International Journal of Electrical and Computer Engineering (IJECE)
Vol. 11, No. 6, December 2021, pp. 5127~5136
ISSN: 2088-8708, DOI: 10.11591/ijece.v11i6.pp5127-5136

Signalling load reduction in 5G network based on cloud radio access network architecture

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Article Info

Article history:

Received Dec 16, 2020
Revised Apr 6, 2021
Accepted Apr 26, 2021

Keywords:

C-RAN
EPS mobility management
LTE
SDN

ABSTRACT

The rapid growth of both mobile users and application numbers has caused a huge load on the core network (CN). This is attributed to the large numbers of control messages circulating between CN entities for each communication or service request, however, making it imperative to develop innovative designs to handle this load. Consequently, a variety of proposed architectures, including a software defined network (SDN) paradigm focused on the separation of control and data plans, have been implemented to make networks more flexible. Cloud radio access network (C-RAN) architecture has been suggested for this purpose, which is based on separating base band units (BBU) from several base stations and assembling these in one place. In this work, a novel approach to realize this process is based on SDN and C-RAN, which also distributes the control elements of the CN and locates them alongside the BBU to obtain the lowest possible load. The performance of this proposed architecture was evaluated against traditional architecture using MATLAB simulation, and. the results of this assessment indicated a major reduction in signalling load as compared to that seen in the traditional architecture. Overall, the number of signalling messages exchanged between control entities was decreased by 53.19 percent as compared to that seen in the existing architecture.

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1. INTRODUCTION

Mobile subscriptions increased by about 4 percent, while cellular data usage increased by around 70 percent between Q1 2016 and Q1 2017 [1]. These increases can be attributed to an increase load of signals from smart phones [2] as well as growth in machine to machine applications (automotive systems, robots, remote controls.) [3], [4]. Such growth leads to an increase in the number of signals exchanged between various long term evolution (LTE) entities, however, creating an urgent need for an efficient network to accommodate this load to be designed and implemented [5]. The standard LTE architecture consists of several evolved node Bs (eNBs) that provide wireless connectivity to user equipment and an evolved packet core (EPC) that consists of four main components: a mobility management entity (MME), a packet data network (PDN) gateway (PGW), a serving gateway (SGW), and a home subscriber server (HSS), as shown in Figure 1. Reshaping this network architecture into something more scalable that can be easily adapted to customer needs is, however, essential to reducing costs and solving the signalling load issues currently experienced by the evolved packet core (EPC). These growing demands will be met by the implementation of fifth generation (5G) cellular networks [6], which support a wider range of technologies, such as machine to machine communications, internet of things, and device to device communications. Such applications are likely to have an effect on multiple industry, societal, and consumer interactions [7]-[15].

The cloud radio access network (C-RAN) is the most promising architecture for supporting the required next generation networks, being expected to accommodate significant growth in traffic while reducing latency and improving data rates [16]. However, mobile network operators (MNO) still require new ways to implement their 5G networks to better exploit the software-defined networks (SDN) and network function virtualization (NFV) offered.

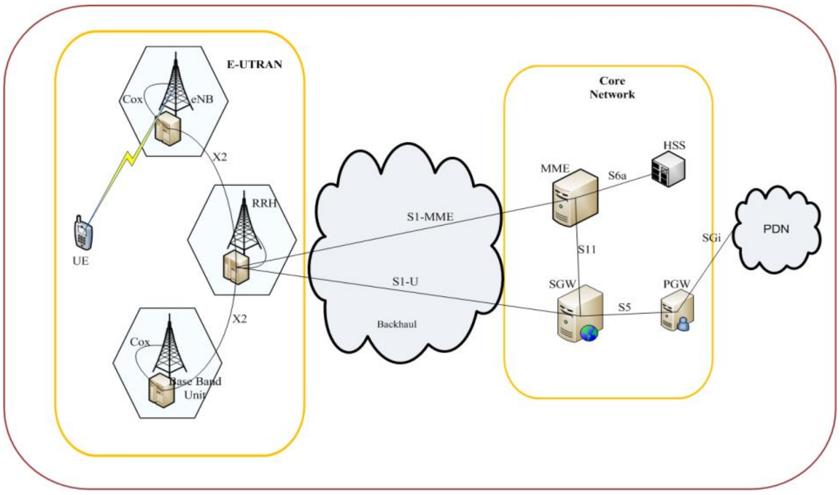

Figure 1. Traditional LTE architecture network

By using virtualization technologies, MNO can utilise distributed data centres to virtualize and decentralize networks elastically and cost-effectively [17]. Deploying network architecture virtual networks should improve adaptable access, reducing effort and increasing efficiency for improved applications [18]. SDN [19] requires an unmistakable segregation between the control and user planes in the network; thus, by applying SDN, various network management tasks can be improved, with new innovations and technologies implemented more easily, allowing network operators to boost their revenue streams. This paper therefore introduces a new approach based on SDN and C-RAN that, as well as distributing and moving the control elements of the core network, aligns these with the BBU in order to achieve the lowest level of load possible on the core network.

The current architecture used in LTE network lacks the flexibility to accommodate significant increases in data request rates. In addition, the control entities in the core networks suffer from excessive signalling load due increases in data demand rates. This paper thus presents fully distributed core network (FDCN) architecture capable of implementing all network activities and reducing the network signalling load to a minimum while ensuring balanced distribution of network loads among control entities. To achieve this, the first step is to separate the data plane from the control plane within the core network entities while allowing the control entities to move and aggregate alongside base band units. The behaviour of the proposed 5G architecture network can then be studied, and various network parameters such as cell area, velocity, and user equipment numbers, analysed in order to evaluate the benefits of the proposed architecture in terms of reducing signalling load. The most important network events, such as initial attachment, active to idle and idle to active transitions, network-triggered services, handover, and tracking area updates were therefore studied in this work.

2. RELATED WORKS

In the last few years, heavy signalling loads on core networks have led several researchers to attempt to develop ways to minimise this load. Distributed networks are thus crucial to reducing the workload on relevant entities and improving the efficiency of such systems [20], [21]. Based on this, in 2012, Pianese *et al*. [22] adopted a distribution of a mobility management entity (MME) based on segregation between the control and user planes, applying this to three scenarios, edge deployment, local deployment, and regional deployment. Their analysis showed an overall decrease in signalling latency, allowing estimation of signal transmission delay based primarily on the number of signals exchanged over the network links. In 2013 and 2014, Said *et al.* [23] and Sama *et al.* [24], respectively, suggested using partial segregation between the planes of control and users at the serving gateway (SGW), a creative method that offered an overall reduction in messaging burden. However, this design remained an incomplete solution due to the fact that the PDN gateway (PGW) still functionally adopted existing 3rd generation partnership project (3GPP) architecture. A method complementing that concept was thus proposed by Nguyen *et al.* [25], based on a complete separation of all core network (CN) entities, including PGW-C. These are separated and virtualized as applications operating over an openflow (OF) controller, and this approach is thus focused on complete segregation between the control and user planes. All of the works above utilise distributed radio access network (D-RAN) structures, however.

In 2016, Al-Samman *et al*. [26] deployed MMEs in a single pool with the base band unit (BBU), [27] for an overall reduction in signalling load. Also in 2016, Pozza proposed segregation between the control and user planes in entities of the LTE architecture in conjunction with SDN and virtualization [28]. This approach similarly offered an improvement in signalling latency. In 2016, Qian *et al.* [29] developed super base station architecture for load balancing and resource sharing between baseband units. To facilitate efficient energy use, the logical and physical entity functions were separated from the base station and dynamically assigned to resources that activate or deactivate the baseband units. In 2017 and 2018, Qazi *et al*. [30] and Cho *et al*. [31] respectively rebuilt the control plane of a core network to reduce state transfer overhead across modules to maximise the control and scalability of the plane, while in 2019, Mahapatra *et al.* [32] proposed a new architecture to reduce energy consumption including an innovative technology for cooperative load sharing between base stations. In 2020, Shah *et al.* [33] suggested the refactoring of mobile cores in order to increase speeds by placing the control plane closer to the end user; their proposed architecture also improved control plane throughput and reduced latency. Finally, in 2020, Mahapatra *et al.* proposed a framework for resource allocation and load sharing among baseband units to overcome unbalanced load conditions [34]. This approach demonstrated improvements in the quality of service for C-RAN architecture.

In this paper, current architecture was reconfigured in a manner capable of accommodating excessive loads on the CN. To achieve this, MME, SGW-C, and PGW-C were distributed from the CN and functionally integrated into the BBU pool in the data centre. The signalling load was then evaluated and compared to the existing LTE architecture as an initial step for feasibility analysis, with the aim of determining whether this offers a better signalling load architecture. This rest of this paper is thus organised as shown in: section 3, the proposed system is described, while in section 4, the results of testing the proposed system are discussed. Finally, some initial conclusions are given in section 5.

3. THE PROPOSED SYSTEM

The proposed system is presented in this section, and it includes the integration of the base band unit controller (BBUC) components and the BBU. A new system architecture is thus proposed to merge the functionality of BBUC components with those of BBU in the data centre. Figure 2 depicts the proposed architecture of the C-RAN within the distributed core network. Each C-RAN is, in effect, a cell with its own BBU and BBUC pool, while the C-RAN actually consists of several remote radio heads (RRHs). In addition, as shown in Figure 2, the PGW-U and SGW-U are combined in the area known as the CN. The main tasks of the BBUC are to establish user sessions and deal with the forwarding elements. The LTE control functions (MME, PGW-C, and SGW-C) are achieved by an application running on top of the BBUC. In this work, all signalling messages being exchanged in all LTE network entities are thus considered.

3.1. Network events in the proposed architecture

a. Initial attachment: The initial attachment is the first step towards network registration after user equipment (UE) is enabled. This is triggered after the attach request message is generated by the UE. As the initial attachment event does not depend on the type of applications used by the user's equipment, the signalling load is not affected by the session arrival rate. As is evident from Figure 3, with the exception of the authentication step, the total number of messages after a tracking area update and session creation procedures are complete thus equals four. No signalling load is caused by the control messages between the BBU and the BBUC, and therefore the total number of messages on the BBU controller remains equal four, with these resulting from user equipment tracking area updates, session creation, and bearer modification. The signalling load from the initial connection procedure is thus calculated as:

$$LPI(n) = 4\,Po\,\rho\,A\,C \quad (1)$$

where,
Po: Probability that the UE initiates an attachment procedure in the network.
A : Area of a cell.
ρ : Density of UEs (UEs/km^2).
C : Total number of RRH in the area of concern.

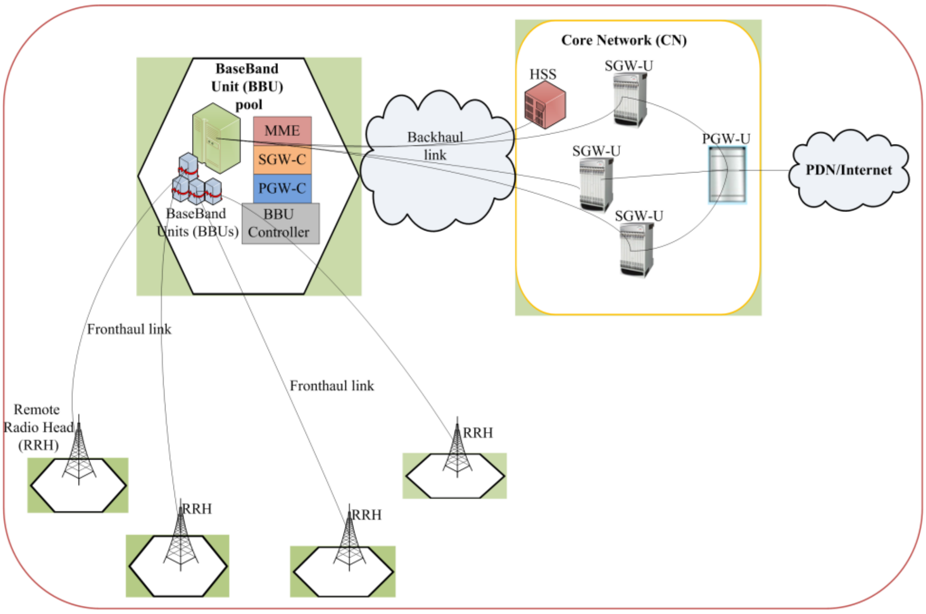

Figure 2. Proposed fully distributed core network (FDCN) architecture

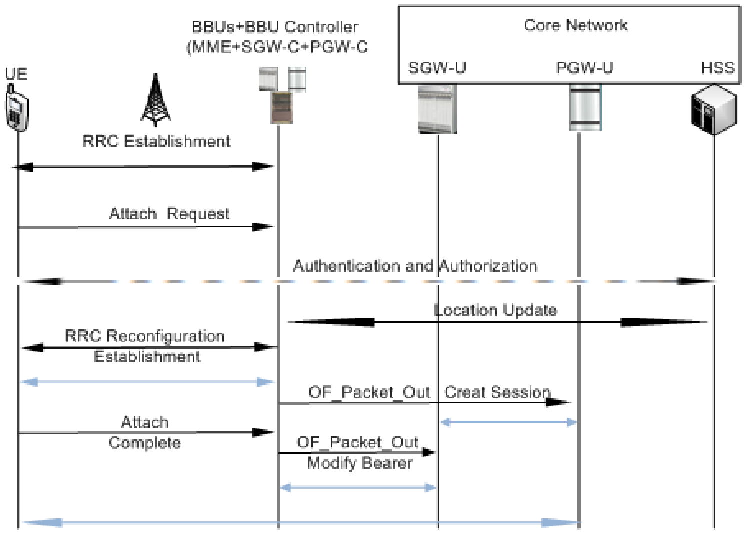

Figure 3. Procedure for the initial attachment

b. Active to idle and idle to active transitions: The call flow for an idle to active event is as follows:
– Service request (UE BBU) ⟶
– Initial UE message (BBU BBU controller) ⟶
– Initial context setup requirement (BBU BBU controller) ⟵

- Initial context setup answer (BBU BBU controller) ⟶
  This information is then sent to the SGW-C by a BBUC that sends the SGW-D IP address, the SGW-TEID values, and the QoS level to the BBU. The BBUC then sends an OF_Packet_Out to the selected SGW-U to establish the bearer.
- OF_Packet_Out (BBU controller SGW-U) ⟶
  the call flow of the active to idle event is thus
- Release request (UE BBU) ⟶
- UE context release request (BBU BBU controller) ⟶
- OF_Packet_Out (BBU Controller SGW-U) ⟶
- UE context release command (BBU BBU controller) ⟵
- UE context release complete (BBU BBU controller) ⟶

Similarly, the signalling burden induced by the active to idle and idle to active transitions is given as (2):

$$LPA2I(n) = 2\,\lambda n\,P\,\rho\,A\,C \tag{2}$$

where,
P: Possibility of an n-type session being generated by the UE and
λn: Average arrival rate of type-n sessions per UE.

c. Network-triggered service request: A service request triggered by the network is executed when the network is required to send traffic to the UE. The paging case includes three messages from the BBUC in addition to the paging messages when UE is in the Inactive state. When paging is not required, as when the UE is connected, the message count is two. The signalling load caused by this event is thus given as (3):

$$LPtri(n) = ((3 + CBBU)\,Rp\,PI + 2\,(1 - PI))\,\lambda n\,(1 - P)\,\rho\,C\,A \tag{3}$$

where,
Rp: Average number of pages for each transmission;
$CBBU$: C-RAN cell in the region considered; and
PI: Possibility of a UE being in Inactive mode.
The study outlined in [35] showed that the UE is most likely to be in a connected state is $(1 - Pi)$.

d. Handover: In the proposed architecture there are two types of handovers: the inner handover as represented in Figure 4, which is similar to the X2 handover in the traditional LTE architecture that occurs between the base stations inside the pool; and the outer handover as represented in Figure 5, which is similar to the S1 handover in the traditional LTE architecture that occurs between the BBU pools. Within the BBU (between base stations) and between the BBU and the BBUC, no signalling load is triggered by the control messages for either inner or outer handover.

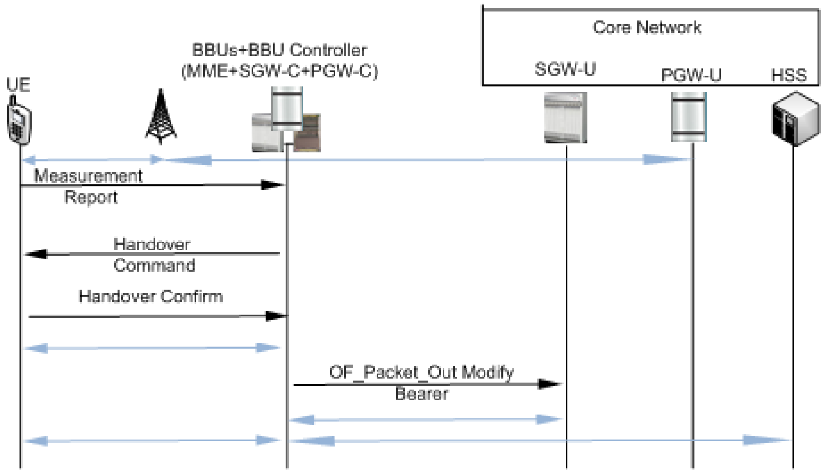

Figure 4. Procedure for the inner handover

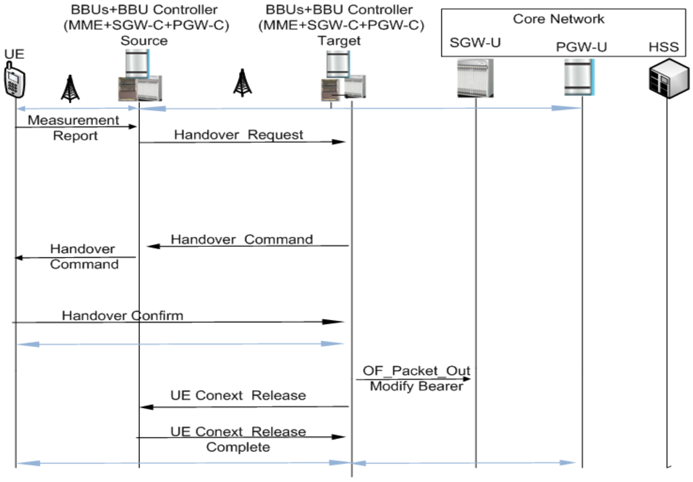

Figure 5. Procedure for the outer handover

The inner handover signalling load is given by (4):

$$LPinh(n) = Rc\,(1 - PI)\,C \qquad (4)$$

where
Rc: Rate of crossing from a closed region of a set of UEs$(Rc = (\rho\, L\, V)/\pi)$.

The full number of messages for the outer handover on the BBUC is equal to 5; the signalling load caused by this event is thus given by (5):

$$LPouth(n) = 5\,RBBU\,(1 - PI)\,CBBU \qquad (5)$$

e. Tracking area update (TAU): This occurs when a UE travels when it recognises that its tracking region is not in the region of tracking or the list of tracking regions reported by the network. In this situation, the UE must update its network tracking zone, whether it is in idle or in active state. The procedure for this event is as depicted in Figure 6. As noted previously, within the BBU (between base stations) and between the BBU and the BBUC, no signalling load is triggered by the control messages; thus, the total number of messages on the BBUC is equal to 7, and the signalling load caused by this event can be given by (6). The total signalling load over the five events is thus the sum of (1) to (6).

$$LPtau(n) = (7/\sqrt{CBBU})\,Rc\,C \qquad (6)$$

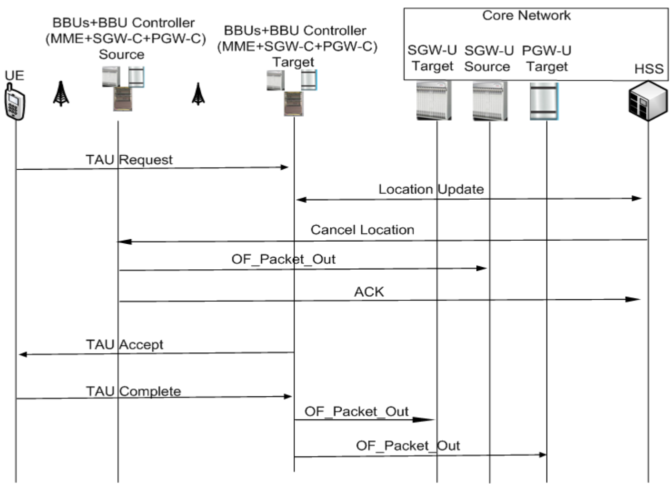

Figure 6. Procedure for the tracking area update

4. RESULTS AND DISCUSSION

In this section, the numerical results for signalling load generated using the MATLAB 2018 software package are presented. To assess the efficiency of the proposed design, the results for this architecture were compared with those for conventional LTE architecture which was explained in detail in [25, 35], and with the full openflow-enabled EPC (OEPC) architecture proposed by Nguyen *et al.* [25] in 2015 and the C-RAN.DMME architecture proposed by Al-Samman *et al.* [26] in 2016. During the evaluation, the authentication step was not taken into account, however, as this is considered to be a fixed step in all architectures. The scenario default values were $\lambda n = 0.05$, an average session duration of 0.2, Rp=1.1, and the number of RRHs and BBUs equal to 500 and 5, respectively. The number of users was set equal to one million. The required cell radius, r, to cover the total area was calculated as:

$$r = \gamma \sqrt{\frac{2\,ST}{3\sqrt{3}\,c}} \tag{7}$$

Assuming a uniform hexagonal cell with an overlap of γ factor of 1.2.

In terms of the number of messages exchanged between control entities for each event, as Table 1 shows, assuming that there is no SGW relocation during X2 and S1 handovers, with the exception of TAU, there are far fewer control messages in the proposed architecture than in the conventional architecture.

Table 1. Number of messages in proposed and traditional LTE architectures

FDCN architecture	No. of messages	Traditional LTE architecture	No. of messages
Initial attachment	4	Initial attachment	10
A2I & I2A transition	2	A2I &I2A transition	10
Inner handover	1	X2 handover	4
Outer handover	5	S1 handover	9
Tracking area update	7	Tracking area update	3

The first analytical case examined involved increasing the region area and then determining the overall number of signal messages handled by the MME and the controller. The total signalling load differences among all considered architectures are shown in Figure 7, which makes it evident that the proposed architecture experiences the lowest load levels, followed by C-RAN.DMM. The full OEPC architecture demonstrates better efficiency than traditional architecture, however, as a result of the decrease in the number of messages exchanged between MME, eNB, PGW, and SGW seen in the conventional architecture. As shown in Table 2, up to 45.394 percent of the average signalling load, relative to conventional LTE architecture, can be reduced with the implementation of the proposed architecture, while compared with the traditional architecture, C-RAN.D-MME and Full OEPC reduce signalling load by 18.823 percent and 5.007 percent, respectively on average.

Changes in the velocity of the user is another metric that must be analysed, as it is logical that increasing velocity increases the overall signalling load by causing handover and tracking area updates to occur more frequently irrespective of the architecture implemented. As shown in Figure 8, where the velocity of the UE varies between 0 and 120 km/h, the proposed architecture results in the lowest signalling load, followed by C-RAN.D-MME and the Full OEPC. As shown in Table 2, the average signalling load was decreased by 38.303 percent in the proposed architecture relative to that seen in the existing LTE architecture.

Table 2. Average signalling load reduction in each architecture as compared with that in traditional LTE architecture

	C-RAN.DMME Architecture [26]	Full OEPC Architecture [25]	Proposed Architecture
Area (km^2)	18.823percent	5.007percent	45.394percent
Number of UEs	19.006percent	6.243percent	46.041percent
Velocity of UEs (km/h)	5.859percent	5.256percent	38.303percent

For the third case, the impact of the number of users on the overall signalling load in the proposed architecture, CRAN.DMME, Full OEPC and traditional architecture was examined. As shown in Figure 9, as the number of network users was increased from 0 to 1,000, the signalling load increased for all architectures. Nevertheless, the proposed architecture retained the lowest signal loads among these architectures at all user counts.

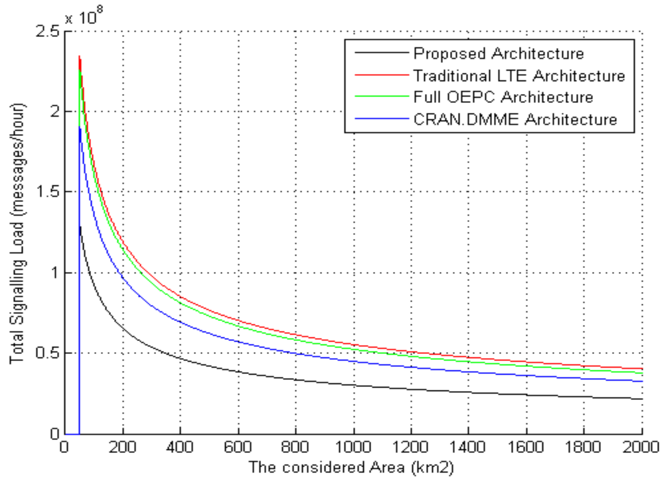

Figure 7. The impact of the area on the architectures

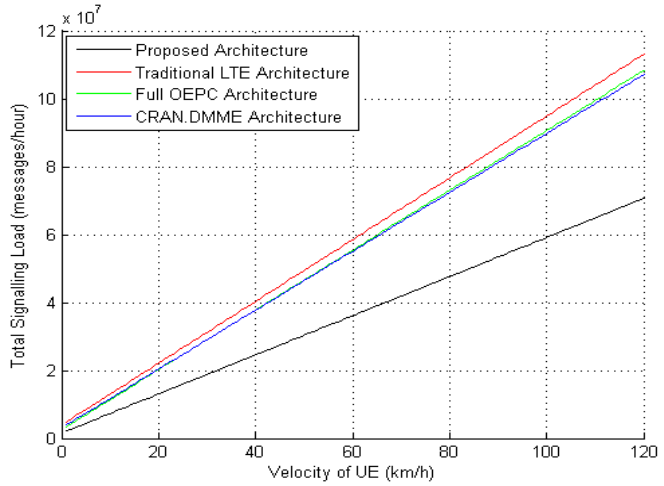

Figure 8. The impact of UE velocity on the architectures

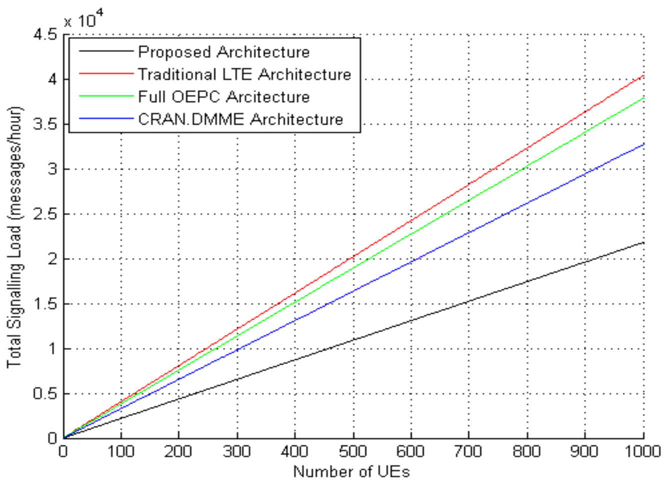

Figure 9. The impact of the number of UEs. on the architectures

5. CONCLUSION

In this paper, a new 5G architecture network was presented as a prospective candidate for growing mobile network systems. The proposed network architecture utilises the Cloud-RAN as a domain for its design. The signalling load was tested and evaluated by considering a range of different parameters, such as area size, velocity, and user density. Based on the results of these considerations, the proposed architecture improves the flexibility of the network configuration as well as simplifying it in comparison with the traditional architecture. Testing the proposed system suggests that it has the capability to reduce the total signalling load overall control entities of the core network. Based on two different cell size scenarios, it was also demonstrated that the signalling load was reduced to less than half that seen in the traditional architecture (44.84 percent) for small cell sizes, while in large cell size scenarios, the signalling load decreased by 46.83 percent over 2,000 km^2. Based on these results, the proposed network architecture could provide good results in terms of reducing total signalling load on control entities and thus offers a new solution for the next generation of mobile networks.

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