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LTE AND WIFI CO-EXISTENCE IN 5 GHZ UNLICENSED BAND

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Abstract. *Since the future mobile networks will require significantly higher data throughput, and the Long-Term Evolution (LTE) licensed bands are already occupied, the frequency band extension and the data rate increase may be achieved by using some of the available unlicensed bands. The most appropriate unlicensed band for this purpose lies in 5 GHz frequency range. However, this unlicensed band is already occupied by WiFi networks and a special attention has to be paid to coordinate these two different networks in the shared spectrum usage. Therefore, this paper considers the shared access co-existence in 5 GHz unlicensed band between uncoordinated LTE and WiFi networks. More precisely, it considers the influence of the LTE downlink transmission on the performance of the WiFi networks. The experimental results show that the LTE significantly degrades the WiFi network performance, which means that some of the coordination algorithms have to be employed.*

Key words: *WiFi, LTE, co-existence, unlicensed band, shared access*

1. INTRODUCTION

Mobile communications industry is rapidly growing over the past decade, and the mobile data transfer was almost completely based on the usage of the licensed spectrum. Having in mind predictions of 1000 times cellular data traffic growth until 2020 [1], and the fact that there is an increasing amount of machine to machine data transfer [2], it is clear that the licensed band communications would have problems to support such a high bandwidth demand. One of the possible solutions to this problem use some additional spectrum out of the dedicated licensed band, while causing minimum interference to the existing systems in that frequency band. The co-existence of the mobile communication networks (Global System for Mobile (GSM) and Long-Term Evolution (LTE)) and digital terrestrial video broadcasting (DVB-T) systems are analyzed in [3]. The paper shows that there could be a significant mutual influence of these systems. Besides, the available ultra

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high frequency (UHF) bandwidth is not very large. All of this indicates that UHF TV bands are not very appropriate for the mobile communication systems bandwidth increase. On the other hand, the unlicensed bands are particularly suitable for the bandwidth extension. The unlicensed band consist of Industrial, Scientific and Medical (ISM) and Unlicensed National Information Infrastructure (U-NII) bands. ISM bands occupy frequencies around 900 MHz, 2.4 GHz, and 5.8 GHz, whereas U-NII occupies frequencies from 5 to 5.8 GHz. 2.4 GHz band provides around 80 MHz of bandwidth, but it is heavily occupied by 802.11b/g WiFi networks, bluetooth and other wireless personal area networks. On the other hand, 5 GHz band provides around 500 MHz of bandwidith and it is lightly occupied mainly by WiFi 802.11ac/n networks. Both 2.4 and 5 GHz WiFi use carrier sense multiple access (CSMA) to access channel, and they are possible victims of some other technologies operating in the same frequency range. Bluetooth use CSMA for data transmission and time division multiple access (TDMA) for audio transmission. Therefore, in case of audio transmission bluetooth may cause interference to other networks. Having in mind the existing interference and the available bandwidth, 5 to 5.8 GHz band was chosen to be used for the bandwidth extension [4]. However, the implemented technology should be flexible enough to support other frequency bands.

LTE was first defined in 3rd Generation Partnership Project (3GPP) Release 8 [5]. It represents an evolving mobile communication standard that provides high data rates, higher capacity, smaller latency and new levels of user experience. In the 3GPP Release 10 [6], LTE was improved to fulfil the requirements of 4G mobile networks and it was named LTE–Advanced (LTE-A). The most important advancement of the LTE-A is the possibility of simultaneous use of multiple frequency bands by the means of the Carrier Aggregation (CA) technology. CA is the key technology that enables the unlicensed spectrum usage by the LTE devices. However, the unlicensed spectrum would only be used for data rate increase, both in downlink and uplink, while the licensed spectrum, having predictable performance, will still be used for the important operations, such as network management, or delivery of critical information and guaranteed Quality of Service.

Although the unlicensed band may be freely used by the communication systems, there are some regulations that have to be followed, such as Dynamic Frequency Selection (DFS) and listen-before-talking (LBT), which may use different technologies, such as carrier sense multiple access or spectrum sensing [7]. These coordination mechanisms, that are variants of dynamic spectrum access (DSA), are essential for achieving efficient co-existence between different systems that are operating in unlicensed spectrum. As the 5GHz band is primarily used by IEEE 802.11ac WiFi networks, the focus should be on the coordination between the LTE and WiFi. The main problem lies in the fact that the LTE was designed to operate in a dedicated, licensed band. Therefore, it does not have shared access mechanisms, like WiFi does. Papers [8] and [9] provide respectively simulation and theoretical results on the co-existence of LTE and WiFi networks and show the need for some sort of coordination between these two networks. Experimental analysis of the 2.4 GHz band WiFi communication influenced by LTE is given in [10]. The LTE is represented only by the base station, without any mobile stations. In this case, LTE eNB waits for the UE and transmits mainly control signals.

There are two possible solutions to the problem of WiFi and LTE networks co-existence. The first approach is to modify the LTE standard and adapt it to work in frequency shared environment. LTE-U (LTE-Unlicensed), proposed by LTE-U forum [11], uses a LTE version with duty cycle i.e. with pauses in the transmission. In this way, WiFi has the opportunity to transmit its data during the silent periods of the LTE-U. Besides, LTE-U access point listens to WiFi transmissions, tries to predict the usage patterns and to adapt to them. Licensed Assisted Access (LAA) will be a part of the future 3GPP LTE Release-13 standard [12], [13], and includes Listen Before Talk (LBT) mechanism to transmit when the channel is free. Standardization progress and the summary of the LAA is given in [14]. Also, an operator level system performance is analyzed for indoor hotspot, indoor office, and outdoor small cell scenarios. The analysis showed that a significant LTE capacity increase may be obtained by using LAA and LBT. Paper [15] considers the design of LBT for the LAA system and analyzes the influence of LAA clear channel assessment threshold on the performance of both LTE and WiFi networks. The paper shows that the proposed LBT algorithm is able to improve LAA and to keep low interference to WiFi. However, both LTE-U and LAA require significant modifications of the LTE standard and will not be available in near future.

The second approach is to introduce a coordinated access to the shared channel. There are two general approaches to spectrum coordination as follows [16]: reactive spectrum coordination and proactive spectrum coordination. The most straightforward reactive spectrum coordination concept is so called agile wideband radio scheme [17]. In this scheme, transmitter analyzes the spectrum and chooses its frequency band and modulation scheme, having in mind the highest allowed interference level. There is no higher-level coordination with the neighboring nodes. This coordination scheme is very simple, but has one serious possible problem with the hidden nodes, i.e. with the nodes that may not be visible to the station, but may interfere with it. Another simple coordination scheme is reactive control [18]. All the radio stations in a network control its transmit power, rate, or frequency band in a way to optimize channel quality and interference levels. The name reactive comes from the fact that the station change its parameters as a reaction to the changes in the wireless environment. Although these schemes are simple, with low software and hardware complexity, their application is limited to some simple scenarios. Proactive spectrum coordination schemes are slightly more complex than the reactive. An example of proactive schemes is the spectrum etiquette protocol [19]. This scheme employs a distributed coordination by the means of either Internet services or a separate coordination radio channel reserved for this purpose within the frequency band common to all participating radio nodes. These schemes enable radio nodes, using different radio access technologies, to coordinate its activities and adjust transmit parameters for successful joint operation. The etiquette approach is capable of operating in more complex scenarios than the reactive schemes. The Common Spectrum Coordination Channel (CSCC) variant of the etiquette approach is given in [19], [20] together with the demonstration of proof-of-concept experiments for co-existing IEEE 802.11b/g and Bluetooth networks in the shared 2.4 GHz unlicensed band. With the coordination approach, only minor modifications of the existing standards are needed. However, the best solution would be to use coordination together with the LTE-U or LAA.

Having in mind the analyzed literature, it may be noticed that there is a lack of the experimental results for the scenario of LTE and WiFi networks co-existence in 5 GHz band. This paper gives the experimental data regarding the interference caused by LTE towards the WiFi in 5 GHz unlicensed band. Unmodified versions of the existing standards are used, 802.11a for WiFi, and 3GPP Release-10 for LTE. Since there is no commercial LTE hardware available that operates in any unlicensed band, we used software radio based LTE implementation named OpenAirInterface (OAI) [21]. OAI is also meant to be used in the licensed bands, so we had to modify source code to allow usage in 5 GHz unlicensed band. The experimentation is performed at NITOS testbed [22].

The rest of the paper is organized as follows. Section 2 briefly describes the OpenAirInterface as well as the NITOS testbed. The experiment description is given in Section 3, while the experiment results and discussion are given in Section 4. Finally, the concluding remarks are presented in Section 5.

2. OPENAIRINTERFACE AND NITOS TESTBED

The OpenAirInterface LTE implementation represents the full real-time software implementation of 4th generation mobile cellular systems compliant with 3GPP LTE standards Release-8/10. OAI is implemented in gnu-C and uses x86 Single instruction, multiple data (SIMD) hardware acceleration. It is primarily targeted for x86 Real Time Application Interface (RTAI), but can be made to run on any GNU environment. OAI implements both LTE eNB, i.e. LTE base station, and LTE User Equipment (US), i.e. LTE mobile station. It supports both Frequency-Division Duplexing (FDD) and Time-Division Duplexing (TDD) configurations in 5, 10, and 20 MHz channel bandwidth. OAI is designed to work with any hardware RF platform with minimal modifications. Currently, two platforms are supported: EURECOM EXMIMO2 [23], and Universal Software Radio Peripheral (USRP) X- and B- series [24]. In our experiments, we used USRP B210. Besides USRP, an Intel Core *i*5 or *i*7 based PC with USB 3.0 port is needed.

The experiment will be performed at NITOS testbed. NITOS testbed consists of several experimentation environments: Outdoor, Indoor RF Isolated, and Office testbeds to meet different experimentation scenarios (Fig. 1).

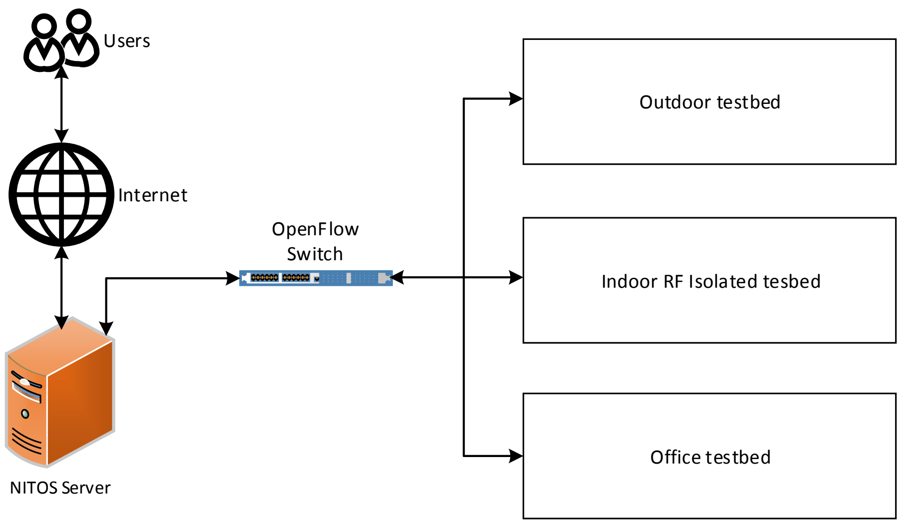

Fig. 1 NITOS testbed block diagram

The experiments were executed at Indoor RF Isolated testbed because it is the only testbed currently equipped with USRP B210. It consists of 4 × 11 nodes arranged in the grid (11 rows with 4 nodes each), as shown in Fig. 2. The distance between the neighboring nodes is 1 m.

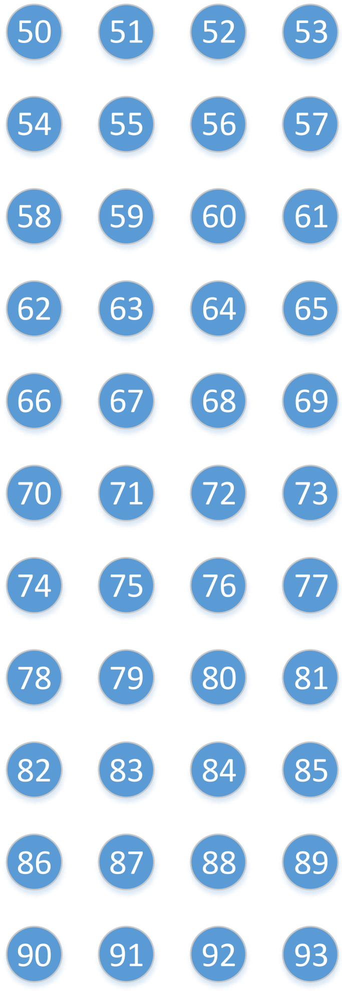

Fig. 2 Indoor RF Isolated testbed topology

The nodes are numbered from 50 to 93 because previous 49 nodes are in Outdoor and Office testbeds. Each node consists of a PC with different RF devices attached, such as WiFi, USRP, Bluetooth, and LTE. After the reservation of a time slot, each node may be accessed online by the user and any software may be executed.

3. EXPERIMENT SETUP AND RESULTS

3.1. Experiment description

The topology of the experiment setup is shown in Fig. 3. Nodes 50 and 68 create an ad-hoc 802.11a WiFi network. Wireless network adapters are Qualcomm Atheros AR9580 (rev 01). Due to WiFi cards regulatory domain, available channels at 5 GHz frequency band are 36, 40, 44, and 48. It was chosen to use channel 48 with central frequency of 5.24 GHz. WiFi adapters output power was set to 0 or 10 dBm in order to make it less than or equal to the output power of the USRP devices. The Transmission Control Protocol (TCP) throughput between these two stations is generated and measured using *iPerf* v2 [25] application during 60 seconds, without parallel streams. The LTE eNB and LTE UE are run on nodes 59 and 60, respectively, using OAI software. It may be noticed that the LTE nodes are close to each other. That is because the OAI is still in the development phase and the link quality between eNB and UE is not very good. Currently, the EURECOM is paying the most attention to the development of OAI eNB in order to make it work correctly with different commercial LTE devices, such as mobile phones.

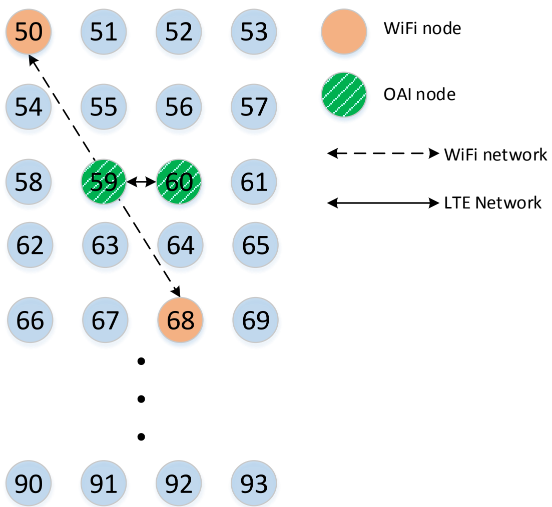

Fig. 3 The experiment setup topology

The LTE channel width may be configured using the Number of resource blocks (N_{RB}) parameter. Possible channel widths are 1.4, 3, 5, 10, 15, 20 MHz for N_{RB} = 6, 15, 25, 50, 75, 100. The OAI is configured to work in FDD mode with 5 MHz channel bandwidth, i.e. the number of resource blocks is set to 25, because OAI works the best with 5 MHz channel width.. The downlink frequency is set to be equal to the channel 48 central frequency, 5.24 GHz, and the uplink frequency offset is set to -100 MHz, i.e. the uplink frequency is 5.14 GHz. The throughput and the round-trip time (RTT) between WiFi stations is constantly measured while the LTE traffic is varied. Again, *iperf* is used, now to generate User Datagram Protocol (UDP) traffic in the downlink of the LTE network.

It should be noted that paper [8] and this paper consider a similar topic. However, the results in this paper may not be compared to those obtained in [8]. Namely, paper [8] analyzes the influence of OAI eNB (without UEs) on the WiFi transmission in 2.4 GHz band. WiFi stations are located at the same testbed node, with 25 cm distance between the antennas. OAI eNB distance to WiFi was varied from 1 to 20 m. Since we did not have a physical access to the NITOS testbed, we could not put two WiFi cards on one node. Also, we could not move USRPs to different nodes, and therefore could not change the distance between LTE and WiFi stations.

3.2. Experimental results

This section presents some experimental results that show the influence of LTE on WiFi network based on scenario described in the previous section.

Fig. 4 shows WiFi throughput over time for different LTE traffic intensity: no LTE network present, only LTE eNB generating light load with control signals, 1 Mb/s, and 10 Mb/s of the downlink LTE traffic. The USRP B210 output power is around 10 dBm, so WiFi output power was chosen to be equal to USRP (10 dBm) and 10 dB lower (0 dBm). It may be noticed that the higher the LTE throughput, the lower the WiFi throughput is. That is because WiFi senses LTE transmission and postpones its own transmission. On the other hand, LTE does not use carrier sensing and it transmits continuously. WiFi transmit power has almost no influence on WiFi throughput (curves *a*, *c*, and *d*), except for the case of light LTE traffic with only eNB (curve *b*), because stronger WiFi packets are more likely to reach the destination, even if they are hit by the LTE signal during the transmission.

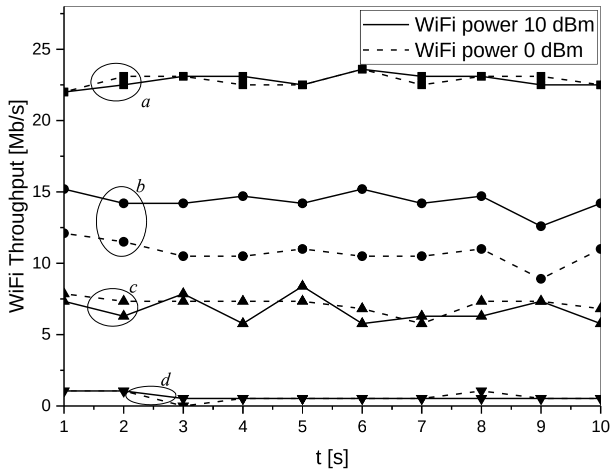

Fig. 4 WiFi throughput over time for different LTE traffic intensity:
a) No LTE, b) Only LTE eNB, c) 1 Mb/s d) 10 Mb/s

Besides the throughput, the transmission delay is also an important parameter of a communication network. The round-trip time, i.e. time needed for a packet to travel from source to destination and back to source, for the WiFi network is shown in Fig. 5. It is measured using *ping* application, which sends Internet Control Message Protocol (ICMP) *Echo Request* packets, and waits for ICMP *Echo Response* packets. The RTT is considered for different LTE traffic intensity and for different ICMP packet size: 100, 1000, and 10000 bytes.

Fig. 5 shows average value and standard deviation of the RTT. The conclusion from Fig. 4 may be applied here: higher LTE throughput increases both average value and the standard deviation of RTT. The average value increases significantly for 10 Mb/s LTE throughput. On the other hand, the RTT standard deviation increases approximately exponentially with the increase of LTE throughput.

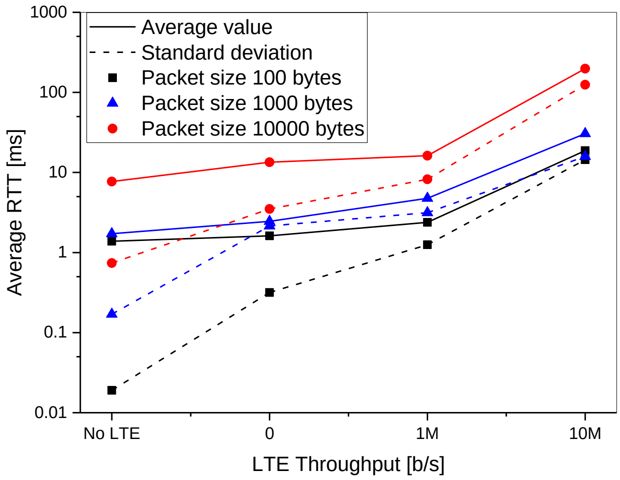

Fig. 5 WiFi network RTT as a function of LTE throughput, for different values of packet size

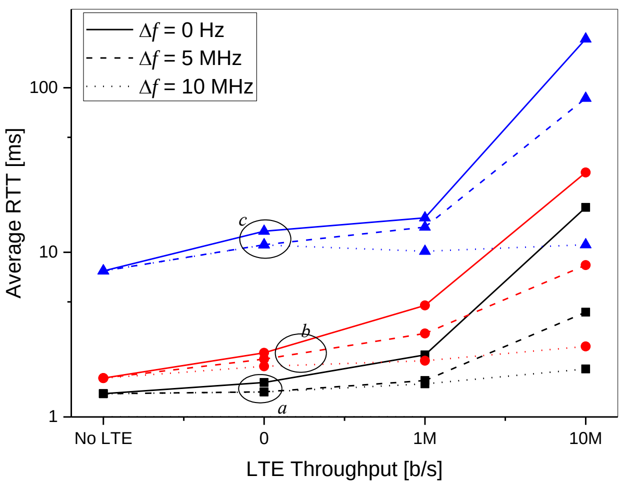

Fig. 6 WiFi network average RTT as a function of LTE throughput, for different values of frequency offset between WiFi and LTE carrier frequency Δ*f*, and WiFi packet size a) 100 bytes, b) 1000 bytes, c) 10000 bytes

Finally, Fig. 6 analyzes the influence of the carrier frequency offset between the WiFi channel central frequency (f_{WiFi}) and the LTE downlink frequency (f_{LTE}) Δf.

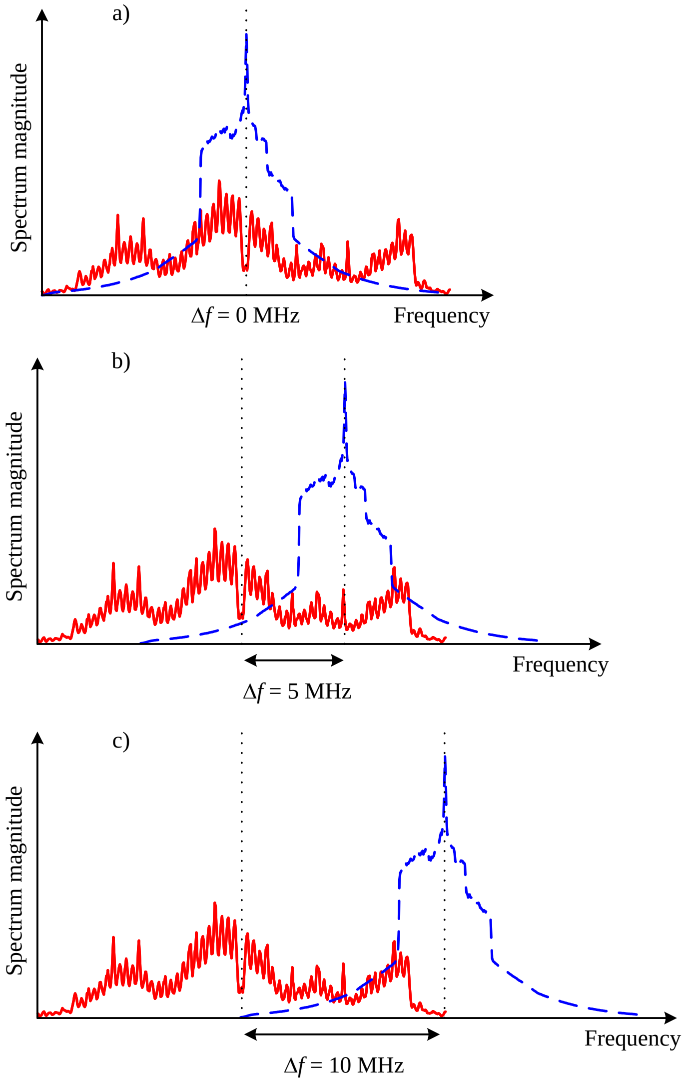

Fig. 7 Mutual position of the WiFi (solid line) and LTE (dashed line) spectra for different carrier frequency offset a) 0 MHz, b) 5 MHz, c) 10 MHz

We should have in mind that WiFi occupies 20 MHz bandwidth (f_{WiFi} ± 10 MHz), and LTE occupies 5 MHz (because N_{RB} is chosen to be 25) bandwidth (f_{LTE} ± 2.5 MHz), as shown in Fig. 7. As can be seen from Fig. 7, for 0 and 5 MHz offset, whole LTE spectrum overlaps with WiFi spectrum and 25% of the WiFi channel is occupied by LTE. Note that

LTE carrier frequency lies within WiFi channel. For 10 MHz offset, a half of the LTE spectrum (2.5 MHz) overlaps with the WiFi spectrum, and LTE carrier frequency is on the edge, or practically out of WiFi channel. The results show that the higher the offset the lower is the influence of LTE on WiFi network. If the offset is 10 MHz, LTE has very little influence on the WiFi network. Figs. 6 and 7 show that the LTE carrier itself is the main cause of the interference.

4. CONCLUSION

The influence of the LTE on the WiFi network, sharing the same 5 GHz frequency range without coordination, is considered in this paper. The results show that the higher the LTE throughput, the lower the WiFi throughput. The LTE similarly influences the round-trip time of the WiFi network packets. The influence is the highest if the LTE downlink frequency is equal to the WiFi channel central frequency. If the difference between these two frequencies is higher, the influence is lower.

Having in mind the presented results, a conclusion can be made that the coordination between the LTE and WiFi networks is very important and will be the topic of our future research. We are currently developing spectrum coordination based on an ontological framework. The coordination process will be centralized on one coordination server. It will communicate to WiFi and LTE clients and provide them all the needed parameters for the successful co-existence in a shared frequency band.

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