System performance of LTE and IEEE 802.11 coexisting on a shared frequency band

Timo Nihtilä*, Vitaliy Tykhomyrov*, Olli Alanen*,
Mikko A. Uusitalo†, Antti Sorri†, Martti Moisio†, Sassan Iraji§,
Rapeepat Ratasuk‡ and Nitin Mangalvedhe‡
* Magister Solutions Ltd., Hannikaisenkatu 41, FIN-40100 Jyväskylä, Finland
† Nokia Research Center, P.O. Box 226, FIN-00045 NOKIA GROUP, Finland
‡ Nokia Siemens Networks, 1421 W. Shure Dr., Arlington Heights, IL, USA
§ Aalto University, P.O. Box 11000, FI-00076 AALTO, Finland

Abstract—**This paper presents the system performance analysis of 3GPP Long-Term Evolution (LTE) and IEEE 802.11 Wireless Local Area Networks (WLAN) in a situation where LTE downlink (DL) has been expanded over to unlicensed frequency band usually used by WLAN. Simple fractional bandwidth sharing mechanism is used to allow both technologies to transmit. The system performance is evaluated by means of fully dynamic network simulations.**

I. Introduction

Long-Term Evolution (LTE) standardized by the 3rd Generation Partnership Project (3GPP) is the most adopted air interface for 4th generation (4G) cellular networks. Large number of frequency bands in the world have already been assigned for LTE operators. However, with exponentially growing wireless data, network capacity can quickly become limited in the future. Increasing bandwidth is a straightforward way to increase capacity but available licensed spectrum is limited and can be very costly to obtain.

Additional spectrum increase opportunities can be found from license-exempt bands. Among examples of these bands are Industrial, Scientific and Medical (ISM) and Unlicensed National Information Infrastructure (UNII) bands, TV white space and managed commons. LTE expanding over to unlicensed spectrum is an attractive idea but the problem is the coexistence with other systems occupying the same frequency and understanding how they perform together with LTE when the band is shared.

IEEE 802.11 standard Wireless Local Area Networks (WLAN) operate on license-exempt 2.4 GHz and 5 GHz frequency bands. User offloading from LTE to WLAN is often listed as a solution to increase capacity. However, LTE offers better performance than WLAN in a situation where a lot of users try to access the medium through the same access point and where hidden nodes are a problem. Thus, there may be uncovered benefits for the end user in deploying LTE on unlicensed band.

Using LTE on WLAN band has been studied before, e.g., in [1]. The authors presented the concept of deploying LTE in the unlicensed band and investigated the modifications needed to allow LTE to operate there. Also, in [2] the authors presented scenarios showing how LTE can be adopted for license-exempt operation, with a focus on LTE usage in TV white spaces. The results of LTE performance in different interference situations were also presented.

However, LTE and WLAN coexistence on the same band has not been thoroughly studied. In this paper we investigate the performance of co-existing LTE downlink (DL) and WLAN on the license-exempt band. A fractional bandwidth sharing mechanism is used to allow both systems to transmit. We examine the performance from both WLAN and LTE network point of view as well as from the users' point of view by means of fully dynamic network simulations.

II. Medium utilization in WLAN and in LTE

When two technologies share a resource such as the physical medium (frequency band), the methodology for sharing is important. LTE and WLAN differ considerably in terms of how they use bandwidth allocated for them. In WLAN, an active (transmitting) terminal uses the whole available bandwidth. The system is based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) [3].

The basic medium access technique of CSMA/CA is the Distributed Coordination Function (DCF), in which a user willing to transmit first senses the channel to find out whether it is busy i.e. another user is occupying it. If the channel is busy, the user will defer and try again. If the channel is free long enough, a user may start transmitting.

On the other hand, LTE does not share its frequency band between its users in as atomic manner as WLAN. The bandwidth is divided into resource blocks, which can be assigned to different users at the same time. Allocation of resource blocks is handled in the LTE base station (eNodeB) Medium Access Control (MAC) scheduler, a centralized entity not existent in WLAN where ”scheduling” is distributed. Fast eNodeB scheduling brings additional diversity gain to LTE, due to the possibility to let users transmit at times when the expected throughput is highest for them.

One basic difference between WLAN and LTE is that in case of channel interference, while WLAN holds its transmission, LTE only reduces its transmission speed by increasing the transmission robustness.

978-1-4673-5939-9/13/$31.00 ©2013 IEEE

It is important to note that WLAN downlink and uplink (UL) use the same band, i.e., terminals and access points (AP) contend together for the usage of the same medium as in LTE Frequency Division Duplex (FDD) mode, DL and UL have their own designated bands.

In our study, we assume overlapping WLAN and LTE DL bandwidths. The user traffic is DL only and in WLAN, UL is only used by the acknowledgements (ACK) of transmitted DL data while in LTE UL is not used at all. Control channels transmitted normally on UL are assumed to be ideally received, due to being on a licensed band. DL on unlicensed band is used for capacity increase.

A. *Handling of system co-existence in shared band*

In order to achieve a successful LTE expansion to unlicensed band, its presence there should affect WLAN performance as little as possible. To allow WLAN a chance to transmit, we limit LTE presence on the bandwidth by allocating only a fraction of the time for it. In other words, LTE follows a muting pattern, which statically prevents its transmissions during part of its Transmission Time Intervals (TTI). In our approach, LTE is silent n out of 5 TTIs, where $n \in [0, 1, 2, 3, 4, 5]$. This results in LTE muting percentages of $[0, 20, 40, 60, 80, 100]$. 0 % meaning that LTE is allowed to transmit in all TTIs and in 100 % case LTE is fully silent. One selected pattern is constant throughout each simulation within all eNodeBs.

III. Modeling of inter-RAT interference

An important part of the coexistence modeling is how the WLAN and LTE devices interfere with each other. It is assumed that LTE DL band (20 MHz) is completely overlapping the 802.11ac [4] WLAN band (20 MHz). WLAN and LTE symbols have different size in both frequency and time as presented in Fig. 1. A rather simplistic, but sufficient modeling is used to capture this effect.

The interference per subcarrier from an LTE radio towards a WLAN radio is assumed to be the average received power over all the resource blocks without fast fading effect. The interference per subcarrier from WLAN radio towards an LTE radio is assumed to be the average received power per subcarrier over the WLAN symbols which occur during the LTE symbol.

In WLAN devices the LTE interference is taken into account while performing the Signal to Interference and Noise Ratio (SINR) calculations in reception of WLAN physical PDUs and in the channel availability sensing. In the LTE side WLAN interference is taken into account in all the necessary places, i.e. SINR calculations and Channel Quality Indicator (CQI) measurements.

IV. LTE-WLAN system simulator

Simulation tool used in the performance evaluation is a dynamic network simulator framework, which combines two different, independent and technology-specific (LTE and WLAN) simulators into one unified tool. The framework

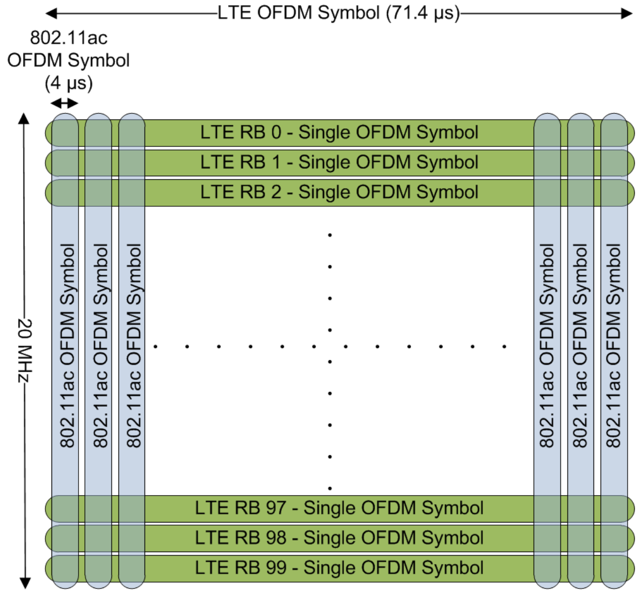

Fig. 1. LTE and WLAN inter-symbol interference.

lets the underlying slave simulators handle all lower layer, technology specific functionality while working as the master simulator handling all higher layer functions such as the simulation world creation, user creation, traffic handling and user mobility management.

The slave simulators operate in different time resolutions which are technology specific: WLAN simulator operates in IEEE 802.11ac Orthogonal Frequency Division Multiplexing (OFDM) symbol length resolution (4 μs) whereas LTE simulator has a coarser resolution of one LTE OFDM symbol (71.4 μs) with the cyclic prefix. Resolution difference is handled by the master framework by stepping the sub-simulators in an alternate manner so that the master simulation step is the lowest common multiple of the two sub-simulator step lengths, i.e., 1 ms.

LTE simulator is itself a dynamic system simulator which has detailed modeling of LTE physical layer functionalities, radio resource management (RRM), mobility, signaling, handovers and MAC scheduling. Both Enhanced UMTS Terrestrial Radio Access Network (E-UTRAN) DL and UL directions are modeled. The simulator has been used earlier in several studies, e.g., [5] and [6] among many others.

WLAN is simulated with a dynamic 802.11ac network simulator encompassing extensive modeling of WLAN physical and MAC layer. Results produced by the WLAN simulator have been presented previously in studies [7] and [8].

V. Simulation scenario

Fig. 2 shows the used simulation scenario. It is an office layout with 44 rooms and two corridors. 6 APs and 6 eNodeBs are positioned in 12 separate rooms. The positioning is selected in a way that APs/eNodeBs are as far away from one another as possible. This is done to ensure an even interference situation from both network perspectives all over the scenario.

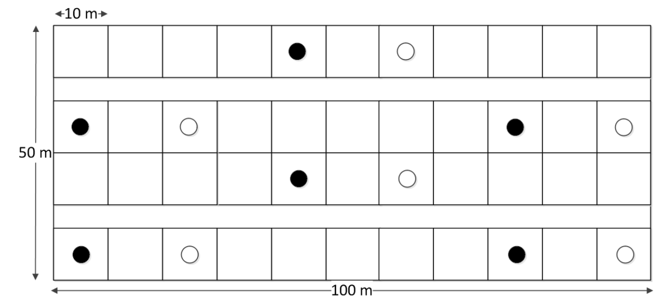

Fig. 2. Simulated office scenario showing LTE eNodeBs (black) and WLAN APs (white).

In the simulations, both WLAN and LTE users are created with a uniform spatial distribution all over the office scenario. User creation interval is governed by the offered load, which is explained in Section VI. Users may reside either in the rooms or in the corridors. Static mobility is selected so users are stationary throughout the simulations. Users select either an LTE eNodeB or a WLAN AP independently based on the measured signal strengths.

Common simulation parameters are shown in Table I. On average, each simulation run lasts for 70 seconds. Each created user starts a single file download session which ends immediately when the download is finished [9].

TABLE I
COMMON PARAMETERS.

Parameter	Value
Simulation time ($T_{simulation}$)	70 s (avg)
Traffic direction	Downlink
Transport protocol	UDP
Traffic application	File transfer
Max. PDU Size	1500 bytes
File size	2 Mbytes
Call arrival	Poisson distributed
User mobility	Static
Signal propagation	Indoor-COST 231 [10]
Antenna pattern (AP/eNB/MT)	Omni-directional

WLAN and LTE specific parameters are presented in Table II and Table III, respectively. All WLAN APs use the same frequency channel, which is not an optimal WLAN AP deployment. However, this was selected simply due to the fact that LTE is assumed to occupy the same band with WLAN.

TABLE II
WLAN PARAMETERS.

Parameter	Value
802.11 version	ac
Bandwidth	20 MHz
Tx power (AP & MT)	20 dBm
RTS/CTS	Enabled
TXOP limit	2 ms
Min CW	15
Max CW	63

TABLE III
LTE PARAMETERS.

Parameter	Value
Bandwidth	20 MHz (DL)
Mode	FDD
Tx power	20 dBm
Scheduler (Time / Frequency Division)	PF/PF
Max. scheduled users (TD/FD)	20/20

VI. SIMULATIONS

The key input to the system performance studies is the system load. In particular, all statements about number of supported terminals assume a certain load for the terminal. The main problem is that load varies widely with types of terminals, types of applications, and time of the day. Thus, to simplify the analysis, we use the system performance evaluation metrics *offered load* and *served load*. Offered load is defined as follows:

$$\textit{Offered load [Mbits/sec]} = \frac{N_{calls} * F_{size}\,[Mbits]}{T_{simulation}} \quad (1)$$

where N_{calls} represents the total number of calls during the simulation, F_{size} represents the file size downloaded during a call and $T_{simulation}$ represents simulation time.

On the other hand we define

$$\textit{Served load [Mbits/sec]} = \frac{D_{received}\,[Mbits]}{T_{simulation}} \quad (2)$$

where $D_{received}$ is the total successfully received data in the system. To simplify, offered load is the input to the system and served load is the corresponding system output.

A. Standalone performance evaluation

In Fig. 3, the performance comparison of LTE and WLAN is presented. In standalone cases, the networks operate independently from one another having the full band for themselves. The obtained results can be used as a reference case. In each simulation, both systems are offered an equal load (0-40 Mbps) and the corresponding served load per cell of each system is measured.

As can be seen from the standalone curves, the served load increases in both systems as offered load is increased. However, the difference in efficiency increases along with the load so that LTE is clearly better. This is as expected since in the selected scenario the load is increased by adding more users to the network, not by increasing the amount of data per call. As discussed in Section II, in situations where a lot of users try to access the network, LTE generally performs better than WLAN. Also WLAN minimum and maximum contention windows were set to quite low values (15, 63), which is a good setting for few contending users but is not optimal when there are many.

Comparing standalone LTE and WLAN systems at high loads, it is interesting that when offered load goes from 20 to 40 Mbps, the increase in WLAN served load is in the range of 2-3 Mbps while LTE served load increases by approximately

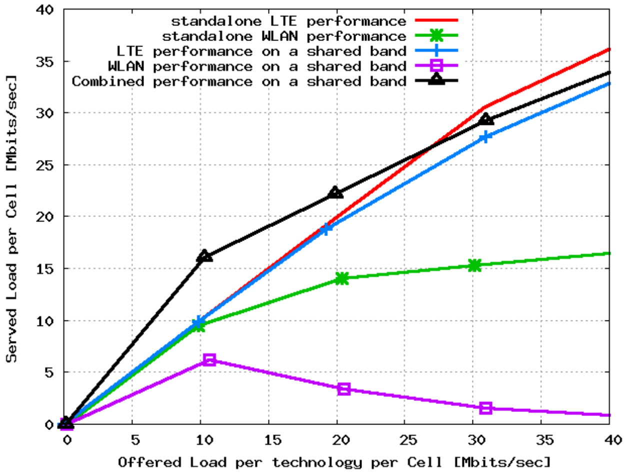

Fig. 3. LTE and WLAN performance. Standalone and shared frequency band cases.

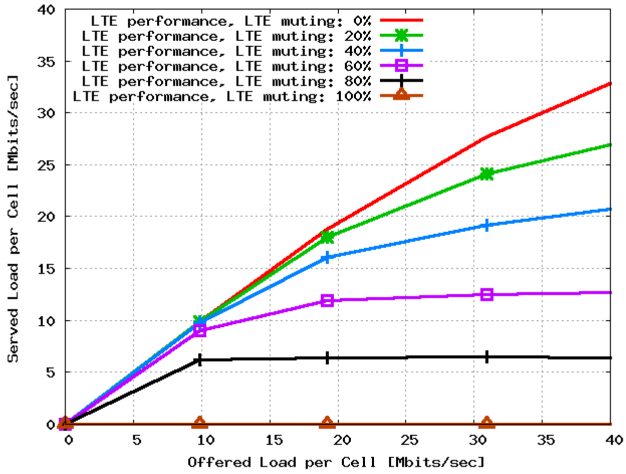

Fig. 4. LTE performance with LTE muting.

14-15 Mbps. This hints of an inefficient resource utilization of WLAN with high load and of potential benefits if these unused resources could be allocated for LTE.

B. Performance in shared band

When we put both systems on the same shared frequency band, we observe that when load is increased, LTE performance suffers only a minor served load degradation, while WLAN performance drops significantly. This illustrates clearly that bringing both systems to the same shared frequency band without handling the co-existence has a huge negative impact on the WLAN system performance.

With relatively low offered load, the combined performance of WLAN and LTE is higher than either of the standalone served loads. However, increasing offered load WLAN performance degrades severely with higher than 10 Mbps offered loads. This can be explained by the increasing LTE occupancy on the shared band. LTE does not follow the same rules as WLAN in channel acquisition: as WLAN defers on detected other transmission on the bandwidth, LTE can always choose to transmit despite possible ongoing WLAN transmissions. It only selects a more robust transmission format by changing, e.g., modulation and coding scheme (MCS) in order to cope with the higher interference. This behavior quickly causes a situation where LTE terminals take all the transmission time while WLAN devices wait in backoff.

C. Performance in shared band with LTE muting

We have shown that bringing LTE and WLAN systems on the same shared frequency band makes especially WLAN existence challenging without any regulations. Next, we evaluate the fractional bandwidth allocation method discussed in Section II-A, where LTE is restricted from transmitting part of the time in order to allow WLAN more opportunities to transmit.

Fig. 4 presents LTE performance with different muting levels. It can be seen that LTE performance decreases quite linearly along with increasing muting percentage. With 30-40 Mbps load each 20 % transmission time allowance steadily increases LTE served load by 5-7 Mbps.

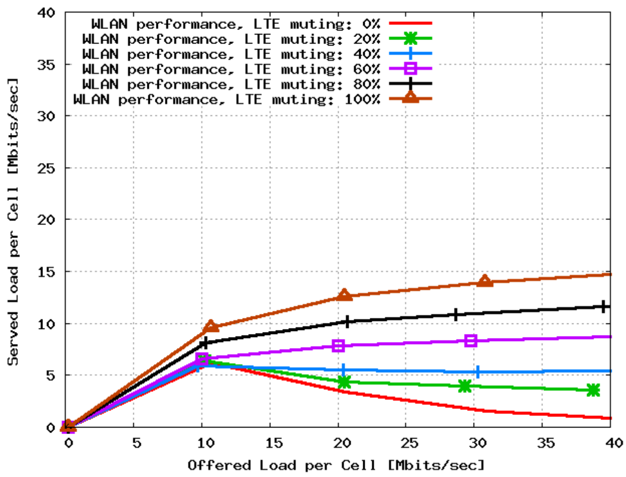

Fig. 5. WLAN performance with LTE muting.

Fig. 5 shows corresponding WLAN performance. With high load, each 20 % allocated for LTE instead of WLAN does not actually drop WLAN performance as much as it increases LTE performance.

As an example, with all offered loads, WLAN served loads drop between 1-3 Mbps when LTE muting is dropped from 100 % to 80 %. With this 20% transmission time allowance LTE achieves a steady 7 Mbps served load with all offered loads. As a result, the total combined throughput increases, which can be witnessed also in Fig. 6, where the combined served load of both systems is shown.

From the figure it is evident that there is a lot of unused capacity in unlicensed band which could be utilized by LTE. This is especially the case with highly loaded WLAN. As LTE is better in handling multiple access situations, the total spectral utilization could be increased by allowing LTE to

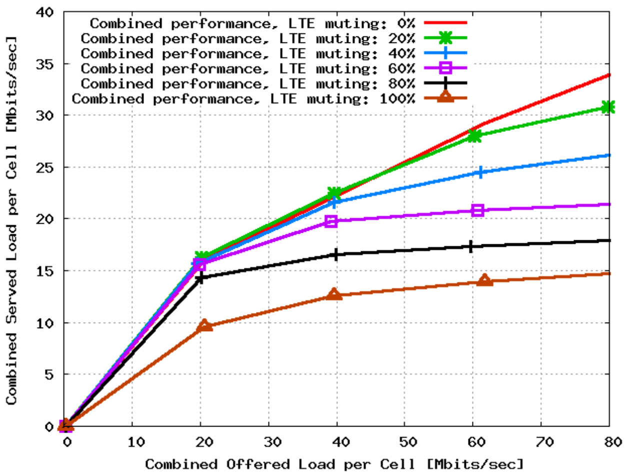

Fig. 6. Combined performance with coexistence mechanism.

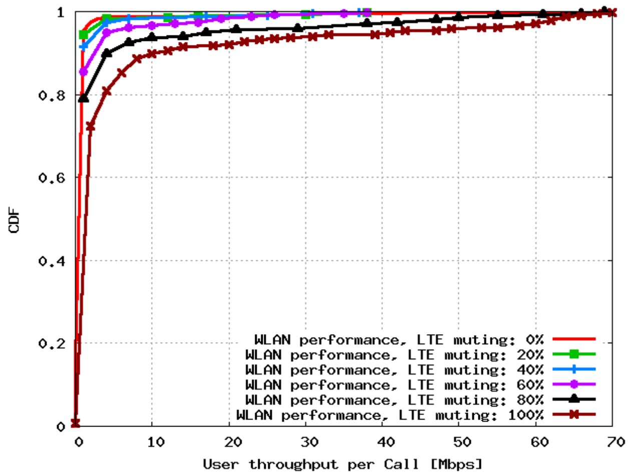

Fig. 8. WLAN user throughput with 20 Mbps offered load.

utilize the band in selected situations.

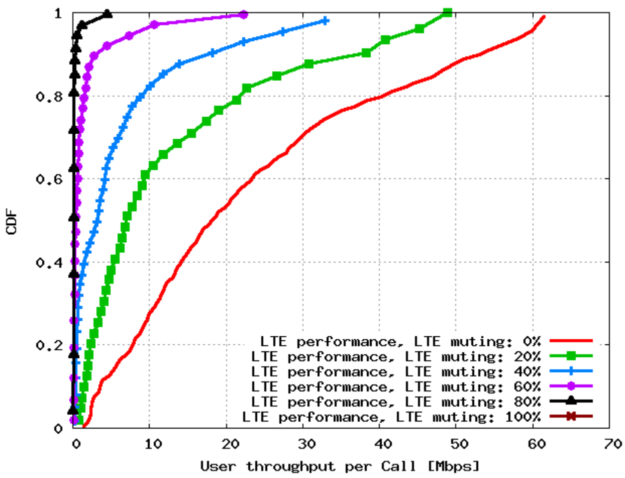

Fig. 7. LTE user throughput with 20 Mbps offered load.

Fig. 7 and Fig. 8 present LTE and WLAN user throughput distributions with 20 Mbps offered load and with different LTE muting patterns. LTE throughput increases expectedly as muting pattern is loosened and at the same time WLAN user throughputs start to decrease.

The increase in LTE user throughput induced by each 20 % transmission time grant is significantly higher than corresponding effect to WLAN user throughput. This is due to the fact that the selected scenario is more favorable for LTE: total offered load is distributed to a large user population. Relatively small offered load by a single call (2 MB) requires high number of calls in order to reach the simulated total offered loads of 10-40 Mbps. WLAN would most probably show better performance with the offered load distributed over a smaller user population.

VII. Conclusions and Future Research

In this study the performance of LTE and WLAN in a shared frequency band was evaluated. It was shown that the co-existence has a negative impact on WLAN system performance but the severity of the impact can be controlled by restricting LTE activity. Especially, in the situation where a lot of WLAN users try to access the network at the same time, the users may spend a long time in backoff while the medium is idle. If LTE could exploit these silent times the WLAN performance would not necessarily degrade but instead the bandwidth utilization efficiency could increase and thus also the total combined system throughput. Future research is needed in order to find sophisticated co-existence handling algorithms that could share the transmission grants between technologies dynamically and discreetly.

References

[1] R. Ratasuk, M. A. Uusitalo, N. Mangalvedhe, A. Sorri, S. Iraji, C. Wijting, and A. Ghosh, "License-exempt LTE deployment in heterogeneous network," in *The 9th International Symposium on Wireless Communication Systems (ISWCS)*, Paris, France, August 2012.

[2] M. I. Rahman, A. Behravant, H. Koorapaty, J. Sachs, and K. Balachandran, "License-exempt LTE systems for secondary spectrum usage: Scenarios and first assessment," in *IEEE Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySpan)*, Aachen, Germany, May 2011.

[3] *Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications*, IEEE Standard 802.11, June 2007.

[4] *Specification framework for TGac*, IEEE P802.11ac, (IEEE 802.11-09/0992r21), January 2011.

[5] T. Nihtilä, J. Turkka, and I. Viering, "Performance of LTE self-optimizing networks uplink load balancing," in *Proceedings of the 73rd IEEE Vehicular Technology Conference (VTC)*, Budapest, Hungary, May 2011.

[6] F. Chernogorov and T. Nihtilä, "QoS verification for minimization of drive tests in LTE networks," in *75th IEEE Vehicular Technology Conference (VTC)*, Yokohama, Japan, May 2012.

[7] E. H. Ong, J. Kneckt, O. Alanen, Z. Chang, T. Huovinen, and T. Nihtilä, "IEEE 802.11ac: Enhancements for very high throughput WLANs," in *22nd IEEE Personal Indoor and Mobile Radio Communications (PIMRC)*, Toronto, Canada, September 2011.

[8] Z. Chang, O. Alanen, T. Huovinen, T. Nihtilä, E. H. Ong, J. Kneckt, and T. Ristaniemi, "Performance analysis of 802.11ac DCF with hidden nodes," in *75th IEEE Vehicular Technology Conference (VTC)*, Yokohama, Japan, May 2012.
[9] *Evolved Universal Terrestrial Radio Access (E-UTRA); Further advancements for E-UTRA physical layer aspects*, 3GPP, Technical Specification Group, RAN TS36.814, Rev. v9.0.0, March 2010.
[10] E. Damosso, Ed., *Digital Mobile Radio Towards Future Generation Systems, COST 231 final report*.