDN controller with the use of OpenFlow protocol can apply a set of actions such as adding, deleting or updating flow entries to the flow tables in the DMM-AR.

One of the issues that can be observed in the first level is the coexistence of various complementary technologies (cellular vs WiFi), in terms of connection type, shared/dedicated medium and QoS requirements. In order to closer incorporate QoS signaling and mobility for these various technologies, we combined the IEEE 802.21 MIH functions with the proposed SDN-based partially distributed MM. The reason of this mapping between MIH and SDN is that WiFi RANs allow handover only to the same network types and behind the same domain. Furthermore, mobility management at upper layers does not tolerate significant delays to get technology-independent handover triggers and to select the best candidate AP.

The aims of MIH standard are to facilitate mobility management by delivering a technology-independent interface under the network layer. The IEEE 802.21 proposes a MIH specification for achieving seamless handover for mobile users in the same or in different networks.

The main functionality offered by MIH is a seamless connection to different RATs. The control messages are relayed by the Function (MIHF) located in the protocol stack between layer 2 wireless technologies and IP layer. This type of deployment makes it easy for mobile nodes to move between different Points of Attachment (PoAs).

The third level is composed of SDN controller which is the key entity in our architecture. The role of this controller is the management and the configuration of DMM-ARs through the Southbound common application programming interface as mentioned earlier. The northbound API is reserved for communications between the SDN controller and the network applications. The Mobility Management Entity (MME) side core network is integrated in the SDN controller. The latter interacts with the AAA server to get the MN’s profile for authentication. Furthermore, SDN controller supports others control plane features related to LTE networks such as Serving Gateway (S-GW), Home Subscriber System (HSS) and others nodes.

3.2 SDN-based Partially Distributed MM Procedures

The suggested mobility management procedures are divided into two stages: (a) The preparation and registration stage and (b) the handover execution stage. In the first step, we take advantage of the MIH standard in SDN context for the optimization of the MN attachment detection.

In the second stage, the proposed mobility management approach uses the PMIPv6 protocol for handover execution. The SDN controller will play the role of LMA in the PMIPv6 context.

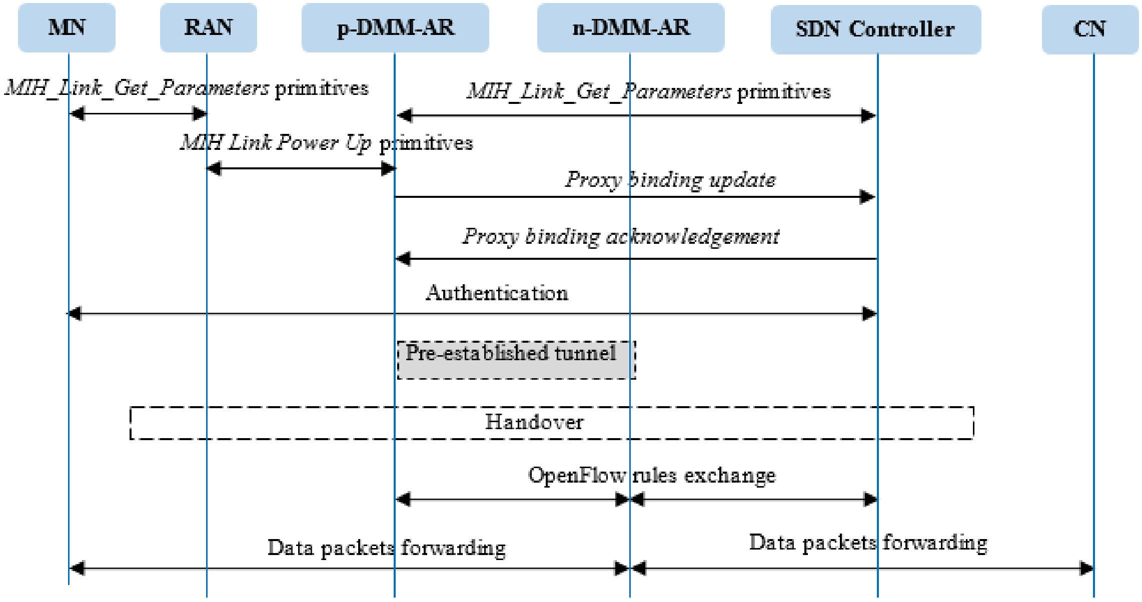

Figure 3: Mobility management operations.

The MAG is replaced by the DMM-AR. Figure 3 shows the proposed mobility management operations.

3.2.1 Preparation and Registration Stage

For the preparation stage, the DMM-AR must be able to be aware of the existing RANs status. These actions can be achieved by applying MIH_Link_Get_Parameters primitives between the MIHF and its users. MIH_Get_Information message primitives can ask Handover policies and network context information from the SDN and the MIIS at the core network. Upper layers can also command specific actions for a given radio interface such as Link Power Up or Link Power down operation.

When a MN moves inside an LTE RAN network, the radio interface is switched on by running MIH Link Power Up primitive. This will trigger the network attachment of the LTE interface to the DMM-AR and an IP route will be established to the MN. Registration occurs when the MN changes its attachment from a previous DMM-AR (p-DMM-AR) to a new DMM-AR (n-DMM-AR) to preserve connectivity with the correspondent node (CN). Two types of messages are exchanged between the MME, which is integrated in the SDN controller, and the new DMM-AR. The latter acts as the HA (Home Agent) of the MN in the PMIPv6 domain during this process; proxy binding update (PBU) and proxy binding acknowledgement (PBA) processes.

A DMM-AR incorporates either mobility anchoring features and is able to forward MN'IP flows without disruption before moving to a new DMM-AR. The SDN controller will play the role of LMA (Local Mobility Anchor) in the PMIPv6 context and maintain the mobile node's (MN) reachability when it is away from home. The MN sends a Router Solicitation message to its DMM-AR. The latter exchanges PBU and PBA messages with the SDN controller. The MN attachment detection is achieved and new IPv6 prefix is assigned to the MN.

3.2.2 Handover Execution

PMIPv6, in the original version, suffers from several limitations such as packet loss and long handover latencies. For that reason, our approach takes benefit from the wireless link layer triggers to anticipate the next handover when the MN changes its attachment. IP flows are directly forwarded to the new DMM-AR in a pre-established tunnel between the two DMM-ARs before the new attachment.

In the following, we give the different steps of handover execution. After the registration stage, the SDN Controller creates a new entry for the MN. After receiving the PBU message from the current DMM-AR, the MN updates its location with the new DMM-AR. As mentioned previously, IP flows are directly forwarded to the new DMM-AR in a pre-established tunnel between the two DMM-AR before the new attachment. After that, DMM-ARs act as OpenFlow switches (OFS) and communicates with the SDN controller with the APIs to achieve the packet

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processing and forwarding feature and the OpenFlow rules in the new DMM-AR are configured.

The final step of handover is achieved when rules on DMM-AR are translated and forwarded. The visited DMM-AR changes the IP destination address with the last MN's IP address to forward traffic in the new MN's domain.

Our approach belongs to the category of partially distributed mobility management. The SDN Controller handles the control plane in a centralized way. While, the DMM-ARs manage the data plane in a distributed manner.

4 OPENFLOW OPERATIONS

DMM-ARs act as OpenFlow switches (OFS). The comportment of OFS is wholly determined by the contents of Flow Tables, whose entries identify flows and the way to analyze packets of these flows. Each entry comprises three features:

(1) Rules: to match incoming packets to current flows. Each entry must contain a set of header values. These are used to look for the flows to which incoming packets belong.

(2) Actions: This entry determines how to handle packets belonging to the flows. A packet can be either forwarded, dropped, or modified.

(3) Statistics: This feature covers statistical data, which can be used by the SDN controller to adjust policies.

The flow-table format is illustrated in the Figure 4. Counters field indicates some statistics such as number of received packets, received bytes and duration. Three actions are defined depending on the case (forward the packet, encapsulate and forward the packet or drop the packet. The priority field in our approach gives priority of the used radio network.

Header Fields	Counters	Actions	Priority

Figure 4: Flow-table format.

The OpenFlow protocol allows handling different nodes in the network in right time by executing configuration changes in the data plane. In OFS, the latency experienced by data plane features to treat packets increases due to the transmission delay between OpenFlow switch and the SDN Controller, the performance of the latter in terms of processing speed and finally the receptiveness of OpenFlow switches in creating new flow and updating their tables after receiving information from the SDN Controller (He, 2016).

DMM-ARs check the SDN controller for the first packet of each new flow. Later all packets belonging to the same flow will be processed in line with the flow-table entry (rules) fixed after receiving the first packet. The traffic between the SDN controller and DMM-ARs is then considerably reduced by flow-based traffic.

We consider that the OFSs adopt a pipeline treatment of the received packets as mentioned in (Javed, 2017). Three components are defined in this pipeline treatment. A flow-table to manage and forward packets, a safe channel to connect a DMM-AR and the SDN Controller and finally the OpenFlow protocol, an open standard for communication between the SDN Controller and DMM-ARs.

Figure 5 illustrates the different steps that the DMM-AR takes to process a packet. When a packet

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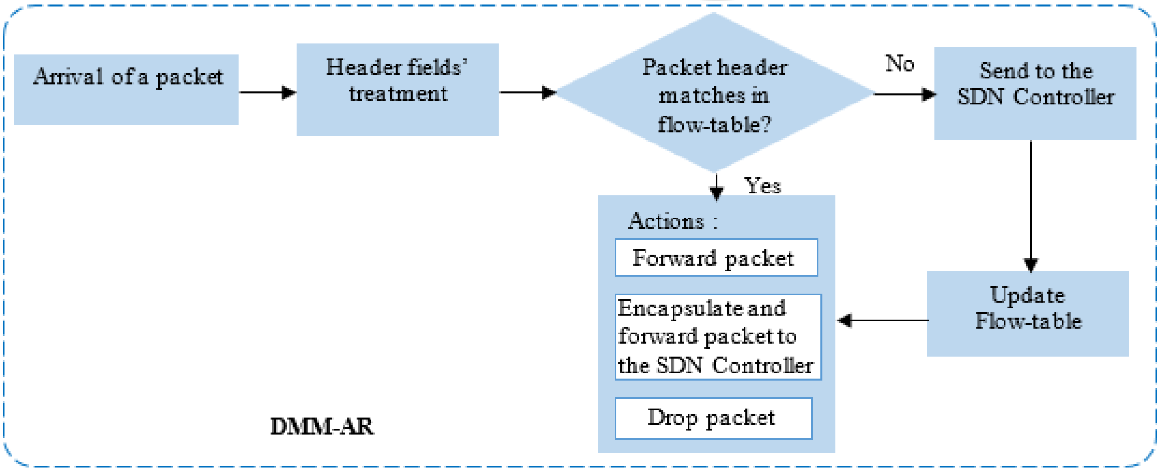

Figure 5: Packet processing steps.

arrives at DMM-AR, which acts as an OpenFlow switch, it checks whether there is an entry matchin its flow-table. In case of correspondence, one of these three actions will be excuted (forward the packet, encapsulate and forward the packet or drop the packet). If not, the packet will be sent to the SDN Controller to update the flow-table.

5 SIMULATIONS RESULTS

5.1 Simulation Setup

The proposed approach is evaluated through simulation. The implementation of the proposed framework is performed in OMNeT++ 5.0. The simulation scenarios are as follows: one eNodeB, one DMM-AR and UEs, where the UEs are dynamically moving from one place to another.

We conduct the simulation in the area of about 2000 m x 2000 m. To simplify the simulation, we assume that control messages are of the same size of a unit length and the distance between the SDN controller and the DMM-AR is set to 1 hop. Table 1 shows the simulations parameters.

Table 1: Simulations parameters.

Parameters	**Values**
Simulation area	2000 m x 2000 m
Mobility model	random walk model
UE distribution	Uniform randomly
Transmission rate	100 Mbps
Distance between eNB and DMM-AR (hops)	1
Radius of eNB coverage	500 m
Velocity of UEs	2 m/s

The performance of our proposed S-PDMM framework is evaluated based on a comparison of signaling cost and number of handovers with the work in (Javed, 2017)

The Signaling Cost (SC) represents the cost of mobility-related signaling messages for a mobile node per unit time. The Signaling Cost (SC) can be calculated as:

$$SC = \sum_{Signaling\ j} [\![(Message_j]\!] \times Hops_j)$$

Where M*essage j* is the size (in bytes) of a signaling message *j,* and Hops *j* are the average number of hops traversed by message j. The number of hops changes for each type of transmission based on the path selected. Here, one hop is assumed to be set as the distance between the SDN Controller and the DMM-AR.The Overall handover indicates the number of networks that are involved in handover.

5.2 Simulation Results

5.2.1 Signaling Cost

Figure 6 shows the performance results of signaling cost in the network over the time interval. We can observe that when the MN moves far away from its DMM-AR, the signaling cost is notably increased because it is proportional to the number of switches along the path from the source to the destination.

We can clearly see that our proposed S-PDMM framework outperforms the other existing system in terms of signaling cost. Compared with the (Javed, 2017), signaling cost is approximately reduced by around 10%.

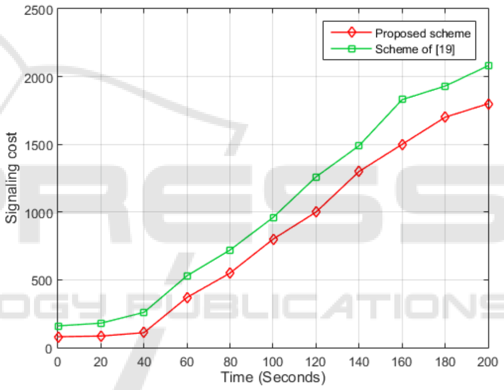

Figure 6: Signaling cost.

Our approach takes benefit from the wireless link layer triggers to anticipate the next handover when the MN changes its attachment.

IP flows are directly forwarded to the new DMM-AR in a pre-established tunnel between the two DMM-ARs before the new attachment and without recourse to additional signaling messages exchange. This act significantly reduces the signaling cost. In conclusion, the low signaling cost makes the proposed scheme more scalable in comparison with other competing approaches.

5.2.2 Overall Handovers

Overall handover indicates the number of networks that are involved in handover. Figure 7 shows the simulation results for the overall handover process in the network. It can be observed that our proposed scheme reduces the overall unnecessary handover.

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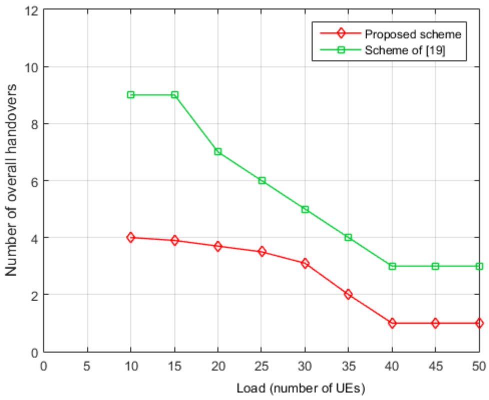

Figure 7: Overall Handover.

Even in the cases of increasing load (number of UEs); the overall handover has been minimized. This result backs up the innate advantages of the combined the IEEE 802.21 MIH functions with the proposed SDN-based partially distributed MM, implied in our framework.

6 CONCLUSION

In this paper, we have presented an SDN-based partially distributed mobility management in cellular and wireless networks. Our solution benefits from the scalability and the flexibility provided by SDN and DMM schemes. The proposed solution belongs to the category of partially distributed mobility management. The SDN Controller handles the control plane in a centralized way, while, the DMM-ARs manage the data plane in a distributed manner. Moreover, we combined the IEEE 802.21 MIH functions with the proposed SDN-based partially distributed MM in order to incorporate QoS signaling and mobility for the various technologies in the network. Simulation results prove that our scheme can guarantee a significant reduction of the number of handovers and the signaling cost. As a future work, we will introduce the OpenFlow v1.3.1 software in a real testbed to better study the performance of the proposed approach.

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