Performance Evaluation of 5G/WiFi-6 Coexistence

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Abstract—The fifth-generation mobile communication network (5G) is the promising technology nowadays to provide not only a higher speed compared to 4G but also a revolution of services to cover different industrial sectors such as health, production, energy, and many. WiFi-6 is a new wireless local area network (WLAN) technology that is suitable to work in an office, home, and dense areas. As a new technology, 5G has some limitations concerning coverage and capacity. To overcome these limitations, one possible solution is to use the free unlicensed spectrum available in Wi-Fi technology, therefore, a complement solution of 5G/WiFi-6 coexistence is proposed to make both technologies complement each other in providing a better quality of service for the end-user concerning a higher speed, low latency, and higher capacity. According to OFDM modulation, the proposed model divides the cell into two virtual zones, the inner zone represents WiFi-6 technology surrounded by 5G technology. All resources will be shared between the two technologies taken into consideration that more bandwidth should be given to the most inner zone with high intensity of traffic. The call admission control algorithm will be based on a minimum bit rate to be given to each zone that should be satisfied to admit the call. The model is solved using MOSEL-2 simulation language, to study different performance parameters such as BER, utilization, blocking probability, latency, throughput, and aggregate average bit rate in both zones. The simulation results show that coexistence causes some degradation in 5G performance, however, a positive effect on the overall cell performance is achieved by balancing the load all over the whole cell.

Keywords—5G, Coexistence, MOSEL-2, Performance Evaluation, WiFi-6.

I. INTRODUCTION

Due to the increasing demand for higher data rates and less buffering times, 5G cellular communication technology will continue evolving to provide the end-user with the promises services that improve performance to the best level and deploy handsets for users much faster than the previous cellular standards as the existing devices will not be completely compatible with the new services provided by 5G [1]. 5G is a wide area network (WAN) technology that is available for diverse applications starting from cellular data, edge computing, internet of things (IoT) as well as different industrial, production and health services. According to [2], people feel excited about 5G technology because they will enjoy a download speed of 1 Gbps to 10 Gbps as well as low latency of less than one millisecond. However, the speed of 5G connection will depend on many factors such as; the used network, the number of people who are connecting simultaneously as well as the type of device being used. The 5G New Radio (NR) specifications provided by the 3GPP group include millimeter wave (mmWave) to achieve high data rates. According to 3GPP [3], Release 17 is introduced to enhance additional features of the physical layer of 5G (physical layer enhancements (RAN1, RAN2, and RAN3)). In RAN1, the features include the efficiency of 5G NR performance: MIMO, spectrum-sharing enhancements, UE power-saving, and coverage enhancements. Therefore, the enhancement of the physical layer will increase the frequency band for 5G networks to reach up to 71

GHz. Another significant feature of RAN1 is the support of low mobility large cell (LMLC) scenarios. This scenario is important for the global success of 5G NR in developing countries. According to 3GPP-Release 17, RAN2 and RAN3 releases will start in the second quarter of the year 2020 to provide additional features for the new generation. On the other hand, Wireless Fidelity version 6 (i.e. WiFi-6) is the new version of wireless local area network (WLAN) that comes after WiFi-4 and WiFi-5 but with higher speed than the previous versions to be operated home, in the office workplace, in the conference room and other dense areas where the traffic is heavily loaded. Therefore, the 5-GHz WiFi-6 with different versions (802.11a/ac/ax) has been implemented in the user equipment (UE) worldwide to replace the old 2.4 GHz. The above features of WiFi-6 will enable operators to connect multiple devices at one time with one router. Many applications in the literature support the use of WiFi-6 due to its features in providing long battery life, supporting multiple devices at the same time because of OFDMA modulation, improved data rate by using MU-MIMO, as well as providing a fast and reliable connection to the end-user [4][5][6]. Based on international reports [1], 92% of the future smartphone data usage will be utilized by the Wi-Fi network. Therefore, as the 5G smartphones are increasingly released nowadays, efficient coexistence between 5G and WiFi-6 technologies in a complementary way will enhance the end-user experience in different real-life applications. This complementary deployment will have a positive effect on the network performance by providing better services for users while maintaining coverage and capacity improvement of the network.

According to 3GPP [7][8], the International Telecommunication Union (ITU) has created the most important key indicators for 5G in Release 15 as shown in Table 1:

Table 1: 5G Service Categories [7] [8]

Indicator	Communication type
>10 Gb/s peak data rates	Enhanced mobile broadband (eMBB)
>1 M/km2 connections	Massive machine-type communications (MMTC)
<1 ms latency	Ultra-reliable low-latency communications (URLLC).

The 3GPP divides 5G into two releases: Release 15, the new radio (NR) phase 1, which has common features with LTE such as using orthogonal frequency division multiplexing (OFDM). Besides, to differentiate between nodes B (NB) for both cases, LTE uses (eNB) and 5G uses (gNB).

II. RELATED WORK

To solve the issue of the shortages of resources in wireless networks, coexistence between different technologies has been proposed and studied intensively in the literature. The main objective is to find possible solutions to increase the coverage of the network by providing an interoperability model between different technologies; hence, the overall network performance will be improved while the end-user enjoys the requested quality of service. One possible solution is to utilize the unlicensed spectrum, which is available for free in other technologies such as Wi-Fi. For example, the study of coexistence between LTE-U and Wi-Fi is investigated in [9] for 5.8 GHz unlicensed spectrum in the real environment. By simulation results, it is shown that significant improvement in system throughput is achieved for both coexisted systems under enhanced ON/OFF cell scheme. The coexistence between different homogeneous Wi-Fi devices is discussed in [10]. Different use cases are investigated taken into consideration the coexistence with inter-networking interference. It is shown in this paper that the 802.11ax version of Wi-Fi will provide future special reuse along with the ability of Wi-Fi networks to provide an interoperability framework for future research direction. In [11], the authors present the coexistence between licensed assistant access of LTE LAA-LTE and Wi-Fi in an unlicensed spectrum, to show that fairness coexistence can be achieved for different single and multi-carrier cases. The results of this research are used to guide researchers towards the future possibility of coexistence between Wi-Fi and 5G. The research work in [12] shows the possibility of collaboration between Light Fidelity (Li-Fi) and Wireless Fidelity (Wi-Fi) technologies to create coexistence between them. It is shown that the throughput values have increased dramatically where high coverage and high data rate have been achieved while coexisting and therefore, this achievement will be proving the ability to achieve high data rate needed in the fifth generation of mobile networks (5G) while different technologies are coexisting. In [13], the authors introduce a co-design of different cellular Wi-Fi cooperated within heterogeneous 5G networks. Under this architecture, different 5G applications and scenarios are investigated and facilitated to overcome many future challenges facing 5G networks. The authors in [14] presented a four-port multiple-input multiple-output (MIMO) Antenna operating on 2.5/5

GHz Wi-Fi and 6 GHz 5G. The authors discovered that the complete Antenna match has occurred between both bands with efficiency reached to 39.6% in Wi-Fi and 60.7% in the 5G. Again, this is another evidence about the compatibility between the two technologies. As LTE licensed assisted access LTE-LAA is considered the promising solution for the coexistence with Wi-Fi in the 5G NR unlicensed according to 3GPP, in [15], the author study the possibility to maximize the total network sum rate by changing different network parameters while maintaining coexistence between LTE-LAA and Wi-Fi in 5G NR unlicensed spectrum. The analysis and verification of the results via simulation help the author to come up with guidance for network optimization and protocol design for such cases of coexistence. To cope with 5G requirements for higher bandwidth, In [16], the authors suggested that the Wi-Fi spectrum should be utilized for the new generation of mobile networks through coexistence between different technologies such as LTE and Wi-Fi or 5G and Wi-Fi where the existing Wi-Fi spectrum can be used with no need to expand the existing technologies or changing the network infrastructure. The idea of this paper is similar to the idea of the proposed model in our research work. However, our research work is based on the idea of dividing the cell into two virtual zones and their work is based on neural networks based approach. This is why it is not possible to compare our results with their results. Besides, no similar work is found in the literature for comparison. In [17], the authors suggested a new mechanism based on neural networks for the coexistence of an LTE-U base station in the unlicensed spectrum accompany by WiFi-6 access points. The obtained numerical results in this paper show that the suggested algorithm can provide the way for LTE-U base station to work efficiently in the unlicensed spectrum while protecting Wi-Fi users with 90% fairness. 5G NR guarantees a higher data rate for users by working on an unlicensed millimeter wave (mmWave). In this regard, in [18], different channel access schemes are compared such as listen before talk (LBT) and listen before receive (LBR) with fair coexistence with 60 GHz Wi-Fi called WiGig. The provided simulation results and analysis in this paper show that directional LBT combined with directional LBR and Omni-directional LBT schemes outperform other schemes concerning the following performance parameters: sum rate, mean rate, and minimum rate.

III. MODELING

This section is divided into two subsections: modeling assumptions and performance parameters.

A. Modeling Assumptions

The numerical solution of the model is produced using MOSEL-2 simulation language [19] [20]. MOSEL stands for modeling specification and evaluation language developed by the group of MOSEL [20] in the operating system department, university of Erlangen, Germany. MOSEL-2 is an extension of the old version MOSEL to include new features for modeling and evaluation processes.

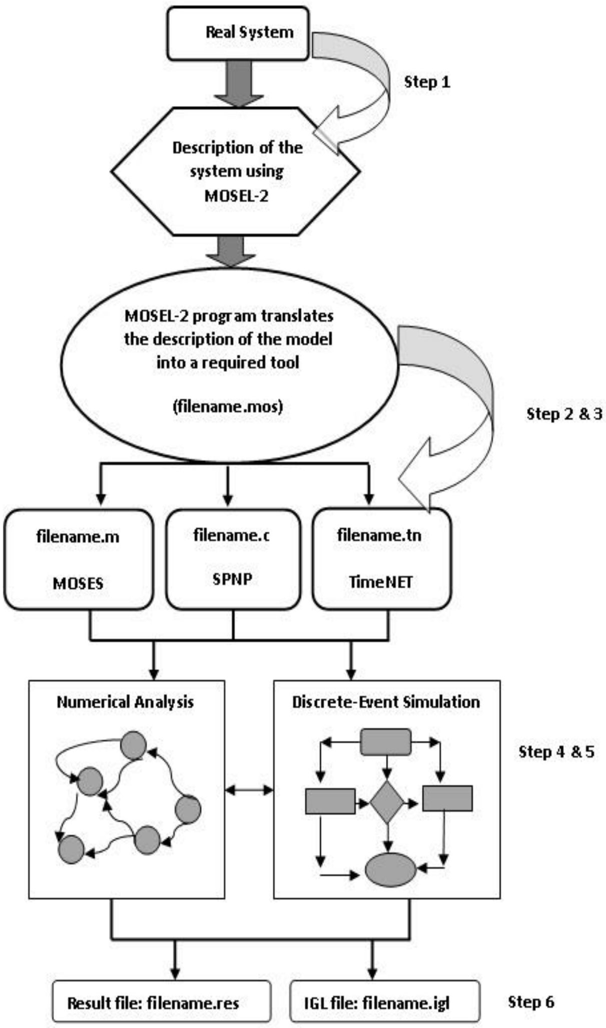

Fig.1:Modeling and Evaluation process in MOSEL-2

Fig. 1 explains the modeling and evaluation process of MOSEL-2 as follows:

In step 1, the proposed model is described easily using MOSEL-2 as it is a C-like simulation language.

In steps 2 and 3, the MOSEL-2 program will be translated into a specific tool (i.e. SPNP or Time NET) incorporated into the package of MOSEL-2.

In steps 4 and 5, and via some options in the command line, the model can be solved either by numerical analysis or discrete-event simulation.

Once steps 4 and 5 are done successfully, then the generated results are stored in two file types according to step 6; numerical results in a result file (".res") and other file contains all generated figures in (".igl") file. IGL means intermediate graphical language package, which is automatically installed with MOSEL-2 to generate the figures and nicely edit them to meet the needs of the users. As MOSEL-2 is working only with Linux operating system, all generated figures can be converted into versions that are compatible with windows (".eps" and ".pdf") files.

The proposed coexistence model is shown in Fig. 2. As 5G NR still supporting the OFDM modulation technique [7], the cell is divided into two virtual zones: the inner zone (Zone 1, WiFi-6 zone) represents an area with high traffic density such as home, business, and areas close to the base station with 64-QAM, whereas Zone 2 (5G zone) represents the outer zone with 16-QAM and lower traffic density such as Pico and Macro areas. The following modeling assumptions are considered in the analysis:

a. One cell is assumed in the simulation with two virtual zones. The inner WiFi-6 zone is surrounded by the outer 5G zone.

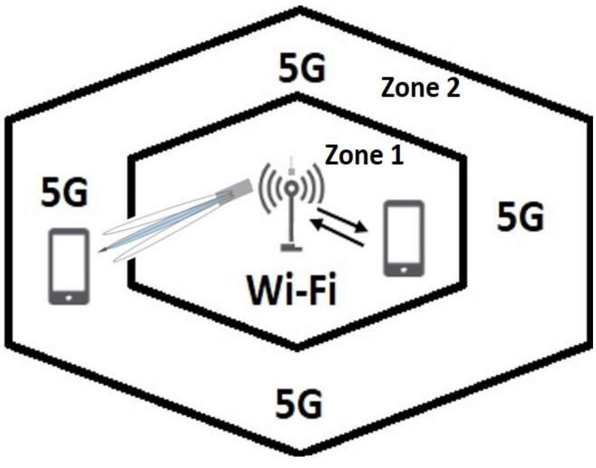

Fig. 2: 5G/WiFi-6 Coexistence Model

b. The maximum bandwidth capacity for the whole cell is assumed. The cell bandwidth is divided between the inner and the outer zone. As the inner zone is closer to the base station (BS) and has more traffic intensity, it is given double the bandwidth given to the outer zone.

c. The minimum bandwidth threshold for call admission is assumed for both the inner and outer zone.

d. In the simulation scenario, the call admission control algorithm (CACA) admits the user either to WiFi-6 zone or 5G zone depending on the minimum threshold criterion given to each zone, however, in a real-life scenario, the admission control depends on the location of the user in the cell and the power of the signal. Fig. 3 shows the CACA used in the simulation.

e. The arrival of the call to the cell is assumed to be Markovian Modulated Poisson Process (MMPP) [21] with inter-arrival time, λ which is calculated concerning the areas of the zones ($\alpha i * \lambda$, $i = 1, 2$ for two zones), the density of the users, and the modulation schemes used in each zone.

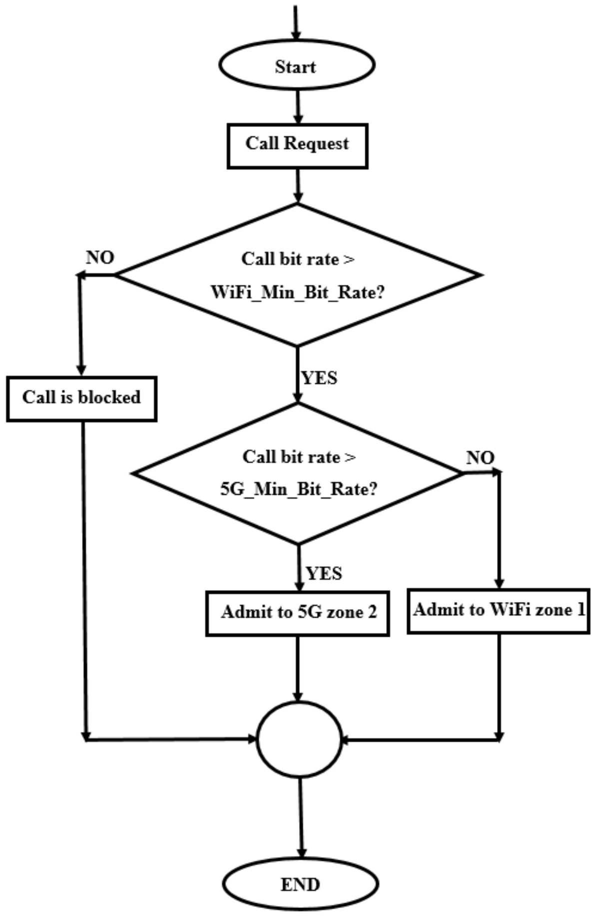

Fig. 3: CACA flowchart for the simulation

f. To meet the challenges of 5G technology, five different groups of service categories are suggested in [22]. Detailed explanations of the categories and related services are given in Table 2. The first category is the immersive 5G services, these services are the most frequent services used by people which includes virtual and augmented reality and 3D applications as well as real-time video streaming through the web. The second category of service is intelligent 5G services. These services include slice-based services such as 4k video streaming, broadcasting, and internet-of-things (IoT). The third category is omni-5G services. These types of services will include all smart applications such as smart cities, health smart buildings. The fourth category is the autonomous 5G services. These types of services will increase people's accessibility via connected appliances such as self-driving smart cars so that the cars will be able to communicate and share traffic conditions and distribution, on the other hand, other applications related to robots are included in this category. The last service category is called public 5G services. These services are related to people's public safety, private security, and emergency services. Based on the above 5G service categories and according to [23], three types of services are assumed in the numerical results:

1. Web content browsing and downloading over 5G (WBDo5G). This type of service includes all types of high-quality browsing and downloading documents from the web.
2. Video streaming over the Web over 5G (STRWo5G). This includes 4k high-quality video streaming and video on demand (VoD).
3. Voice emergency services over 5G (VEo5G). This type of service includes emergency calls that should take higher priority overall services.

Table 2: 5G Service Categories [22]

Categories	Services
1. Immersive 5G	Massive Contents streaming Virtual Augmented Reality Telepresence
2. Intelligent 5G	Crowded Area Service User-centric Computing Edge/FOG Computing
3.Omnipresent 5G	Smart Personal Devices /Health Smart Building/Grid Smart City/ Smart Factory Systems
4. Autonomous 5G	Smart Transportation /Teleoperation Drone-based 3D connectivity Robot-based Service
5. Public 5G	Private Security and Public Safety Disaster Monitoring Emergency Service

B. Performance Parameters

The following performance parameters are used in the simulation to study the effect of 5G/WiFi-6 coexistence on cell performance. The performance parameters are produced by MOSEL-2 simulation which is based on a continuous-time Markov chain (CTMC) solution.

1. Bit error rate (BER): is the ratio of the number of bits received by a receiver in error, e to the total number of bits received, N, $BER = \frac{e}{N}$.
2. Blocking probability: is the percentage of calls that are blocked since their bit rate is below the required minimum threshold according to the CACA.
3. Latency (milliseconds, ms): is the time required for a set of data to travel between two points. Therefore, this value depends on different parameters: the maximum available bandwidth in the network, the speed and the size of data to be transmitted. In the simulation, it is calculated as the available average bit rate concerning the maximum cell bit rate. 5G applications are targeting latency of less than 1 ms.
4. Utilization: is the performance parameter that shows the best allocation and utilization of the bandwidth in the cell. It is calculated as the percentage of the total mean bit rate concerning the maximum cell capacity.

5. Throughput: in a communication network is the total bit rate of successful message delivery over a communication channel. In the simulation, it is the mean total bit rates that are transmitted successfully.

6. Aggregate average bitrate: refers to the total number of data bits that are transmitted successfully through the communication media. The aggregate average bit rate is calculated in the simulation for each zone and each service.

IV. NUMERICAL RESULTS AND DISCUSSION

The numerical results are produced and prepared using MOSEL-2 simulation language and its associated package IGL [20] to assess the evaluation of the suggested model. All figures are generated against the offered bit rate (from 7-76 Mbit/s). The graphs are divided into two groups. The first group of results (Fig.4-Fig.10) is to show the performance of both technologies with coexistence as well as the effect of this on overall cell performance. The second group of results (Fig. 11 -Fig.14) is comparative results to show 5G performance with and without coexistence. All performance parameters are shown against the offered traffic bit rate in the cell. Fig. 4 represents the blocking probability for both technologies. In this figure, 5G has shown better performance than WiFi-6 at different traffic loads. This happens because the inner zone is given double the bandwidth of the outer zone, therefore, most of the traffic is served successfully by the inner zone, and hence not many calls are transferred to the 5G zone. This situation occurs in real-life status when there are applications in homes, offices, or even inside a department. On the other hand, overall cell performance is improved dramatically since most of the requests are served successfully either by zone 1 or by zone 2. Most achieved results of blocking probability values are less than 9e-4. The bit error rate (BER) measures the number of bits received by a receiver with an error. In this regard, the BER for both technologies is shown in Fig. 5 along with the BER in the whole cell. Looking at Fig. 5, one can notice that very low values for BER are shown for both technologies and all BER values are almost similar and therefore, the BER values for the whole cell are almost similar at different traffic values (i.e. less than 1e-6). According to 3GPP standardization, the latency values for 5G applications should not exceed 1 ms.

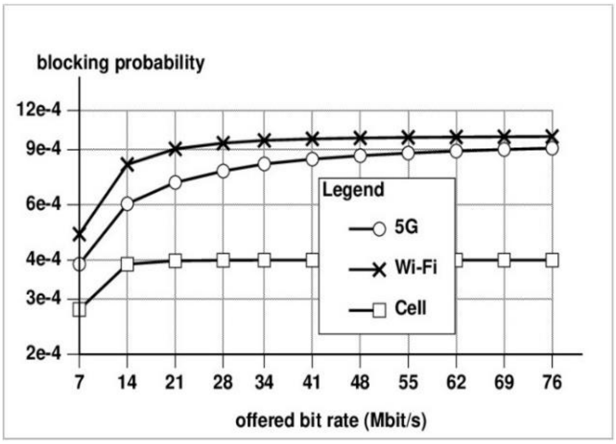

Fig. 4: Blocking probability for different technologies

Considering 3GPP standardization, in Fig. 6, the latency performance of the cell is shown. Both technologies have similar values for the latency at different traffic values which starts from 0.07 ms at 7 Mbit/s offered bit rate and ends with around 0.10 ms at 76 Mbit/s offered bit rate.

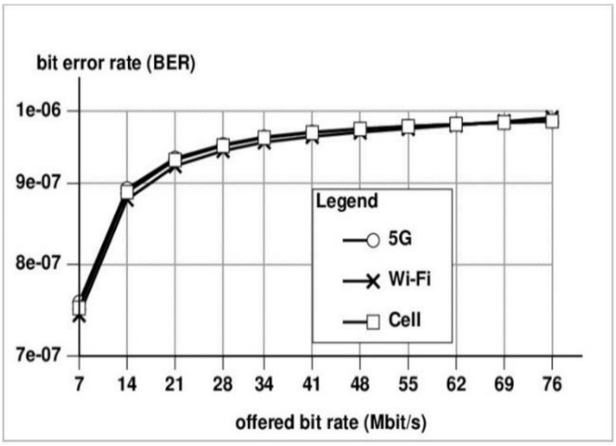

Fig. 5: The bit error rate for different technologies

These optimal values for latency have a positive reflection on the latency values for the whole cell as the latency results improved even at higher traffic loads, which are still below the minimum values given by 5G standards. Besides, interesting behavior is shown in this figure. When the offered bit rate increased, the latency values for both technologies and the cell become very close at around 0.10 ms. Utilization is a performance parameter that describes the best allocation and utilization of the bandwidth in the cell. It seems from Fig. 7 that the 5G zone has better utilization than the WiFi-6 zone. The reason for this is that many requests are supposed to be served by zone 1 (i.e. WiFi-6 zone) as zone 1 has higher traffic density than zone 2, however, some of these calls are already blocked and other calls will be forwarded to be served by the outer zone (i.e. 5G zone). As a result of this competition between both technologies, cell utilization is optimized for better performance. The utilization of the whole cell in Fig. 7 reaches 98% at the maximum traffic load.

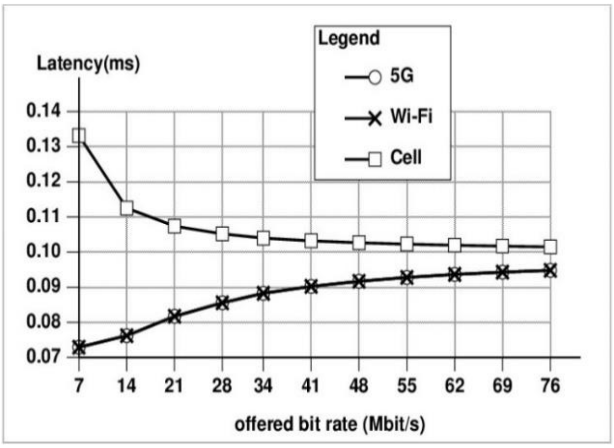

Fig. 6: Latency for different technologies

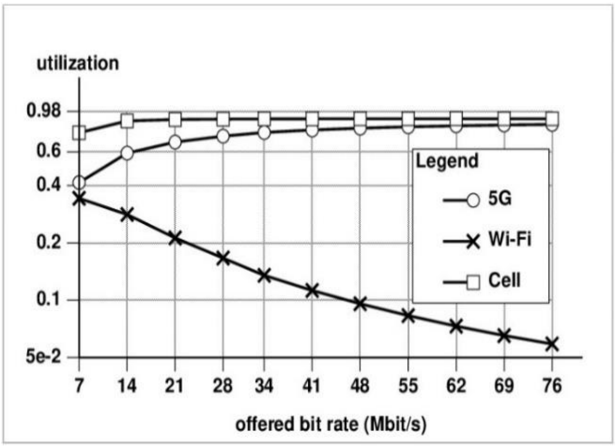

Fig. 7: Utilization of different technologies

In Fig. 8, the throughput is shown. Throughput is the measure of the total bit rate of successful message delivery over a communication channel. As shown in the figure, with coexistence, WiFi-6 has less total bit rate for message delivery than 5G, however, the cell overall total bit rate has been improved dramatically. Fig. 9 and Fig. 10 demonstrate the aggregate average bit rate per service for both zone 1 and zone 2. Three types of services are assumed in the analysis: WBDo5G, STRWo5G, and VEo5G.

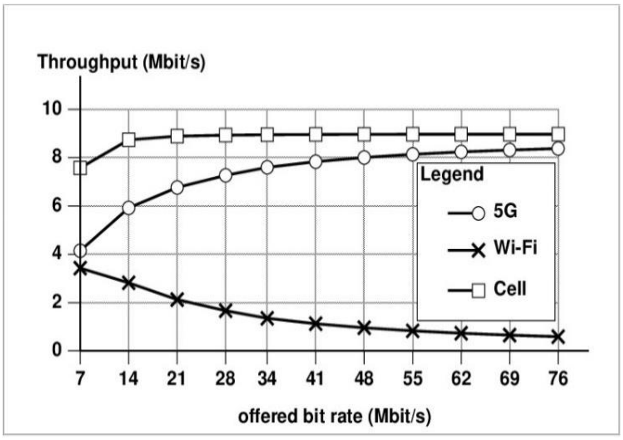

Fig. 8: Throughput for both technologies

According to Fig. 9, for low traffic loads, the aggregate average bit rate is higher for STRWo5G and emergency calls, VEo5G. When the traffic load goes up, web content downloads and browsing users are consuming most of the bit rate as most real-life daily applications are based on this type of service.

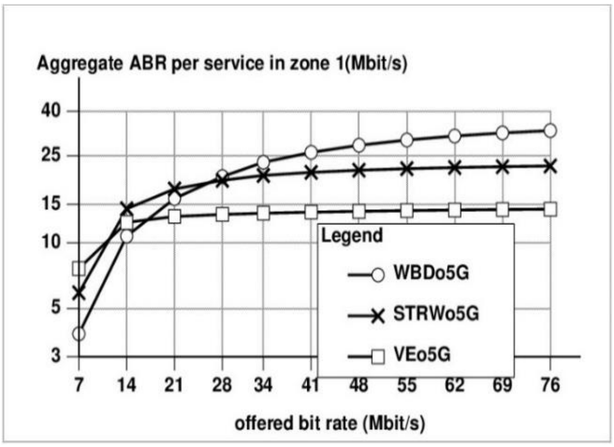

Fig. 9: Aggregate Average bit rate per service in Zone 1

Different behavior is shown in Fig. 10. Most of the requests that are not served by the inner zone are forwarded to be served by the outer zone. Therefore, the requests are divided between both technologies, and hence, the load is balanced all over the whole cell. Consequently, all types of services have equal bit rate values at low traffic loads, when the load increased, zone 2 will give priority for emergency requests over other requests as those types of services are given higher priority in the model simulation. The second group of results is divided into four figures. From Fig. 11 to Fig. 14. This group demonstrates comparative results to compare 5G performance with and without coexistence. Fig. 11 shows the blocking probability results. Looking at Fig.11, one can notice that 5G performance degrades with coexistence at different traffic loads.

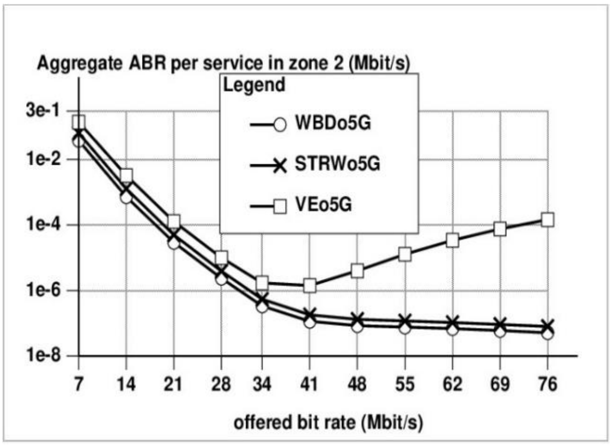

Fig. 10: Aggregate Average bit rate per service in Zone 2

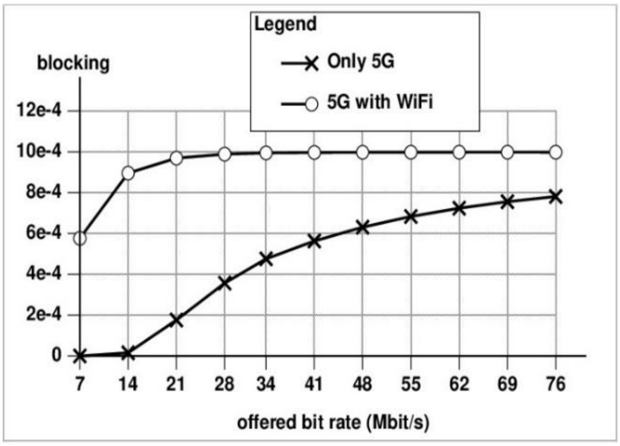

Fig. 11: 5G blocking comparison with and without coexistence

Nice behavior is shown in Fig. 12 for BER. It can be seen from this figure that although 5G performance is degraded with coexistence at lower traffic loads, at some level of the traffic (i.e. between 34 Mbit/s and 62 Mbit/s), it appears that BER results of 5G become equal regardless of the coexistence, but still within an optimal value of BER (i.e. close to 1e-6). This situation can be explained as follows: as both technologies are sharing resources, at some point in time they will have equal opportunities to successfully serve the same number of requests whether they coexist or not. Another comparative performance parameter is shown in Fig. 13 for latency and Fig. 14 for throughput. 5G performance for latency values is improved with coexistence compared to degradation in performance for throughput. While coexisting with WiFi-6, the performance of the whole cell is improved. Therefore, the 5G coexistence scenario with WiFi-6 has a positive effect on cell performance by dividing the load between both technologies, and hence the load is balanced overall the whole cell.

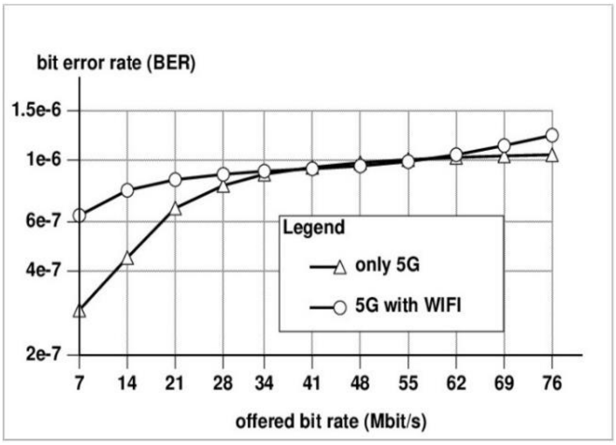

Fig. 12: 5G bit error rate comparison with and without coexistence

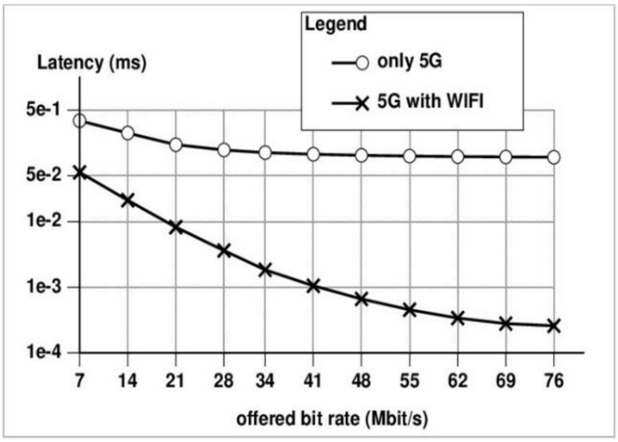

Fig. 13: 5G Latency comparison with and without coexistence

V. CONCLUSIONS AND FUTURE WORK

In this paper, a new model of coexistence between 5G and WiFi-6 technologies is proposed. The cell is divided into two virtual zones according to OFDM modulation. The inner zone represents WiFi-6 technology, whereas the outer one is a 5G technology. The provided numerical results show that the proposed model has a negative effect on 5G performance. However, the coexistence principle between the two technologies provides a complementary solution that has a positive effect on whole-cell performance since all requests are served by both technologies by balancing the load over the whole cell. In future work, the same model can be extended to a more realistic multi-cell scenario where handover between different cells should be considered and therefore, comparison with other research work in the literature will be more practical.

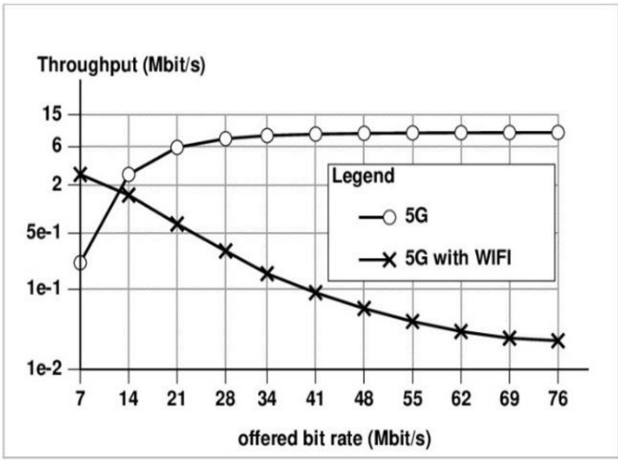

Fig. 14: 5G Throughput comparison with and without coexistence

VI. ACKNOWLEDGMENT

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