LTE-WLAN Integrated Virtualization Network Architecture

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Abstract. Heterogeneous network is an inevitable trend for the fifth generation wireless communications (5G). The existing scheme for the interworking of the Long Term Evolution (LTE) system and Wireless Local Area Network (WLAN) system is achieved by Packet Data Network Gateway (PGW) at the core network. However, it is not efficient enough since 5G may bring in signaling storm for some increasing popular scenarios, such us instant messaging, device-to-device communications. In this paper, we propose a new LTE-WLAN integrated architecture. This architecture is designed based on Software Defined Mobile Network (SDMN) and network virtualization. A new entity called Macrocell Integrated Controller (Ma-IC) is introduced in the new architecture. It can shield the differences of the two systems for core network to simplify the management procedure and minimize the change of the core network to be adaptive to this proposed architecture. In addition, some control functions originally in core network are immigrated into Ma-IC, which can help save some backhaul signaling overhead. Another main function of Ma-IC is to coordinate the LTE system and WLAN system to provide user equipment (UE) more available resources. Besides, a new mechanism of handover for UE is designed based on this proposed architecture, and the simulation shows that handover signaling can be reduced by 29.8% compared with existing mechanism defined in 3GPP standards.

Keywords: LTE · WLAN · Architecture · Handover

1 Introduction

Recently, enormous multi-media equipment rushes into the market. The demand of high-speed wireless communications is increased [1]. Many advanced technologies, such as Orthogonal Frequency Division Multiplexing (OFDM) and Multiple-Input Multiple-Output (MIMO), are adopted to improve the user experience. However, in the traditional network architecture, interaction among base station (BS) is unable to support a unified resource scheduling and high performance mobility management. To some extent, the architecture is a bottleneck to the development of the wireless network. A more intelligent architecture is the key of the research in 5G. Moreover, the diversity of the user services and

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the explode of the traffic pose a huge challenge to the LTE network since the spectrum resource has already been extremely scarce [2,3]. Meanwhile, WLAN can use the unlicensed frequency band to provide high-speed data transmission service, so it forms a great advantage in resource utilization. Besides, as a low-cost, easy-deployment wireless access network, WLAN has been wildly used. So converge LTE and WLAN is an effective way to alleviate the shortage of resource.

Except from different modes, 5G will also converge base stations that with different coverages [4], different powers and different service bearing capabilities to constitute a complex heterogeneous network. Heterogeneous network can increase the density of the access networks in an area [5], so how to manage and coordinate these networks to make full advantage of every one of them is another problem. The proposal of the SDMN [6] provides a new thought to this problem. SDMN is an extension of SDN, which is used to be applied in computer field. One of the core concepts of SDN is to decouple the control plane and the data plane [7,8]. In SDMN, a centralized control plane can dispatch different access networks for users, thus realize the network virtualization. And some network equipment only takes charge of data plane, and forward data according to the signaling from centralized control plane. Ijaz Ahmad et al. [2] do a survey about SDMN, but they give no technical details. In this paper, we conduct a thorough study about SDMN and apply it to a new wireless network architecture. LTE network and WLAN network are integrated in this architecture, to realize the effective utilization of different frequency bands and take full advantages of multi modes access network. Except from different modes, the coverages of access points are also different. With control-service split technology [10], the control signaling and service data are decoupled, and are respectively forwarded by access points in macrocells and microcells. The employment of SDMN facilitates the management of heterogeneous networks and also reduces the service response time. Meanwhile, frequent handover caused by dense deployment is reduced, which help avoid extra signaling overhead and negative effect on user experience.

The rest of the paper is organized as follows. Section 1 introduces the background information and some related work is described in Sect. 2. Then, the proposed architecture is presented in Sect. 3. After that, Sect. 4 is about the new mechanism of handover and Sect. 5 is the simulation results. Finally, a conclusion is given in Sect. 6.

2 Related Work

The existing system in Fig. 1 integrates LTE and WLAN at the PGW in core network [11], and the high throughput may make it a bottleneck to the performance of the whole network. Besides, instant messaging is wildly used, and in the existing network, every short message has to go through the backhaul to core network, which may cause a severe signaling overhead.

In [12], the author proposes three different LTE-WLAN integration architectures. In the first one, the Mobility Management Entity (MME) serves as the

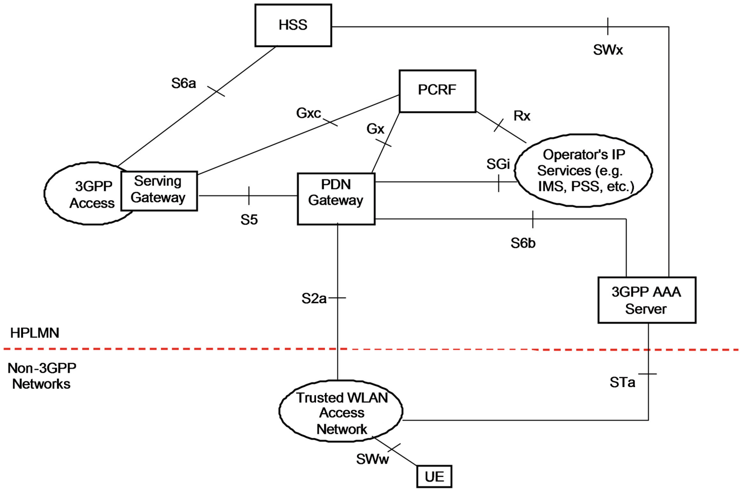

Fig. 1. Existing integrated network [11]

control plane integration point while the Serving Gateway (S-GW) serves as the user plane integration point. The second one integrates LTE and WLAN system. The integration point is moved out of the EPC to a proposed ISW Gateway. In the third architecture, an enhanced X2 interface is proposed directly between the WLAN AP and the HeNB. However, all these networks give no consideration to the coordination of all these densely-deployed access networks. And the modification of the existing network is significant, which will cause a great expense to adopt this architecture.

To address these problems, an optimized architecture is proposed in this paper and the details are described in the following sections.

3 Controller-Based Converged Architecture

The Controller-Based Converged Architecture (CBCA) is deployed as Fig. 2. Ma-IC, a new added entity, mainly takes charge of control signaling, and the data forwarding is accomplished by Microcell Connection Point (MiCP): Microcell Wi-Fi Access Point (Mi-WAP) and Microcell LTE Base Station (Mi-LBS). To realize the above functions, the protocol stack of CBCA network is designed as Fig. 3, which demonstrates an obvious control-service split design. UE sends control signaling to Ma-IC, after processing, it is sent to MME in core network. As for service data, multi-mode UE send them through two individual link: Mi-LBS and Mi-WAP, and are both received by SGW.

3.1 Ma-IC

Ma-IC is the core entity of CBCA. It can implement basic function of a base station, but with a larger coverage. And there are some enhancements in the

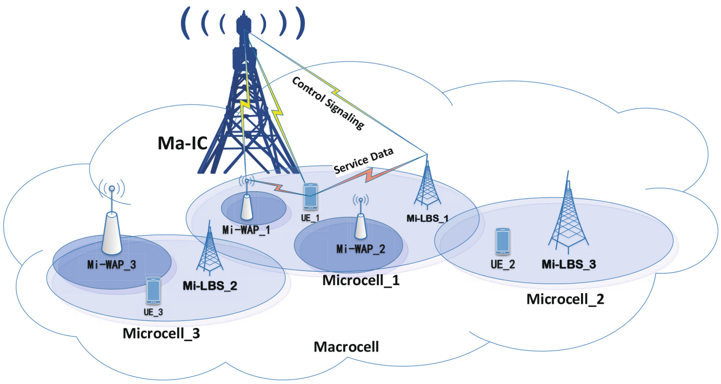

Fig. 2. Controller-based converged architecture

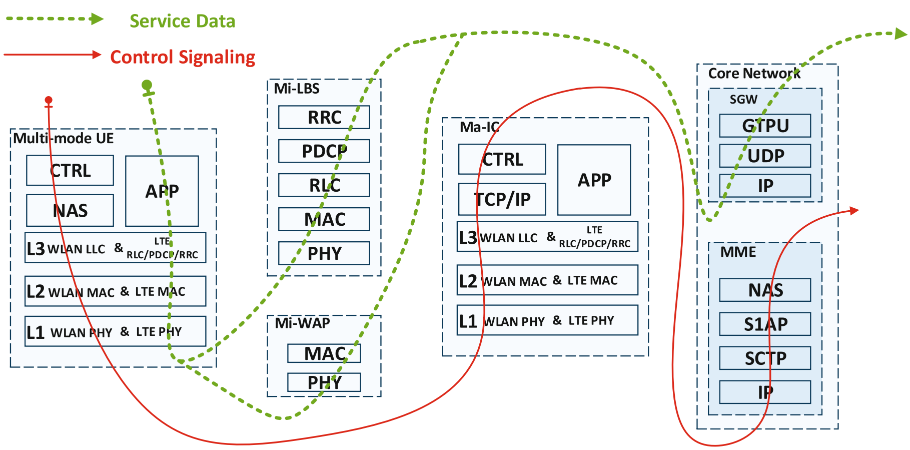

Fig. 3. Protocol stack of CBCA

control plane. The current core network gateway devices, such as MME and S-GW, forward both service data and control signaling, which are coupled together. However, Ma-IC adopts the idea of SDN, that is, decoupling control plane from data plane. The relevant control functions in core network gateways and base stations are extracted into Ma-IC to achieve a centralized control.

Since Ma-IC has the ability to communicate with both cellular network and WLAN network, so the entire WLAN protocol is added to the original LTE protocol. The PHY layer, MAC layer and LLC layer in WLAN protocol, corresponding to the PHY layer, MAC layer, RLC layer, PDCP layer and RRC layer in LTE protocol are stay unchanged. Above these layers and below the TCP/IP layer of LTE protocol, a new layer called CTRL layer is added. And there are mainly three function modules in this layer:

1. Data Processing Module
   When communicate with MiCP, this module demultiplexes signaling from upper layer, and encapsulates them respectively into LTE and WLAN format, then send them down to the corresponding lower layers, and then to the corresponding MiCP. And when Ma-IC responds to Mi-WAPs' request, it can transform packets from WLAN LLC into LTE format and integrate them with those from LTE lower protocol, then send the complete packets to upper layer to be processed. By this way, the differences of access networks can be shielded from the core network, and WLAN network can be easily integrated into the LTE system. In this design, UE is a dual-link device, and it can simultaneously connect with Mi-LBS and Mi-WAP to receive data. So the protocol stack of UE also integrates both LTE and WLAN protocol. But when interact with Mi-IC, to streamline the process, only LTE protocol is used.
2. Information Management Module
   By broadcast channel, every Ma-IC establishes a RAN Table. This table tracks the location information, configuration information, and connection status of Mi-WAPs, Mi-LBSs as well as UEs that are connected to that Ma-IC. This can help Ma-IC have an overall view about the entire network. And when there are some changes in those connected Mi-WAPs, Mi-LBSs or UEs, Ma-IC will update these RAN Table. In addition, information about Ma-IC itself is also recorded in the table to decide whether there is enough resource for another connection. Furthermore, Home Subscriber Server (HSS) in core network can also obtain information from RAN Table.
3. Connection Control Module
   Ma-IC executes access procedure when there are some new Mi-WAPs, Mi-LBSs or UEs. Two different sets of access process are executed correspondingly for LTE system and WLAN system, which are the same as the existing standard process for users. So users can arrange their own microcell access networks based on requirement. And the Ma-IC can dynamically adjust the resource allocation according to user demand and network traffic statistical characteristic. Besides, the handover process of the access equipment is also executed by this module. And the details will be described in Sect. 4.

3.2 Mi-CP

The features of Mi-WAP and Mi-LBS are dense deployment and high-speed transmission. Work principle is still in accordance with the 3GPP standards. However, since UE can simultaneously connect to a Mi-WAP and a Mi-LBS to receive packets, so every packets will be labeled in order to be rearranged by UE. And when a packet needs to be retransmitted, the only information that needs to be feedback is the label. It can help reduce the signaling overhead.

With the change of the architecture, the interaction among network entities is also changed. Take a basic data request scenario for example to illustrate how Mi-CP works. As shown in Fig. 4:

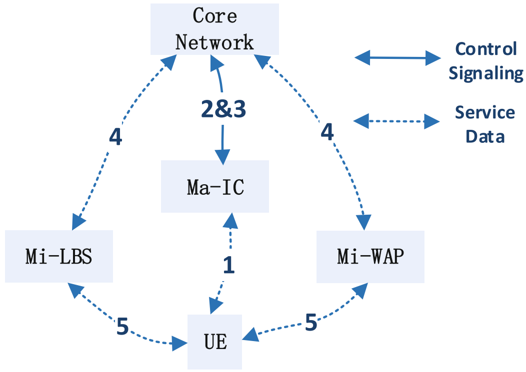

Fig. 4. Interaction among entities in CBCA

Step 1 UE sends data request to Ma-IC.

Step 2 Ma-IC obtains UE connection status from the RAN Table and calculates a Distribution Ratio (DR). RAN Table keeps records about the configuration information, available resources, network status of the Mi-CPs under the coverage of that Ma-IC. It also keeps real-time updates of UEs connection status of Mi-CPs.

Step 3 Ma-IC send DR and data request together to core network, which informs core network to split downlink data transmission to the corresponding access network according to DR.

Step 4 Core network encapsulates data and send them to Mi-LBS and Mi-WAP respectively.

Step 5 Then Mi-CPs forward data to UE.

4 Handover Scenario

There are two scenarios: Microcell Handover (MiHO) and Macrocell Handover (MaHO). As in Fig. 5, MiHO occurs when UE handovers between two microcells while the Ma-IC stay connected; MaHO occurs when UE handovers between two macrocells, both Ma-IC and MiCP need to be reselected.

The detailed procedure of MiHO is:

Step 1 Ma-IC checks for real time update of RAN Table, and when strength of signal UE receives from Source MiCP is smaller than a threshold, Ma-IC trigger the Mi-HO and send Handover Preparation signaling to UE, including relevant information of optimal Target MiCP selected from RAN Table.

Step 2 UE sends Handover ACK back to Ma-IC.

Step 3 Ma-IC then sends the same information of Target MiCP to Core Network., in order to inform core network to send the data packet to both source MiCP and Target MiCP.

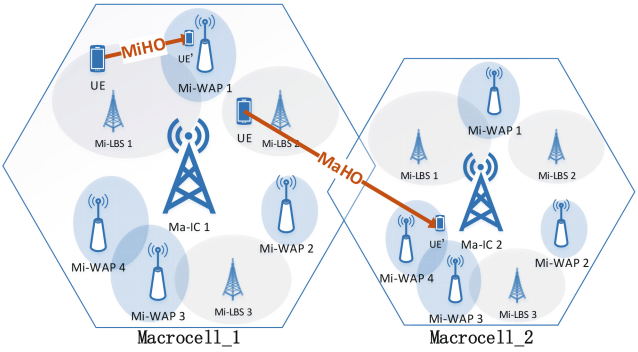

Fig. 5. MiHO and MaHO

Step 4 Ma-IC sends Handover Request to Target MiCP to prepare it for UE's access.
Step 5 UE sends synchronization information to Target MiCP, receive acknowledgement information and execute access procedure. After successful access, UE begins to receive packets from Target MiCP that prepared in step (3).
Step 6 Target MiCP send successful handover ACK back to Ma-IC.
Step 7 Ma-IC send Resource Release to Source MiCP and Core Network, so UE disconnects with Source MiCP and Core Network stops to send data packets to Source MiCP (Fig. 6).

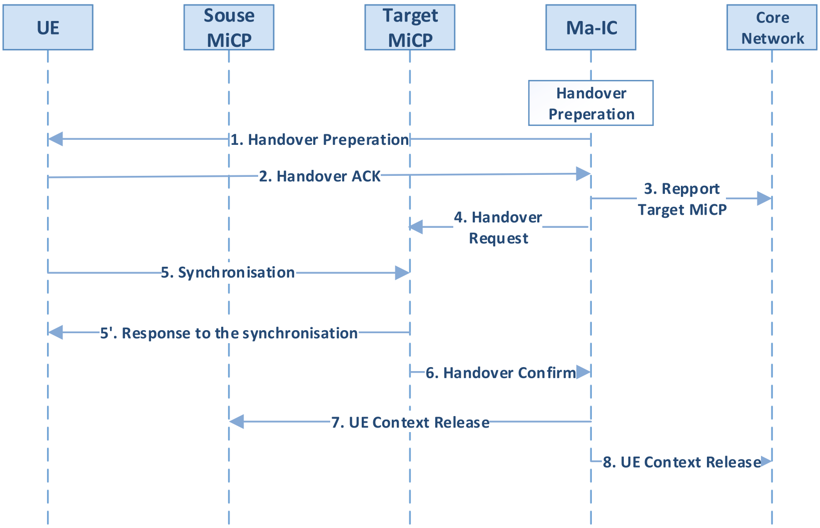

Fig. 6. Microcell handover procedure

The Detail procedure of MaHO is:

Step 1 Source Ma-IC checks for real time update of RAN Table, and when strength of signal UE receives from Source MA-IC is smaller than a threshold, Ma-IC trigger the Ma-HO and send Handover Decision to Core Network.
Step 2 Core Network send relevant information of optimal Target Ma-IC selected from HSS to Source Ma-IC.
Step 3 Source Ma-IC send Handover Request and information of UE to Target Ma-IC.
Step 4 Target Ma-IC select Target MiCP using information of local RAN Table, then send relevant information and handover acknowledgement back to Source Ma-IC.
Step 5 Source Ma-IC then sends the information of Target MiCP and Target Ma-IC to Core Network and UE, in order to inform core network to send the data packet to both source MiCP and Target MiCP.
Step 6 UE sends synchronization information to Target MiCP, receive acknowledgement information and execute access procedure. After successful access, UE begins to receive packets from Target MiCP that prepared in Step 5.
Step 7 Target Ma-IC send successful handover ACK back to Source Ma-IC.
Step 8 Source Ma-IC send Resource Release to Source MiCP and Core Network, so UE disconnects with Source MiCP and Core Network stops to send data packets to Source MiCP (Fig. 7).

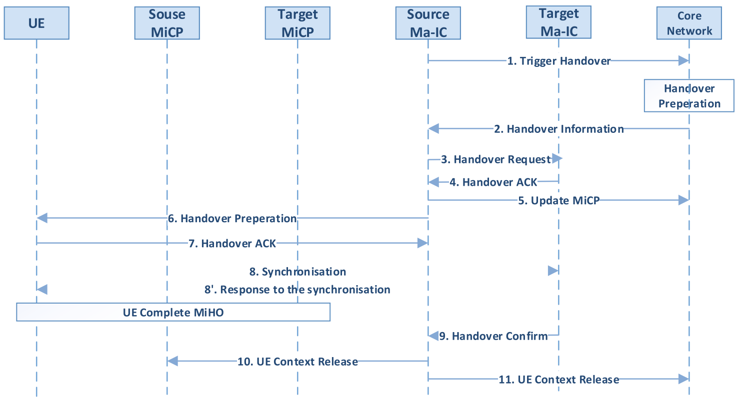

Fig. 7. Macrocell handover procedure

It can be noticed that the procedure of MiHO is simplified to a great extent, and both MiHO and MaHO are soft handover. Under the wide area of an Ma-IC, only MiHO will be triggered. So, the overall handover signaling overhead is reduced.

5 Simulation Results and Analysis

In order to testify the performance of the CBCA, a simulation is performed using OPNET. OPNET is a fully functional network simulation platform, and it has the complete network entity modules with standard configuration. Based on these modules, we reprogram to realize the Ma-IC and the corresponding UE.

5.1 Simulation Setup

The simulation parameter is set as Table 1. Contrast network is the network that used in the present LTE system, in which the UE can only access one network and handover procedure is hard handover.

Table 1. Simulation parameter

Parameter	CBCA network			Contrast network	
	Ma-IC	Mi-LBS	Mi-WAP	Mi-LBS	Mi-WAP
Quantity	1	3	1	3	1
Quantity of UE	12	3	3	3	3
Effective UE	3 in Mi-LBS2				
Transmission power	46 dbm	30 dbm	17 dbm	30 dbm	17 dbm
Radius of coverage	100 m	50 m	10 m	50 m	10 m
Cell selection metric	RSRQ	RAN table	RAN table	RSRQ	RSRQ
Service	Video Conference				

The CBCA is deployed as in Fig. 8, and the contrast architecture is deployed as in Fig. 9.

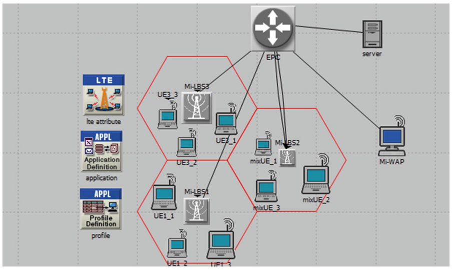

Fig. 8. Controller-based converged architecture deployment

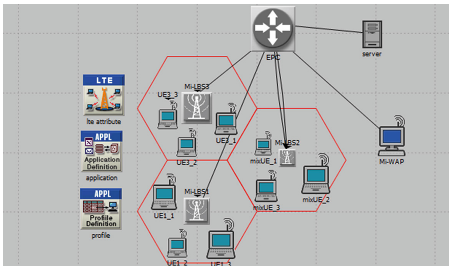

Fig. 9. Contrast network deployment

The mixUE in CBCA deployment is a new developed entity, which can access to LTE and WLAN simultaneously. Its protocol is designed in accordance with

Fig. 3, and the process of UE is shown in Fig. 10. The lower layer protocol of WLAN is added into the original LTE protocol. So mixUE can receive data from both LTE port and WLAN port, then integrate them at CTRL layer and forward to upper layer.

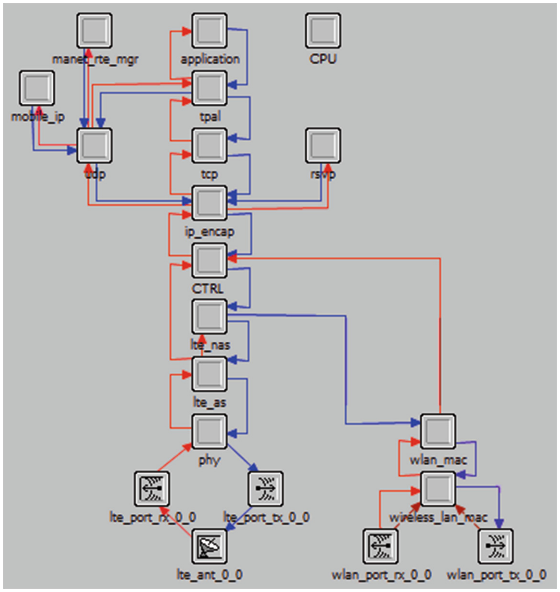

Fig. 10. Process of UE

As for the Ma-IC, to simplify the programming, we put the code of it in core network (EPC in figure), as shown in Fig. 11. The modules in the green square is used for interaction with WLAN network.

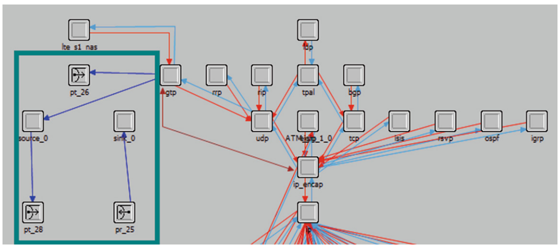

Fig. 11. Ma-IC in core network (Color figure online)

In contrast network, due to the limitation of OPNET, we split a UE into two part to simulate the UE that can only access one network during the handover:

one part can access LTE system and the other one can only access WLAN network. For example, UE2-1 and STA1-1 forms a complete UE handovering from LTE to WLAN network.

5.2 Simulation Results

When simulation starts, mixUE in CBCA firstly execute the access procedure to Mi-LBS2, that is, LTE system. And then when the handover is triggered, mixUE connect to WLAN AP without breaking the connection with eNB2 as described in Sect. 4. The throughput of mixUE is shown in Fig. 12. We can see that the soft handover is achieved since the data transmission is successive during the handover.

And in contrast network, take UE2-1 and STA1-1 as an example again. When simulation starts, UE2-1 initiate the access procedure to Mi-LBS2, that is, LTE system. And then when the handover is triggered, STA1-1 access to Mi-WAP and then UE2-1 disconnects with Mi-LBS2, simulating the hard handover. From Fig. 13, we can see that there is a break-off of the data transmission when handover to the WLAN network.

Three hundred simulation is performed, and the average handover signaling overhead in CBCA network is 73 entries and in contrast network is 104 entries. By contrast, the signaling overhead in CBCA network is reduced by 29.8%.

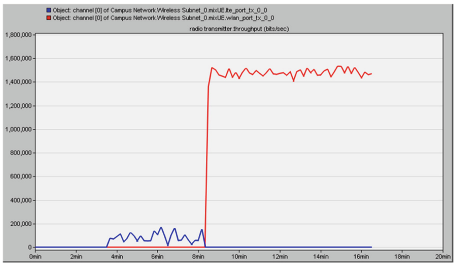

Fig. 12. MixUE throughput

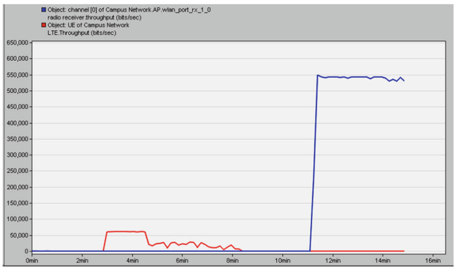

Fig. 13. Existing UE throughput

6 Conclusion

In this paper, we have proposed a new integrated architecture and a corresponding handover mechanism to improve the current interworking between LTE system and WLAN system. A centralized controller which includes data processing module, information management module and connection control module has been employed. It possesses the ability to flexibly dispatch resources among Mi-CPs and also it has a global view of the attached entities to maintain a RAN table, which can be utilized to control the network. The simulation results show that the performance of handover mechanism is enhanced by decoupling the control signaling and service data, since that the control procedure is simplified and thus release more spectrum occupation. In summary, the controller-based integrated architecture satisfied the trend of 5G.

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References

1. Gupta, A., Jha, R.K.: A survey of 5G network: architecture and emerging technologies. IEEE Access **3**, 1206–1232 (2015)
2. Zhang, H., Chu, X., Guo, W., Wang, S.: Coexistence of Wi-Fi and heterogeneous small cell networks sharing unlicensed spectrum. IEEE Commun. Mag. **53**(3), 158–164 (2015)
3. Abinader, F.M., Almeida, E.P., Chaves, F.S., Cavalcante, A.M., Vieira, R.D., Paiva, R.C., Sousa, V.A.: Enabling the coexistence of LTE and Wi-Fi in unlicensed bands. IEEE Commun. Mag. **52**(11), 54–61 (2014)
4. Ling, J., Kanugovi, S., Vasudevan, S., Pramod, A.K.: Enhanced capacity and coverage by Wi-Fi LTE integration. IEEE Commun. Mag. **53**(3), 165–171 (2015)
5. Kim, D.S., Noishiki, Y., Kitatsuji, Y., Yokota, H.: Efficient ANDSF-assisted Wi-Fi control for mobile data offloading. In: International Wireless Communications and Mobile Computing Conference (IWCMC), pp. 343–348 (2013)
6. Chen, T., Matinmikko, M., Chen, X., Zhou, X.: Software defined mobile networks: concept, survey, and research directions. Commun. Mag. IEEE **53**(11), 126–133 (2015)
7. Wood, T., Ramakrishnan, K.K., Hwang, J., Liu, G., Zhang, W.: Toward a software-based network: integrating software defined networking and network function virtualization. IEEE Netw. **29**(3), 36–41 (2015)
8. An, X., Kiess, W., Perez-Caparros, D.: Virtualization of cellular network EPC gateways based on a scalable SDN architecture. In: IEEE Global Communications Conference, pp. 2295–2301 (2014)
9. Ahmad, I., Liyanage, M., Namal, S., Ylianttila, M.: New concepts for traffic, resource and mobility management in software-defined mobile networks. In: Conference on Wireless On-Demand Network Systems and Services, pp. 1–8 (2016)
10. Jha, S.C., Sivanesan, K., Vannithamby, R., Koc, A.T.: Dual connectivity in LTE small cell networks. In: IEEE Globecom Workshops (GC Wkshps), pp. 1205–1210 (2014)
11. 3GPP TS 23.402: Architecture Enhancements for Non-3GPP Accesses (2016)
12. Tomici, J., Starsinic, M., Mohamed, A.S.I., Li, Q.: Integrated small cell and Wi-Fi networks. In: IEEE Wireless Communications and Networking Conference (WCNC), pp. 1261–1266 (2015)