Seamless Mobility Management in Heterogeneous 5G Networks: A Coordination Approach among Distributed SDN Controllers

Ali Saeed Dayem Alfoudi[1], S.H. Shah Newaz[2, 3], Rudy Ramlie[2], Gyu Myoung Lee[1], Thar Baker[1],
[1] Department of Computer Science, Liverpool John Moores University, L3 3AF, UK.
[2]School of Computing and Informatics, Universiti Teknologi Brunei (UTB), Gadong, Brunei Darussalam.
[3] KAIST Institute for Information Technology Convergence, Daejeon, South Korea.
Email: a.s.alfoudi@gmail.com, shah.newaz@utb.edu.bn, rudy.ramlie@utb.edu.bn, G.M.Lee@ljmu.ac.uk, T.M.Shamsa@ljmu.ac.uk.

***Abstract*—The major objective of evolution towards 5G networks is to support increasing number of end devices with stringent latency and high bandwidth requirements. Software Defined Networking (SDN) and Network Function Virtualization (NFV) are paving the way in supporting such requirements of 5G networks. In this paper, we propose a seamless mobility management for the users when they move from a SDN controller coverage to another in 5G heterogeneous networks. Our proposed solution utilizes the key-value Distributed Hash Table (DHT) to catch users' mobility in a distributed SDN controller to address scalability and seamlessness, where mobile device may join and leave between different associated SDN controllers. The proposed solution allows to select an appropriate AP with cooperation of mobile devices and controllers, so that network performance can be maximized and users' demand can be met in a dynamically changing of network condition. The performance evaluated using OMNeT++ simulator imparts that the solution introduced in this paper can successfully reduce handover latency around 50% compared to the conventional mobility management solutions.**

***Index Terms*—5G network, LTE, WiFi, SDN, NFV, Mobility management.**

I. Introduction

Currently, with wireless networks, there are 9 billion connected devices and the number is expected to reach 24 billion by the end of 2020 [1]. These devices use various wireless interfaces, such as WiFi and LTE, to connect to the network using traditional network infrastructure. The traditional network infrastructures and networking protocols are insufficient and limited in satisfying the required level of scalability, large amount of traffic management and seamless mobility [2] [3]. These limitations of the traditional network may lead to poor users' satisfaction (users may experience low throughput, long latencies and network outages due to congestion and overload of data traffic at the access network). Therefore, taking this into account, 5G technology presents a promising solution to overcome the inflexibility of the current cellular network. The 5G network architecture has been developed based on the conceptual architectures of the Software Defined Networking (SDN) and Network Function Virtualization (NFV) [4] [5].

SDN is a network architecture that opens new trends to eliminate the rigid nature of traditional networks [6]. SDN divides the network architecture into two planes, namely control and data planes. It supports the programming capability of the network infrastructure through an open Application Programming Interface (API). In a 5G network, the NFV virtualizes most of the network infrastructure functionalities as a software. Therefore, it reduces the CAPEX/OPEX of the Mobile Network Operators (MNOs).

SDN and NFV network architecture structures make the behavior of the network to be more flexible and adaptable to meet different requirements of each organization, campus, or group of users. Moreover, they are a centralized architecture that is designed to enable collection of information from different networking equipment used for promoting and adopting their policies. The centralized network architecture enables heterogeneous management of wireless access networks with the huge numbers of mobile devices to overcome the complexity of the access network in terms of connectivity [7] [8]. For instance, when a group of mobile devices move between different interfaces in a heterogeneous access networks, the switching process will experience processing and signalling overhead in order to maintain seamless mobility management (keep a link connected) in such complex networking environment.

In this paper, we propose a novel architecture to facilitate a coordination among distributed SDN controller networks so that user mobility can be managed seamlessly in a 5G heterogeneous access networks. We deploy the concept of Distributed Hash Table (DHT) [9], to manage the distributed agents (controllers) in different access networks with the objective of tracking user device movement (each agent represents one access network coverage area). By doing so, our solution presented in this paper ensure seamless mobility support. The proposed solution considers several metrics when selecting an Access Point (AP) to a certain user. Considering various parameters, the APs are arranged in descending order of values of satisfaction parameters, such as user preferences (e.g., cost and location), services requirements (e.g., audio, video streaming and file sharing applications) and AP capacity in term of user density and throughput.

The main objective of the proposed architecture in 5G network is to facilitate seamless connectivity in a heterogeneous wireless network environment. In our solution, for a user device an appropriate AP is selected with cooperation of the mobile device and controllers.

The rest of the paper is organized as follows. The related works are presented in Section II. In Section III, we briefly describe the System model of 5G distributed architecture. Conclusion follows in Section IV.

II. Related Work

5G technology is still under investigation of research study [10]. Therefore, it needs a lot of effort from researchers to address challenges of 5G network in term of mobility management in heterogeneous access networks [11]. In [12] authors proposed a network architecture for seamless mobility in slice network environment. This architecture developed based on the functionality of SDN and NFV concepts, where the LTE and WiFi networks collaborating together to seamless a user traffic utilizing IP-Flow concept. It is important to highlight that, before the SDN appeared, Proxy Mobile IPv6 (or PMIPv6) was used (introduced by IETF) to support IP network based mobility support [13]. PMIPv6 is network-based mobility, in such an approach the MN does not needs to signal direct to the local mobility anchor, where all this signalling is done by the network. The MN registration is done in a Local Mobility Anchor (LMA) by the Mobility Access Gateway (MAG) that is managed by the network. When the MN moves and changes the current network, it is detected by a new MAG that belongs to a new network. The new MAG in turn will send signalling messages to the LMA for updating the location of the MN and the LMA establishes bi-directional tunnelling to the MAG. Notice, the tunnelling between the LMA and MAG (the MN is not involved). This protocol provides better network performance in handover delay and less signalling cost. Moreover, there is another ip based mobility management namely Hierarchical Mobile IPv6 (HMIPv6) [14] . HMIPv6 is host-based mobility protocol, when a Mobile Node (MN) moves between different APs as a first step, it registers to Mobility Anchor Point (MAP) during mobility management that it works as a Home Agent (HA) to the MN. Then a bi-directional IP-tunnelling is established between the MAP and the MN for exchanging packets. However, if the MN changes its location and leaves the current MAP domain, it will assign to a new MAP in the form of a hierarchical-tree. In this manner, the HMIPv6 reduces the handover overhead and optimal utilizing network resource.

In [15] and [16], authors proposed heterogeneous architecture which accommodates multi radio access technologies such as LTE, WiFi and UMTS. In these research efforts, heterogeneous small cell networks are sharing unlicensed spectrum access points in densely areas to meet the increasing data traffic demand in 5G networks. The authors in [17] proposed a hybrid computation offloading scheme for managing the increasing traffic demand in 5G dense area networks. The proposed scheme takes into consideration the impact of the users' mobility and the network caching in distributed Small-cell Base Stations (SBS).

The solution in [18] is based on the Individual Mobility Model (IMM) instead of the traditional Random Waypoint (RWP), in order to evaluate the results performance of user mobility. The main consideration of this solution is to investigate the impact of human tendency and clustering behaviours on the performance of user mobility in 5G small cell networks. A novel resource-based mobility management mechanism is proposed in [19] for video users in 5G networks. This mechanism proposed N-step algorithm for selecting optimal routes between serving nodes and utilized the Homogeneous Discrete Markov model for user mobility patterns.

III. System Model of Proposed Distributed Architecture

In the proposed system model, we consider a super SDN controller which is in charge of controlling other distributed SDN controllers as illustrated in Fig. 1. As delineated in the figure, in our proposal, we consider two types of connections: inter-domain and intra-domain. The inter-domain connection represents the links between distributed SDN controllers through the Super SDN controller, whereas the intra-domain illustrates the connection of different types of APs within a controllers coverage area. In each domain, the distributed SDN controller allows integration of different network elements in a feedback control loop in order to distinguish different behaviors of networking nodes in the network architecture. The super controller distributes the flow tables between distributed SDN controllers (as described in Section III-A). Next, we explain each of the components of the super SDN controller in our proposed architecture.

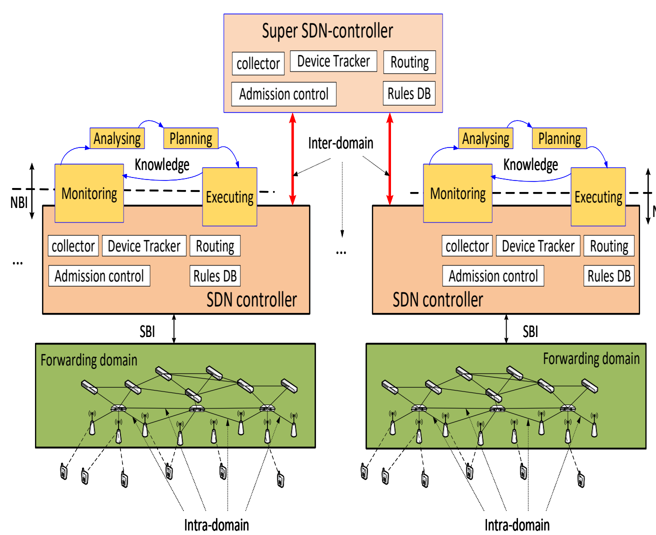

Fig. 1. A distributed SDN architecture in 5G networks.

- *Admission control:* this element receives network requests to support resources from the management plane, and decides whether these requests can be admitted or not. It uses the NorthBound-API (NB-API) in SDN to support resource requests in network devices. The NB-API can be able to reserve network resources, such as queues, flow table entries, bandwidth, time cost, etc. If the network devices have enough resources, the admission control accepts the requests. Otherwise, the request is rejected (blocked).
- *Routing:* this element determines available paths and calculates routes based on control rules in database (DB). Selection of suitable routes is determined by the type of network (i.e. heterogeneous or homogeneous network) and network performance metrics such as latency, jitter, throughput, error rate and redundancy. The control plane collects these data by using the collector and device tracker elements.
- *Device Tracker:* this element is responsible of checking link status (link up/down) between an individual AP and its mobile devices. The Device Tracker knows the links' status by listing the asynchronous messages exchanged between an AP and a connected mobile device. The data collected by the device tracker help the management plane to maintain the global view of the network.
- *Collector:* this element uses network monitoring technologies (i.e. passive and active monitoring) to measure different network metrics (e.g., bandwidth usage, remaining resource availability and number of dropped packets) at various aggregation levels (e.g. per flow, per AP, per user). Moreover, it also measures per flow latency, jitter and error rate by inserting packet probes in the network.
- *Rule DB:* The management plane translates high level network-wide policies to control rules and stores them in the Rule DB. The controller and other control elements (e.g. routing) use these rules to compute the flow table entries for each AP and mobile device.

A. Distributed Hash Table (DHT)

In this section, we use the DHT peer-to-peer to manage a distributed communication among SDN controllers (each controller represents one zone) through the Super SDN controller. Each SDN controller has a DHT table where all networking information is held. The work mechanism of the distributed SDN controllers through the DHT is performed in a master and slave relationship, where the master represents the Super SDN controller and other SDN controllers act as slaves. The slave (SDN controller) updates its flow table periodically or dynamically depending on the network conditions, then it sends the updated flow table to the master (Super SDN controller). The master collects the routing information from the SDN controllers and it calculates this information and distributes the decision of the inter connectivity network between them.

The hash table in the Super SDN controller consists of two fields (pointer and controller ID), as shown in Fig. 2. The

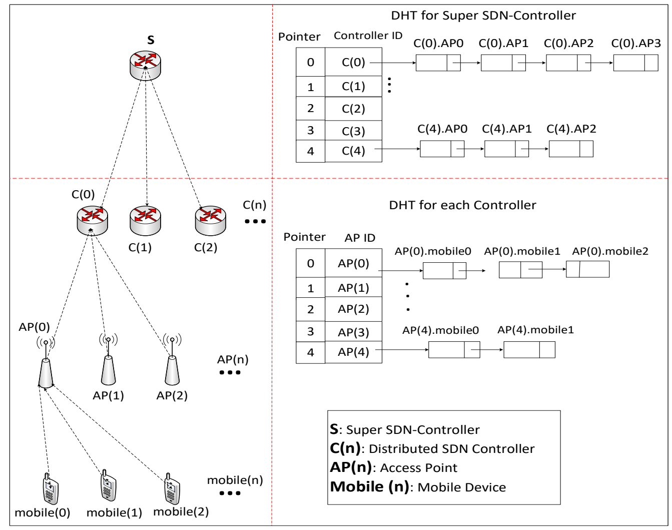

Fig. 2. Distributed hash table.

pointer field refers to the SDN controller ID in the hash table, where it represents as (i^{th}) entry for the hash table. Moreover, controller ID field illustrates the name of each SDN controller that connected to the Super SDN controller. Further, via the controller ID the super SDN controller can refer to all the APs associated with the SDN controller. In addition, the controller ID in an SDN controller represents all APs IDs, where each AP pointed to a number of users under the coverage area. For example, in the DHT of Super SDN controller, there are a number of connected SDN controllers (e.g. C(1), C(2), C(3)), each of these controllers are managed a number of APs, and the controller ID refers to these APs as a link list such as (C(1).AP1, C(1).AP2, C(1).AP3, etc.) (see Fig. 2).

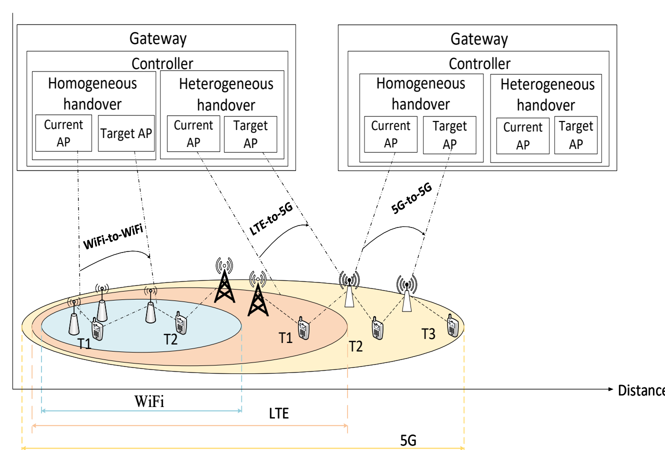

Fig. 3. Homogeneous and heterogeneous handover.

B. Detailed Operations for Handover

In the proposed 5G architecture, before we explain the handover process in detail, we identify two terminologies regarding the handover processing: homogeneous and heterogeneous handover. The homogeneous handover in our context means that when a user moves between two APs (base stations) belonging to the same type of access network. In contrast, the heterogeneous handover means that a user moves between two APs each one from different access network such as LTE and WiFi, as illustrated in Fig. 3. The handover starts when the mobile device requests to join a new AP, it will initially send a request message to the SDN controller, and then the controller sends the assigned decision back to the current AP with which the user is connected to, as depicted in Fig. 4 and 5.

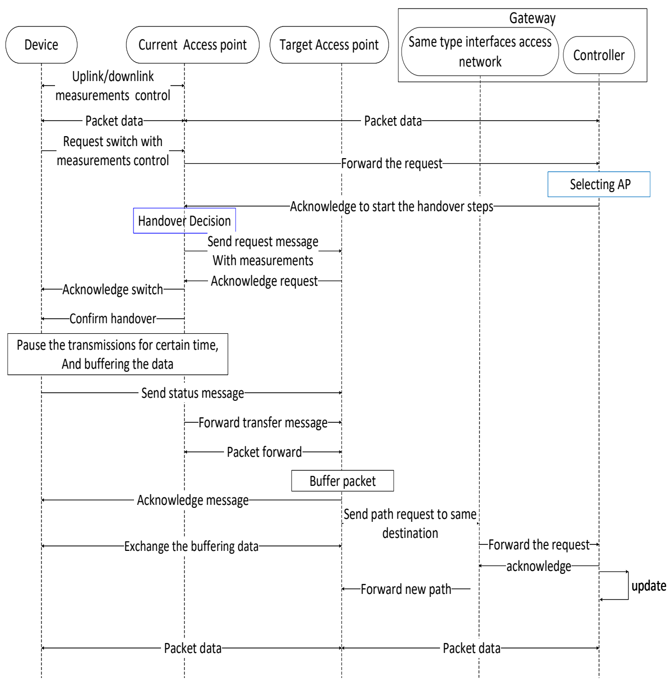

Fig. 4. Sequence messaging of homogeneous handover.

In case of homogeneous handover, the user mobile device sends forward request through a current AP to SDN controller, then the SDN controller acknowledges the request to start the handover processing through steps, which is shown in Fig. 4. The procedure and steps for the homogeneous handover are described as follows:

- The mobile device sends a request message for associated SDN controller via AP to switch to another AP, when it in the overlapped area and the RSS below the threshold (according to the network interface). This message contains a list of APs listed in a descending order based on which AP (or base station) has the highest RSS in multi-interfaces access networks, along with a set of parameters specified by location, time and current service.
- The current AP forwards this message to the SDN controller to select the highest satisfaction AP among different APs.
- Then the SDN controller acknowledges the request message to start the handover steps based on the selected AP (homogeneous handover).
- Handover starts from the current AP, it sends the message request with measurement parameters to the target AP.
- The target AP sends acknowledgement message to the current AP, then the current AP forwards this message to the mobile device to confirm the handover to the target AP.
- The transmission between the mobile device and current AP will pause for a certain of time. The current AP continues buffering the data of current service for the mobile device (from the core network side).
- The mobile device sends status message to the target AP includes the location, the device status and the current service,
- At the same time, the current AP also sends a message to start transferring the buffered data packets to the target AP.
- The target AP will acknowledge the message from the mobile device and exchange the buffered data.
- Finally, the target AP sends a request to the controller to establish a new path to the destination for exchange the data service with the mobile device.

Within the same context, if the heterogeneous handover procedure, where the current AP forwards the request message of a mobile device to the SDN controller. Then, the SDN controller sends control message (serve) to the multi-interface part in the gateway to serve the mobile device request. After sending an acknowledgment message to the current AP of the mobile device, the handover steps will start, as shown in Fig. 5. The procedure and steps of heterogeneous handover are described as follows:

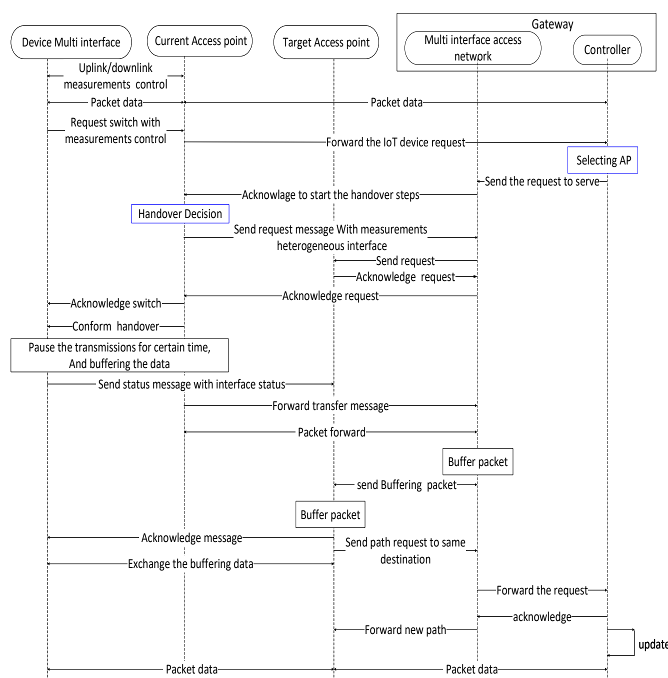

Fig. 5. Sequence messaging of heterogeneous handover.

- The mobile device sends a request message via current AP (or base station) to the associated SDN controller in order to switch to another AP, when it in the overlapped area and the RSS under a threshold value (according to the interface). This message contains a list of APs (or base stations) arranged in a descending order depend on the highest Received Signal Strength (RSS) in multi-interfaces of access networks, along with a set of parameters specified by location, time and current service.
- The current AP forwards the message to the SDN controller in order to select the highest satisfied AP (or base station) among the list for start the heterogeneous handover.
- Then the controller sends the request to the multi-interface access network part in the gateway to start the handover process because the target AP (or base station) from different access network.
- Then the multi-interface access network part acknowledges the request message to start the handover steps based on the selected AP (or base station).
- The target AP (or base station) sends acknowledgment request to the current AP (or base station) via the multi-interface part, then the current AP (or base station) forwards the message to the mobile device to confirm the handover to the target AP (or base station).
- The transmission between mobile device and current AP (or base station) will pause for a certain of time, and the current AP (or base station) buffers the current data service of the mobile device (from core network side).
- The mobile device sends a status message to the target AP (or base station) contains a location, the device status and the current service.
- At the same time, the current AP (or base station) also sends a message to the target AP (or base station), via the multi-interface access network part, to start transferring the buffered data packets as shown in fig. 5.
- After acknowledges the message, the target AP (or base station) establishing the session of exchange the buffered data to the mobile device.
- Finally, the target AP (or base station) sends a request message to the SDN controller in order to establish a new path to the service destination for exchange the data service to the mobile device.

IV. Results Evaluation

In this section, we present a comprehensive performance evaluation of our proposed architecture. In the subsequent part, we refer to our solution as Distributed Mobility Management Architecture (DMMA). We compare our mechanism against two well-known mobility management approaches, namely PMIPv6 [20] and HMIPv6 [14] using OMNeT++ simulator. The network topology considered in this simulation is presented in Fig. 6.

In order to simulate the mobility management of DMMA between LTE and WiFi we use IPv6 to tunnel the IP-Flow of the MN when it moves between LTE and WiFi and vice versa.

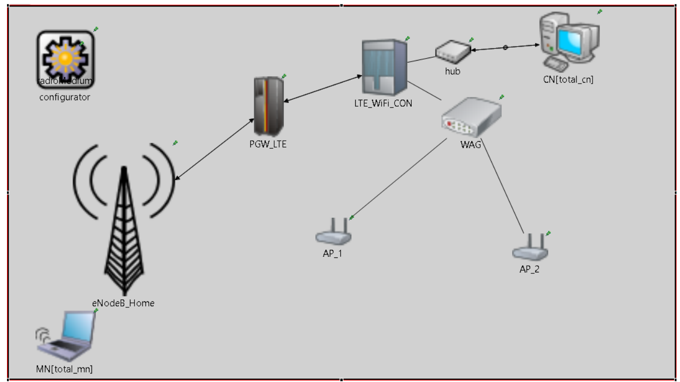

Fig. 6. The network topology in OMNeT++ simulator.

In simulation, we consider heavy video traffic service, which is composed of 24 frames/second and the frame size is 1562 bytes (300 Kbps).

A. Handover Latency

Handover latency results obtained from the simulation under the three different mobility mechanisms are presented in Fig. 7. In particular, this figure illustrates handover latency for three different handover scenarios. The first handover is from LTE eNodeB to WiFi AP. And the second and third handovers are between the WiFi APs. Looking at this figure, we notice that the HMIPv6 has the highest handover latency among all three handover scenarios (2.208s and 1.537s in the first and second handover scenario, respectively). This is because HMIPv6 mobility management is Host-based where a Mobile Node (MN) involves the most mobility management related activities (e.g. binding update to the mobility anchor point, on-link care-of-address creation and wireless media access signaling), resulting high handover latency. On the other hand, PMIPv6 and DMMA outperform compared to HMIPv6 mainly because both of them are Network-based mobility management schemes where all the mobility events that are mentioned above are managed by a network without involvement of an MN. Additionally, this figure delineates that the latency in PMIPv6 is notably higher compared to proposed DMMA. This is due to the fact that, when the MN moves between different APs, the signalling messages exchanged between Mobile Access Gateway (MAG) and the Local Mobility Anchor (LMA) are needed in order to update the binding table for a new LMA of the MN [13]. Whereas, such messages are not required in DMMA because all the binding updates are done in the LTE-WiFi-controller.

B. Traffic Overhead

In this section, we describe the total traffic delivery packets between the Corresponding Node (CN) to the MN. The total traffic overhead is depending on the number of hops between the CN and MN in respect of mobility and the packet size. Figure 8 illustrates the comparison of traffic delivery with respect to different flow rates for the three mobility management schemes (DMMA, PMIPv6 and HMIPv6). From the figure,

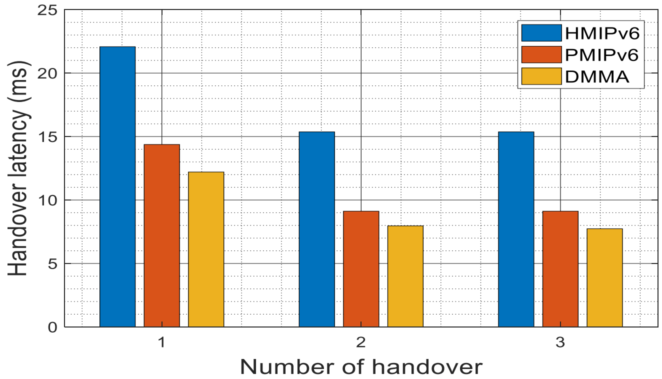

Fig. 7. Handover latency evaluation among HMIPv6, PMIPv6 and DMMA.

we can see that the DMMA has lower packets delivery cost compared to other mobility management schemes. This is due to fact that in DMMA the global address of a MN remains unchanged, there is no signalling required between the MN and CN, thereby reducing signalling message overhead.

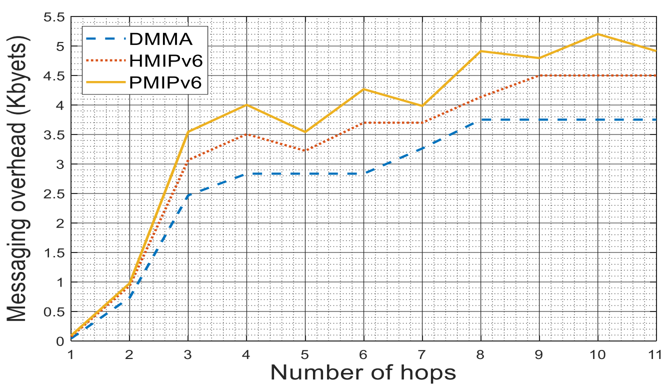

Fig. 8. Signalling messages overhead comparison among HMIPv6, PMIPv6 and DMMA.

V. Conclusion

In this paper, a novel mobility management architecture is proposed in order to facilitate seamless mobility management for the users when they move from a SDN controller coverage to another in 5G heterogeneous networks. Findings based on simulations impart that proposed framework (DMMA) outperforms other mobility management schemes. Among other important research issues, in future, we are planning to study: mobility prediction aware forwarding path establishment mechanism, mobility aware early resource reservation (network slices) mechanism, and reducing number of control messages among the SDN controllers for updating forwarding path in data plane in 5G heterogeneous mobile networks.

References

[1] E. Dahlman, G. Mildh, S. Parkvall, J. Peisa, J. Sachs, Y. Seln, and J. Skld, "5G wireless access: Requirements and realization," *IEEE Communications Magazine*, vol. 52, no. 12, pp. 42–47, 2014.

[2] Z. Arslan, M. Erel, Y. Özçevik, and B. Canberk, "SDoff: A software-defined offloading controller for heterogeneous networks," *IEEE Wireless Communications and Networking Conference, WCNC*, vol. 3, pp. 2827–2832, 2014.

[3] J. Liu, Y. Li, M. Chen, W. Dong, and D. Jin, "Software-defined internet of things for smart urban sensing," *IEEE Communications Magazine*, vol. 53, no. 9, pp. 55–63, 2015.

[4] 5G PPP SN Working Group, "Vision on Software Networks and 5G," *5G-PPP Initiative*, no. January, pp. 1–38, 2017. [Online]. Available: https://5g-ppp.eu/wp-content/uploads/2014/02/5G-PPP_SoftNets_WG_whitepaper_v20.pdf

[5] V.-g. Nguyen, A. Brunstrom, K.-J. Grinnemo, and J. Taheri, "SDN / NFV-Based Mobile Packet Core Network Architectures : A Survey," *IEEE COMMUNICATIONS SURVEYS & TUTORIALS*, vol. 19, no. 3, pp. 1567–1602, 2017.

[6] P. Rost, C. Mannweiler, D. S. Michalopoulos, C. Sartori, V. Sciancalepore, N. Sastry, O. Holland, S. Tayade, B. Han, D. Bega, D. Aziz, and H. Bakker, "Network Slicing to Enable Scalability and Flexibility in 5G Mobile Networks," *IEEE Communications Magazine*, vol. 55, no. 5, pp. 72–79, 2017.

[7] M. Qian, Y. Wang, Y. Zhou, L. Tian, and J. Shi, "A super base station based centralized network architecture for 5G mobile communication systems," *Digital Communications and Networks*, vol. 1, no. 2, pp. 152–159, 2015. [Online]. Available: http://linkinghub.elsevier.com/retrieve/pii/S2352864815000073

[8] M. Jammal, T. Singh, A. Shami, and Y. Li, "Software-Defined Networking : State of the Art and Research Challenges," *Computer Networks Elsevier*, vol. 72, pp. 74–98, 2014.

[9] A. Potluri and G. Prathyusha, "An efficient dht-based elastic sdn controller," in *Communication Systems and Networks (COMSNETS), 2017 9th International Conference on*. IEEE, 2017, pp. 267–273.

[10] Arcep, "5G: Issues & Challenges," Tech. Rep., 2017. [Online]. Available: https://www.arcep.fr/uploads/tx.../Report-5G-issues-challenges-march2017.pdf

[11] J. Lee and Y. Yoo, "Handover cell selection using user mobility information in a 5G SDN-based network," in *International Conference on Ubiquitous and Future Networks, ICUFN*, 2017, pp. 697–702.

[12] A. S. Dayem Alfoudi, M. Dighriri, G. M. Lee, R. Pereira, and F. P. Tso, "Traffic management in LTE-WiFi slicing networks," *Proceedings of the 2017 20th Conference on Innovations in Clouds, Internet and Networks, ICIN 2017*, pp. 268–273, 2017.

[13] S. S. Newaz, R. U. Akbar, J. Choi, G. M. Lee, and N. Crespi, "Efficient ip mobility management for green optical and wireless converged access networks," in *Vehicular Technology Conference (VTC Fall), 2012 IEEE*. IEEE, 2012, pp. 1–5.

[14] S. Pack, T. Kwon, and Y. Choi, "A performance comparison of mobility anchor point selection schemes in Hierarchical Mobile IPv6 networks," *Computer Networks*, vol. 51, no. 6, pp. 1630–1642, 2007.

[15] H. Zhang, X. Chu, W. Guo, and S. Wang, "Coexistence of Wi-Fi and heterogeneous small cell networks sharing unlicensed spectrum," *IEEE Communications Magazine*, vol. 53, no. 3, pp. 158–164, 2015.

[16] H. Zhang, N. Liu, X. Chu, K. Long, A. H. Aghvami, and V. C. Leung, "Network Slicing Based 5G and Future Mobile Networks: Mobility, Resource Management, and Challenges," *IEEE Communications Magazine*, vol. 55, no. 8, pp. 138–145, 2017.

[17] M. Chen, Y. Hao, M. Qiu, J. Song, D. Wu, and I. Humar, "Mobility-aware caching and computation offloading in 5G ultra-dense cellular networks," *Sensors*, vol. 16, no. 7, p. 974, 2016.

[18] X. Ge, J. Ye, Y. Yang, and Q. Li, "User mobility evaluation for 5G small cell networks based on individual mobility model," *IEEE Journal on Selected Areas in Communications*, vol. 34, no. 3, pp. 528–541, 2016.

[19] V. Sharma, I. You, and R. Kumar, "Resource-based mobility management for video users in 5G using catalytic computing," *Computer Communications*, 2017.

[20] S. M. Raza, D. S. Kim, and H. Choo, "Leveraging PMIPv6 with SDN," in *Proceedings of the 8th International Conference on Ubiquitous Information Management and Communication*. ACM, 2014, p. 13.