Modeling Optimal Values of the Traffic Load-Based Factors over Performance of LTE Cellular and 802.11ac

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***Abstract*—The load-based features of the traffic particularly in resource-limited wireless systems, including LTE and 802.11ac, are among the primary factors that any changes in their values can directly affect the efficiency of the networks. Keeping in mind the fact that proper selection of the parameters is very crucial for performance optimisation of the networks, this work proposes a comprehensive framework called load-based factors (LBF) with two main purposes. First, to quantify and determine the effects of the load- based parameters including traffic source rate, traffic type, and packet size on the performance of LTE and 802.11ac networks. Second, to accurately determine the actual effective values of these parameters and achieve the performance optimality in both LTE and 802.11ac networks. The NS3 tool is used to implement and evaluate the LBF framework. The experimental results show that the proposed framework by varying these parameters and testing the corresponding impacts via implementing a wide range of scenarios and experiments can be used as a comprehensive model to determine and compare the optimal values of these parameters in both LTE and 802.11ac networks.**

***Index Terms*— LTE, 802.11ac, Load-Based Factors, Traffic Source Rate, Traffic Type, Packet Size.**

I. INTRODUCTION

Due to the current optimisations and improvements in different aspects of LTE and 802.11ac, these networks particularly have attracted the global attention in the research and industrial communities. In practice, testing and verifying different aspects and effective parameters related to these networks is highly essential for both performance optimisation and getting all the designed benefits from their end-users. The major key factors that closely affect the network functionality fall into different categories among which the traffics load-based parameters including the traffic source rate, traffic type and packet size are well-known.

Depending on the data application to be transferred, the TCP and UDP transport protocols can be used as the traffic type. The UDP protocol is utilised for the certain data applications that do not require reliable delivery and are delay-sensitive. In contrast, for reliable and error-free data delivery, the TCP protocol is used. In either way, the maximum packet size is based on the underlying link maximum transmission unit (MTU) which in turn depends on the type of the network. For instance, while the MTU in wired networks is 1500B, it is 2312B in wireless networks [10]. However, this larger size is only practical for traffic exchanging inside the network. When the packets are destined out of the network over the Internet, they are further broken down into the smaller packets and reassembled into the original form at the final end-user. This additional fragmentation/reassembly procedure for every transmitted packet imposes extra complexity and overhead and results in unsatisfactory performance especially for the applications that demand timely delivery of data. Thus, the size of the packets must be in a proper range to avoid any excessive transmission delay and inefficiency.

About the traffic source rate parameter, it is evident that the higher the data rate, the higher the network throughput. However, when the traffic source rate exceeds beyond the network capabilities, it results in buffer overflows and packet losses occur. Consequently, the service quality of the network suffers from dropping the packets and data error rate increases due to higher collision rate. Thus, for reliable data transfer, the networkability in terms of its effective data rate must be accurately determined.

Due to bandwidth restrictions and also the existing differences between the design characteristics of LTE and 802.11ac networks, any misconfiguration of each parameter can significantly degrade the overall network functionalities. This highlights the fact that a proper choice of the parameters is very crucial for the optimum performance of the networks which is the main contribution of this work. The structure of this work is as follows. Section 2 gives a brief overview of the related works. Section 3 provides the details of the developed framework and the simulation setup along with the designed scenarios. Section 4 presents the results and discussion and Section 5 concludes the work.

II. RELATED WORKS

The authors in [1] evaluate the performance of TCP, SCTP, DCCP and UDP protocols for MPEG-4 video data transmission in the LTE environment. The corresponding effects are measured by varying the number of nodes using the NS3 simulation tool. However, the key factors for the network load are not investigated while there is no performance comparison with the 802.11ac network.

The effect of the TCP packets size on network performance is investigated in [2]. Using the NS-2 tool, the authors determine the size of TCP packets as a factor that can degrade the network performance. Variable packet sizes range from 500 to 1650 bytes are examined for the TCP packets. The results reveal that as the size of packets increases beyond 1500B, the throughput performance of the wired network degrades. However, other performance metrics are not investigated while the work does not include wireless and LTE networks.

The possible changes in UDP performance under variation of the UDP packet size and traffic load on network performance is examined in [3]. Two packet sizes as 1550B and 2048B and 0 to 25 packets per second in intervals of 5 are the factors that are simulated using NS-2 tool using which the delay and throughput are measured. The results prove dependency of the UDP performance to these factors so that for the higher packet size and traffic load, the delay and throughput increase. However, the work has tended to focus on the wired network rather than current 802.11ac and LTE networks while other traffic types such as TCP are not investigated.

The authors in [4] investigate the performance of IEEE 802.11 b/g/n standards. The impact of the factors such as traffic type, length, and rate are investigated regarding throughput, response time, encryption overheads, frame loss, and jitter. Unfortunately, their approach does not take into account the current 802.11ac and LTE networks.

The IEEE 802.11ac performance in Vehicular Ad hoc Network (VANET) is investigated by the authors in [5]. The impacts of the packet size, number of users, and traffic rate are measured in terms of goodput. The results are used to be compared with 802.11P and 802.11n while LTE is not included. The authors in [6] vary the number of users (5, 10, 20) and packet size (512B, 1024B) for TCP and UDP to measure possible impacts on throughput in only LTE network.

The authors in [7] investigate the 802.11ac networks under 15.5Mbps CBR and 35Mbps bursty UDP traffics along with the 15.5Mbps CBR TCP traffics while varying the number of access points. The impact of the number of users per cell and data rate on TCP performance in LTE networks is examined in [8,9].

As the related works show, any variation in the load-based parameters consist of packet size, data rate, and also packet type can highly influence the overall performance of the networks. However, despite its importance, there have been no studies to determine the actual impacts in an experimental comparative method between the two commonly used networks, i.e. LTE and 802.11ac. In an attempt to address these limitations and ambiguities, this work aims to propose a comprehensive framework called load-base factors (LBF). Firstly, the impact of the different load-based parameters consist of the traffic source rate, traffic type, and packet size on the performance of LTE and 802.11ac networks is analysed. Secondly, the actual effective values suited for performance optimality of these networks are determined. The NS3 simulation tool is used to implement and validate the framework in terms of a variety of scenarios and performance metrics including throughput, loss ratio, delay, and jitter.

III. LBF FRAMEWORK

The procedure used to set up the simulation framework along with the details of the corresponding scenarios are explained in this section.

A. *Simulation parameters*

In order to design our proposed framework, the NS3 simulator tool is used. The primary purpose is that the framework is carefully designed to be one of the most comprehensive and practical methods to analyse the effectiveness of the load-based parameters. The framework preparation is performed in three steps. In the initial step, the data to be transmitted is separated based on types of its underlying transport protocol. At this point, for each protocol type, the LBF parameters are further configured in the second step. For the packet size parameter in LBF, two different values 1000B and 3000B, are set up. The 1000B packets, which are smaller than typical MTU (1500B), are adapted to determine the functionality of LTE and 802.11ac services when there is no extra overhead and complexity in terms of fragmentation and reassembly. In contrast, in order to determine how these two networks would behave differently under the imposed additional overheads of the fragmentation and reassembly, the 3000B packet size is adapted which is larger than typical MTU.

After completing the second step and as the final adjustments, the framework is further extended for stress testing in the third step to investigate different traffic source rates. Therefore, four different rates as 1Mbps, 2Mbps, 5Mbps, and 10Mbps are adapted to continually increase the load starting from the lowest to low, medium, and high rate respectively on both LTE and 802.11ac networks. The main purpose of this step is to determine whether link saturation (due to generating high traffic load) happens in either at the networks to cause service performance degradation or they can dynamically adjust the resources under the overloading conditions. Note that the step two and three together directly affect the load capacity in term of packet interval which is a division of the packet size and traffic source rate. The LBF parameters setup is presented in Figure 1 along with the simulation parameters specific to LTE and 802.11ac in Table 1 and Table 2 respectively and common simulation parameters in Table 3.

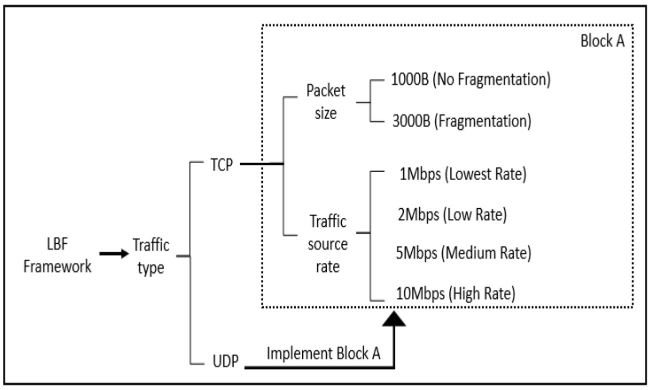

Figure 1: LBF framework configuration setup

Table 1
Simulation Parameters for LTE Network

Parameters	Value
Channel Bandwidth	100 RB (20 MHz)
eNodeB TxPower	14.0 dBm
Radio link control mode	RLC unacknowledged
Number of PGW	1

Table 2
Simulation Parameters for 802.11ac Network

Parameters	Value
Modulation coding scheme	VhtMcs7
Physical channel width	20MHz
Number of 802.11ac AP	1
Wi-Fi type	SpectrumWifiPhy

Table 3
Common Simulation Parameters

Parameters	Value
Traffic type	UDP: UdpSocketFactory TCP: TcpSocketFactory
MTU	1500
TCP socket type	TcpNewReno
Modulation algorithm	64QAM
Coding rate	5/6
Data Rate	1,2,5,10Mbps
Packet size	1000B, 3000B
Number of users	10
Number of server	1
Simulation time	10

B. *Network Model Design*

In order to implement the framework, two network models for LTE and 802.11ac are designed. Both networks are common on some general elements and parameters as the number of users is 10, the underlying modulation algorithm is 64QAM with 5/6 coding rate, the channel width is 20MHz, and the simulation time is 10 seconds. The LTE architecture is EPC-based in which the ten user equipment (UE) are connected to eNodeB (eNB0) which in turn is connected to the PGW. Furthermore, the proposed framework resides in a remote server which is also connected to the PGW. With the same purposes, the ten user stations (Sta) in 802.11ac network are connected to an access point (wifiAP) which in turn is connected to a remote server with the proposed framework built into it. The designed topology of LTE and 802.11ac are presented in Figure 2 and Figure 3 respectively.

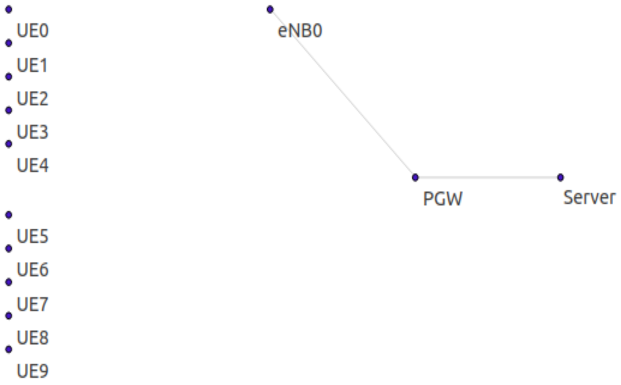

Figure 2: LTE simulation topology

Figure 3: 802.11ac simulation topology

IV. RESULTS AND ANALYSIS

This section presents the obtained results from *the* implementation of the LBF framework in the designed scenarios and then based on these results, a comparative analysis *of* LTE and 802.11ac services functionalities *are* provided.

A. *Traffic Type: TCP stream*

In order to identify the TCP performance differences between LTE and 802.11c in the presence of the LBF framework with TCP data flow, the results are detailed in this section.

1) *TCP Throughput Performance*

In this scenario, first, the TCP packets are transmitted with the lowest data rate, i.e. 1Mbps, with two different packet sizes, i.e. 1000 and 3000 bytes in both LTE and 802.11ac networks. The results are measured and then the data rate increases to 2Mbps for both packet sizes. The procedure is then repeated each time for 5Mbps again and then 10Mbps in order to impose a higher traffic load than before. The main purpose is to quantify and analyse the throughput behaviour of the TCP protocol under higher stress in both LTE and 802.11ac. The results are presented in Figure 4.

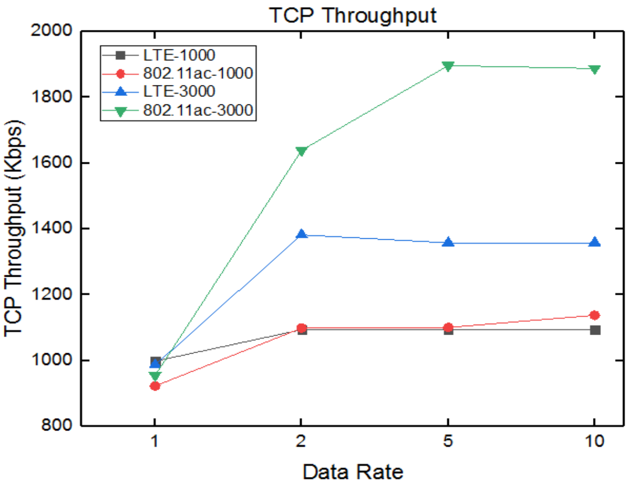

Figure 4: TCP throughput performance

As shown in the results, regardless of the amount of load on either of the networks, both the LTE and 802.11ac show approximately the same performance in term of throughput for the smaller packet size (1000B). However, when the size of the packet increases to 3000B, 802.11ac network shows better throughput than LTE. At this point, for a lower data rate (1Mbps), the difference is negligible. However, as the number of load increases on either of the networks, the differences increase as well. These results signify that fragmentation of the TCP packets (due to a size beyond the size of the MTU), will affect the throughput of LTE more than that of the 802.11ac. The reason behind this is related to how 802.11ac networks work. In order to access to the media, the 802.11ac standard relies on carrier sense multiple access with collision avoidance (CSMA/CA) method while LTE is based on orthogonal frequency division multiple access (OFDMA). The CSMA/CA method imposes two significant overheads during packet transmission which are header overhead and contention overhead. Due to these overheads, the majority of the transmission time is wasted, and the actual data transmission is reduced.

As a solution for the header overhead, unlike LTE, the 802.11ac networks support frame aggregation as a MAC layer enhancement. The MAC Service Data Unit (A-MSDU) is the default aggregation method which groups several data frames into one large frame. In this case, instead of transmission of several smaller frames each with its own distinct TCP header, one larger frame with just one TCP header is transmitted. This reduces the amount of TCP header overhead in the 802.11ac network which in turn increases the amount of throughput compared to LTE networks. Accordingly, as the size of the packet increases, the number of fragmentation increases in LTE network and due to lack of frame aggregation, each fragmentation is transmitted independently with its own TCP header. This decreases the efficient throughput in LTE network compared to the 802.11ac for the larger packets.

2) TCP Loss Rate Performance

The measurements performed in this scenario are based on loss rate comparison using LBF framework in the presence of TCP packets. The 1000 and 2000 bytes TCP packets are transmitted to measure the performance of LTE and 802.11ac network under traffic source rate variations as 1, 2, 5, and 10 Mbps. The results of the loss rate ratio are provided in Figure 5.

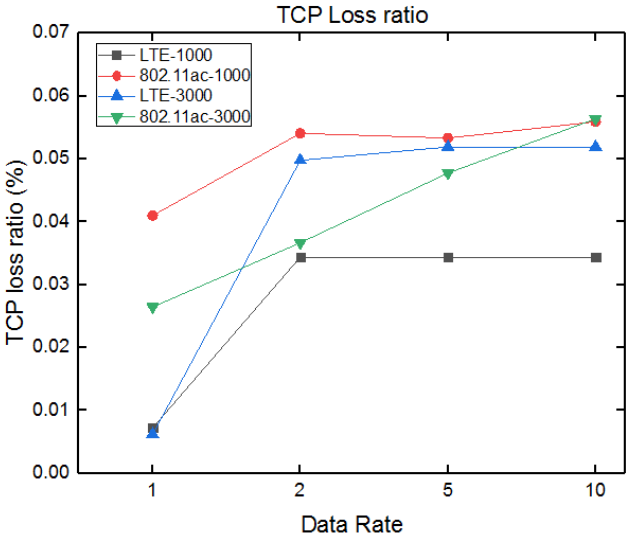

Figure 5: TCP loss rate performance

Even though there is some inconsistency, on average, the end-users in LTE network experience a lower loss rate compared to users in the 802.11ac network. Typically, the main reason causing packet loss is network congestion. Based on the obtained results, we can see that the lowest loss ratio belongs to the lowest traffic source rate (1Mbps) when the network is not under traffic stress. After that, as the rate increases (2, 5, 10 Mbps), the loss ratios grow as well with a slight difference from each other even when both LTE and 802.11ac networks are highly congested due to 10 users simultaneously communicating with their highest traffic source rate (10Mbps). Even at this point, the results confirm the low loss ratio in both networks during the entire simulation time. The reason is that since the packet loss can severely degrade the performance of the networks when packet loss is detected, TCP's congestion control algorithm will temporarily decrease the transfer speed to resolve the situation until all the retransmitted packets are received. Another reason causing packet loss in wireless networks is radio frequency interferences that occur during packet transmission. Since in wireless networks all the users that share a given access point have to be in a limited distance from it, the problem of RF interference can cause different ranges of the performance degradation including packet loss. The RF interference increases as the 802.11ac wireless stations transmit more packets.

3) TCP E2E Delay Performance

Through the use of experiments in this scenario, we can assess the latency of the TCP packets travelled across LTE and 802.11ac networks. The results are presented in Figure 6.

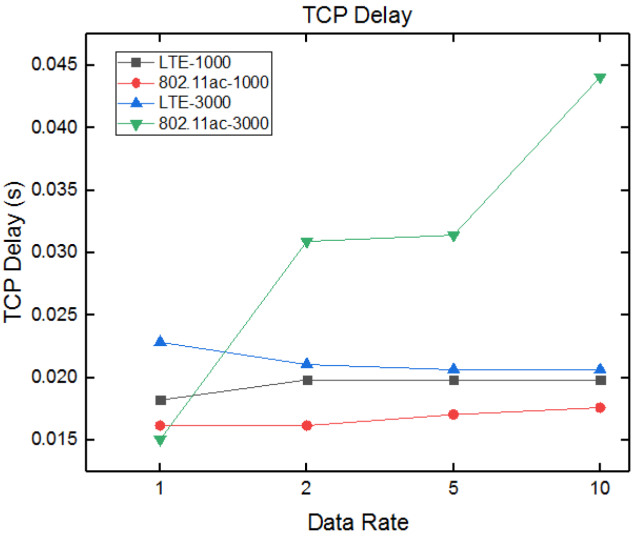

Figure 6: TCP E2E delay performance

Based on the results, almost the same behaviour is found for both networks in term of latency except when the size of packets increases beyond the MTU value in 802.11ac networks. For the 1000bytes packets, regardless of traffic source rate, both networks function similarly in term of the delay. However, when the 3000bytes packets are transmitted, the delay increases only in the 802.11ac network while it remains approximately the same in LTE. These findings confirm our loss ratio findings in the previous section based on the fact that increasing the number of lost packets results in a higher delay due to the retransmissions procedure. The loss ratio in the case of 3000bytes packets in 802.11ac increases as the traffic source rate increases. Thus, the higher loss ratio will result in increasing the latency of the packets at this point.

4) TCP jitter performance

This scenario is prepared by identifying any changes in delay, i.e. jitter based on LBF variations. The results are presented in Figure 7.

Based on the results, it is observed that jitter is highly affected by the size of packets in 802.11ac which causes this network to perform poorly. In contrast, LTE functions completely stable with very low jitter. Since the precise timing is essential for real-time services such as voice and video, in which high jitter can effectively render them unusable, comparing the high jitter in 802.11ac with low jitter in LTE determines a better performance of real-time applications in LTE network.

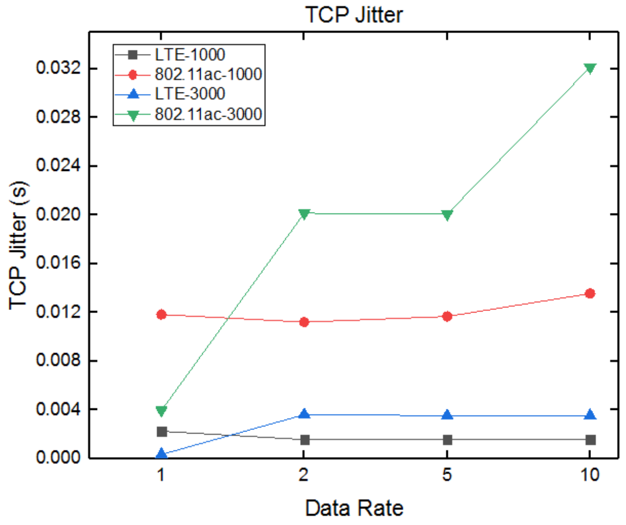

Figure 7: TCP jitter performance

B. *Traffic Type: UDP Flows*

In an attempt to analyse the UDP functionality in LTE and 802.11ac network, the scenarios designed in this section provide comprehensive measurements based on the LBF framework. The results are additionally utilised to be compared with the corresponding TCP results in previous scenarios.

1) *UDP Throughput Performance*

The experiments in this scenario provide a basis on comparative effectiveness of the LBF framework for LTE and 802.11ac networks in term of UDP throughput. The results are presented in Figure 8.

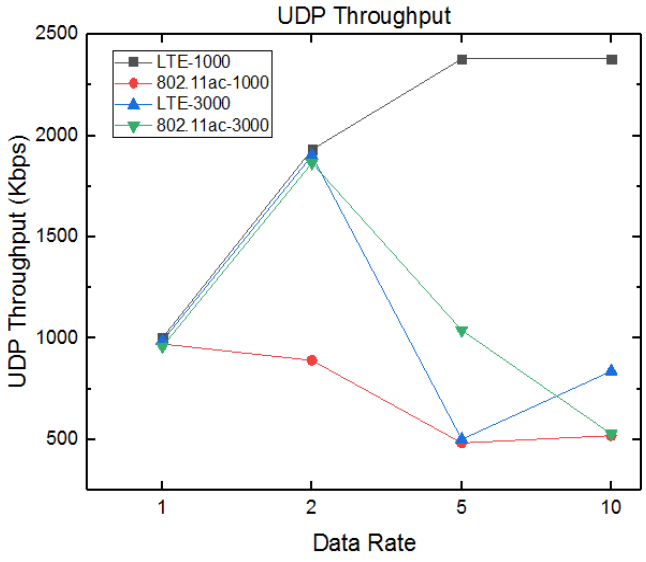

Figure 8: UDP throughput performance

Based on the results, the UDP throughput reduction under congestion conditions of the LBF framework is observed. When there is no packet fragmentation, i.e. 1000bytes packets, unlike TCP throughputs that are the same for both LTE and 802.11ac, the UDP throughputs are significantly different. At the low data rate, 1Mbps, the LTE and 802.11ac networks behave the same. However, as the data rate increases, 802.11ac throughput for smaller packets decreases significantly compared to LTE. The reason behind this is that as the data rate increases, the number of packets transmitted by each user increases as well. These transmission attempts create the RF interferences which result in packet loss increase. On the other hand, due to lack of any congestion control mechanism in UDP protocol, it is not able to force retransmission of the lost packets and therefore the throughput reduction is significant. However, when it comes to packet fragmentation, the overall responses of both networks under different LBF framework conditions are approximately the same.

According to LBF framework, another interesting finding is that when the network is not congested, i.e. under lowest traffic source rate (1Mbps) and low traffic source rate (2Mbps), UDP is more efficient than TCP in term of a better throughput. However, as soon as the network gets congested and the packets are dropped, TCP ability to control congestion and retransmit the lost packets, will optimise the overall throughput compared to UDP. Under the lowest traffic source rate (1Mbps), the TCP and UDP perform the same in both LTE and 802.11ac. However, when the traffic source rate increases to 2Mbps, UDP as being a best-effort protocol is more efficient and provides higher throughput. Further increasing the traffic source rate to 5Mbps and then higher to 10Mbps will congest both LTE and 802.11ac networks and at this points, packets start to drop which reduce the throughput.

2) *UDP Loss Rate Performance*

The analysis used to test in this scenario will focus on functionality comparison of LTE and 802.11ac networks in term of a loss ratio of the UDP packets. The results are presented in Figure 9.

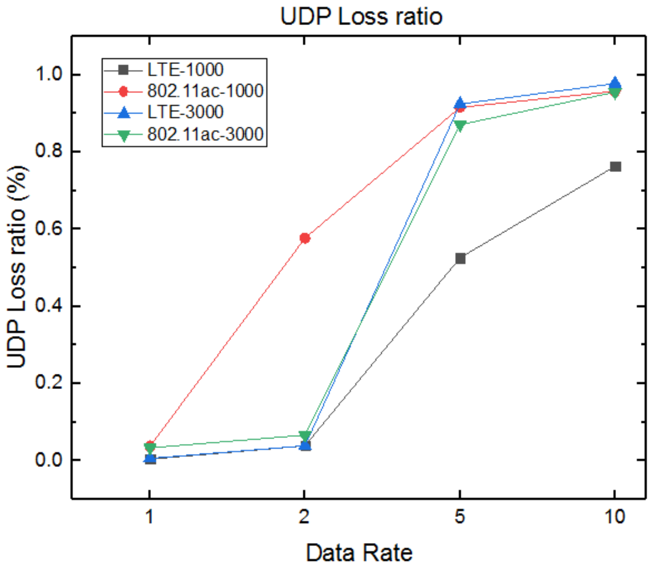

Figure 9: UDP loss rate performance

Based on the results, we can see a better performance for LTE in term of lower loss ratio when UDP packets are not fragmented. As mentioned, the reason is that due to the existence of RF interferences during packet transmission by the 802.11ac wireless stations, the number of lost packets increases in this network. Afterwards, under the fragmentation condition of the LBF framework, the results show the exact same loss ratio in both LTE and 802.11ac networks. Analyzing UDP results reveals the very high rate of loss ratio for UDP packets in both LTE and 802.11ac networks compared to loss ratio of the TCP packets. While

LTE and 802.11ac suffer from losing many UDP packets, the congestion control algorithm existing in TCP protocol decreases the overall number of lost packets.

3) UDP E2E Delay Performance

We perform further analysis to show the impact of the parameters in the LBF framework on the delay of the UDP packets. The results are presented in Figure 10.

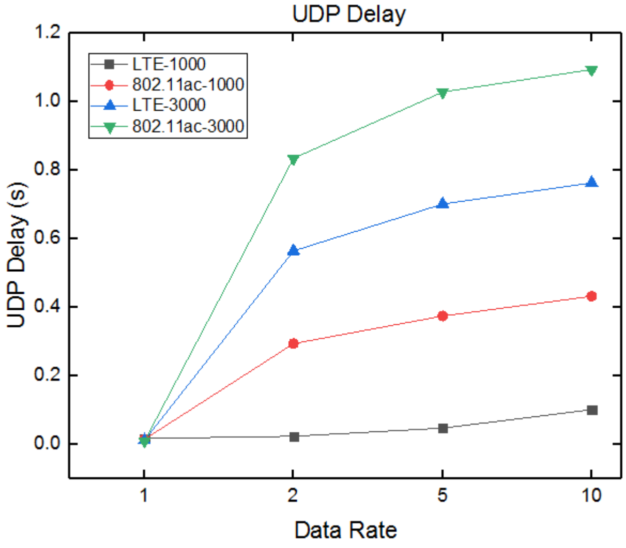

Figure 10: UDP E2E delay performance

Based on the results, the amount of delay experienced by the users in LTE network is much lower than the users in the 802.11ac network. The results interestingly show that while the traffic source rate has a direct impact on increasing the amount of delay, the size of the packets is much more effective than the traffic source rate. Based on the results, delay slightly increases in both networks as the traffic source rate increases for the UDP packets with the same size. However, comparing the delay for the same traffic source rate but with different packet size shows that delay is almost three times higher. This provides evidence that when using UDP protocol, the big packets can reduce the overall efficiency of the network in term of higher delay, particularly for time-sensitive applications.

Furthermore, comparing the UDP delay results with the TCP results show that the users in both LTE and 802.11ac networks experience much less delay using TCP packets. As mentioned, the reason is related to the congestion control algorithm for TCP protocol which decreases the rate of packet transmission when a congestion is detected in the network. Consequently, congestion is resolved and packets delivery is done faster with less delay.

4) UDP Jitter Performance

Further tests are carried out in this scenario to determine the amount of jitter in LTE and 802.11ac networks in the presence of UDP packets. The results are presented in Figure 11.

The results show that regardless of the traffic source rate and the size of packets, the UDP packets in LTE achieve much lower jitter than in the 802.11ac network. The jitter for UDP packets in 802.11ac is much higher than LTE particularly when the size of the packets reaches beyond the MTU boundary. Comparing the amount of jitter for UDP packets with the TCP packets show that UDP packets impose a much higher jitter on both LTE and 802.11ac networks compared to TCP packets. The reason as mentioned before related to lack of congestion control in UDP protocol.

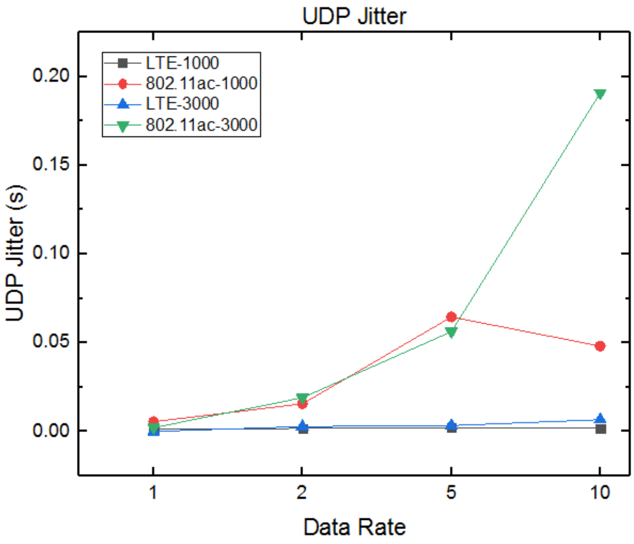

Figure 11: UDP jitter performance

V. CONCLUSION

This work proposed a framework called load-based factors (LBF) to first investigate the impact of the load based parameters on the performance of LTE and 802.11ac networks and then determine the effective values to optimise the performance of these networks. Results from the implementation of the LBF framework show that among the load based parameters, the type of traffic is the most effective one which can highly impact the performance of both LTE and 802.11ac networks. Transmission of UDP packets imposes a higher delay, jitter, and loss ratio than TCP on both networks. On the other hand, the other two parameters investigated in the LBF framework, i.e. traffic source rate and packet size will directly influence the congestion condition of the two networks. As the results show, when the traffic source rate increase to 5Mbps and 10Mbps, the networks get congested, and throughput significantly decreases in the presence of UDP protocol while TCP can manage the congestion conditions in both LTE and 802.11ac networks. At this point due to the lack of ability of UDP protocol to manage congestion condition, the number of dropped packets increases significantly which in turn results in higher delay and jitter.

Furthermore, comparing LTE and 802.11ac network reveals the very similar behaviour of the two networks under the same variations of the parameters in the LBF framework. Based on the obtained results, it is concluded that transmission of the larger packets (3000B) is better than, the smaller packets to increase the overall performance of both LTE and 802.11ac networks due to header overhead reduction. Also, 2Mbps was more suitable for 802.11ac networks than the higher data rates to avoid RF interference while it is not a problem in LTE network.

REFERENCES

[1] S.A. Nor, R. Alubady, and W.A. Kamil, Simulated performance of TCP, SCTP, DCCP and UDP protocols over 4G network, Elsevier 8th International Conference on Advances in Information Technology (IAIT2016), PP. 1-6, 2016.

[2] A.U. Shah, D.H. Bhatt, P.R. Agarwal, and P.R. Agarwal, Effect of Packet-Size over Network Performance, International Journal of Electronics and Computer Science Engineering, PP. 762-766, 2007.

[3] S.U. Mostfa and R. Alsaqour, Performance evaluation of UDP based on traffic size and traffic load using NS2, ARPN Journal of Engineering and Applied Sciences, Vol. 11, No. 9, 2016.

[4] P. Jinda and B.Singh, Quantitative analysis of the security performance in wireless LANS, Journal of King Saud University - Computer and Information Sciences, 2015.

[5] K.A. Khaliq, M.S. Akbar, A. Qayyum, and J. Pannek, Suitability of IEEE 802.11ac/n/p for Bandwidth Hungry and Infotainment Applications for Cities, SAI Intelligent Systems Conference, PP.499-507, 2016.

[6] N. Shojaedin, M. Ghaderi, and A. Sridharan, TCP-Aware Scheduling in LTE Networks, IEEE 15th International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2014.

[7] L. Simic, J. Riihijarvi, and P. Mahonen, Measurement Study of IEEE 802.11ac Wi-Fi Performance in High Density Indoor Deployments: Are Wider Channels Always Better? IEEE 18th International Symposium on A World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2017.

[8] M. Lossow, P.Arnold, H. Droste, and G. Kadel, TCP Flow-Level Traffic Model for Evaluating LTE-Advanced Networks, IEEE Eighth International Conference on Ubiquitous and Future Networks (ICUFN), PP.1026-1030, 2016.

[9] B. Nguyen, A. Banerjee, V. Gopalakrishnan, S. Kasera, S. Lee, A. Shaikh, and J. V. D. Merwe, Towards Understanding TCP Performance on LTE/EPC Mobile Networks, Proceedings of the 4th workshop on All things cellular: operations, applications, & challenges, PP. 41-46, 2014.

[10] N. Abuhamoud and E. Geepalla. Using Ad Hoc-network with IEEE802.11 ac: Possibilities and Challenges, The First Scientific Symposium Of Electrical And Electronic Engineering (EEES), 2016.