

Power Control based Fair Coexistence of LBT-Free 5G New Radio Small Cells with WiGig Networks

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Resume of the Presenter



RONY KUMER SAHA received the B.Sc. degree in electrical and electronic engineering from the Khulna University of Engineering and Technology, KUET, in 2004, the M.Eng. degree in information and communications technologies from the Asian Institute of Technology (AIT), Thailand, in 2011, and the Ph.D. degree in electrical engineering from Chulalongkorn University, Thailand, in 2017. Since 2017, he has been working as a Postdoctoral Fellow/Research Engineer with the Radio and Spectrum Laboratory, KDDI Research, Inc., Japan.

He worked as a Lecturer and later promoted to an Assistant Professor with American International University-Bangladesh, Bangladesh, AIUB, from January 2005 to August 2013. From September 2013 to July 2014, he was with East West University, Bangladesh. His current research interests include 5G and beyond ultra-dense HetNets, spectrum sharing, policy, and management in multiple communication systems, and millimeter-wave communications. He has research experiences on mobile wireless communications in universities and industries for more than ten years. He has authored about 60 peer-reviewed, reputed, and highly recognized international journal and conference papers. He also filed an international patent.

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Topics of Research Interests

- Terahertz and millimeter wave communications
- 5G NR-U: 5G New Radio on Unlicensed Bands
- Dynamic spectrum sharing and policy for 5G and beyond mobile networks
- Cognitive radio networks and spectrum sensing techniques
- Co-channel interference analysis, mitigation, avoidance, and cancellation strategies
- In-building small cell network planning, design and deployment
- Planning, design and development of spectrum sharing algorithm for homogeneous (mobile networks) and heterogeneous networks (mobile networks and satellite networks)
- Radio resource allocation and scheduling policy and algorithm
- Mobile MAC layer and physical layer issues
- Proof-of-concept evaluation of virtualization and Slicing of 5G radio access network (RAN)
- Cloud RAN (CRAN) in 5G era
- Fronthaul design for CRAN

Presentation Outline

- Background and Problem Statement
- Related Study
- Contribution
- System Architecture and Proposed Coexistence Mechanism
- Mathematical Analysis
- Performance Evaluation and Comparison
- Conclusion
- References

Background and Problem Statement (1)

- The continuing growth in mobile devices and data traffic over the past decade causes mobile network operators (MNOs) to face tremendous challenges since the availability of the mobile spectrum for an MNO has not been increased correspondingly.
- Though several approaches, such as small cell deployments have been employed, no significant improvement toward addressing the growing demand to serve data traffic has been observed.
- This causes the focus of an MNO to shift from serving its data traffic by the allocated **licensed spectrum only to the unlicensed spectrum bands as well.**
- Globally, a large amount of spectrum is available in the unlicensed bands, including 2.4 GHz, 5 GHz, and 60 GHz.
- Proper co-channel interference (CCI) management is necessary to coexist a cellular network with a WiFi network in the same unlicensed band.

Background and Problem Statement (2)

- In this regard, by enabling cellular nodes (e.g., small cells) with **Listen-Before-Talk (LBT)** (Alhulayil and Lopez-Benitez, [1]), a fair coexistence of cellular and WiFi nodes can be made possible.
- The LBT is basically similar to the **Carrier-Sense Multiple Access with Collision Avoidance (CSMA/CA)**. Instead of allowing a cellular node to always use a channel, it shares between a cellular node and a WiFi Access Point (AP) fairly (Zhang et al. [2]) by periodically stopping the cellular node to occupy the channel and detecting the activities of other shared nodes on the channel.
- But, *LBT is not used in all regions* such as the United States of America (USA) and China where **LBT is not required** particularly for early commercialization (Lagen et al. [5]). For such regions, the **coexistence of small cells can be provided by managing CCI with WiFi networks in time and power domains.**

Related Study

In this direction, numerous studies already addressed the coexistence issues between cellular and WiFi networks in the time-domain using the **Almost Blank Subframe (ABS)** based Enhanced Inter-cell Interference Coordination (**eICIC**) technique in LTE.

For example, by employing ABSs, **Almeida et al. [6]** proposed a scheme to coexist LTE with WiFi in an unlicensed band.

Likewise, **Nihtilä et al. [7]** proposed the LTE muting mechanism to allow access to the channel to WiFi users and

Zhang et al. [8] presented an ABS-based coexistence scheme to avoid co-channel interference between small cells and WiFi systems.

Related Study (2)

With regard to providing the **coexistence between cellular and WiFi networks in the power-domain**,

Huang et al. [9] discussed the coexistence of LTE/WiFi in **the power domain** such that by adjusting the output power of LTE nodes, the transmission opportunity of WiFi nodes can be changed.

Sagari et al. [10] proposed Wi-Fi and LTE coordination algorithms based on optimization in the power and frequency domain.

Further, **Chaves et al. in [4]** proposed to use the uplink power control to improve the performance of coexistence of LTE with WiFi by introducing an additional factor to the conventional uplink power control mechanism of LTE..

Contribution

However, different from these above contributions in power-domain, in this paper, we present a simple, yet effective, transmit power control technique for in-building small cells of Fifth-Generation (5G) New Radio (NR) to coexist with the incumbent WiFi Access Points (WiAPs) of the Wireless Gigabit (WiGig) in the 60 GHz band.

In doing so, we first present the system architecture and the coexistence mechanism in Section II, followed by the mathematical analysis to derive average capacity, Spectral Efficiency (SE), and Energy Efficiency (EE) metrics for NR small cells in Section III.

We evaluate the performance of the proposed technique in Section IV and conclude the paper in Section V.

System Architecture and Proposed Coexistence Mechanism

- Consider a set of small cells and WiAPs such that one from each set is deployed per apartment of any multistory building located within the coverage of a macrocell of a 5G NR operator.
- A set of picocells are also located within the macrocell coverage to offload some macrocell traffic.
- Each small cell or WiAP serves one User Equipment (UE) at a time.
- For clarity, we consider only one apartment to show the coexistence of a small cell and a WiAP as shown in Figure 1(a).
- From Figure 1(a), it can be found that each small cell is equipped with two transceivers, one operates in the 28 GHz band and the other in the 60 GHz band.
- Since the 28 GHz band is a licensed band for an MNO, the transceiver operating at the 28 GHz band can serve both the uplink and downlink traffic at all time. However, since WiAPs operate in the 60 GHz band by default, and small cells are not Listen-Before-Talk (LBT) enabled, it can be possible that all WiAPs are blocked by the small cells due to having relatively a higher interference margin of a small cell than that of a WiAP.

System Architecture and Proposed Coexistence Mechanism

Hence, to overcome this problem, we propose the following power control technique to coexist small cells with WiAPs as shown in Figure 1(b).

Small cells of any 5G NR can get access to the 60 GHz band either when no UEs of any WiGig network are present within an apartment of a multistory building or when small cells of any 5G NR can operate in the 60 GHz band at a reduced transmission power causing less interference than that of the interference threshold set by the corresponding WiGig network, as shown in Figure 1(b).

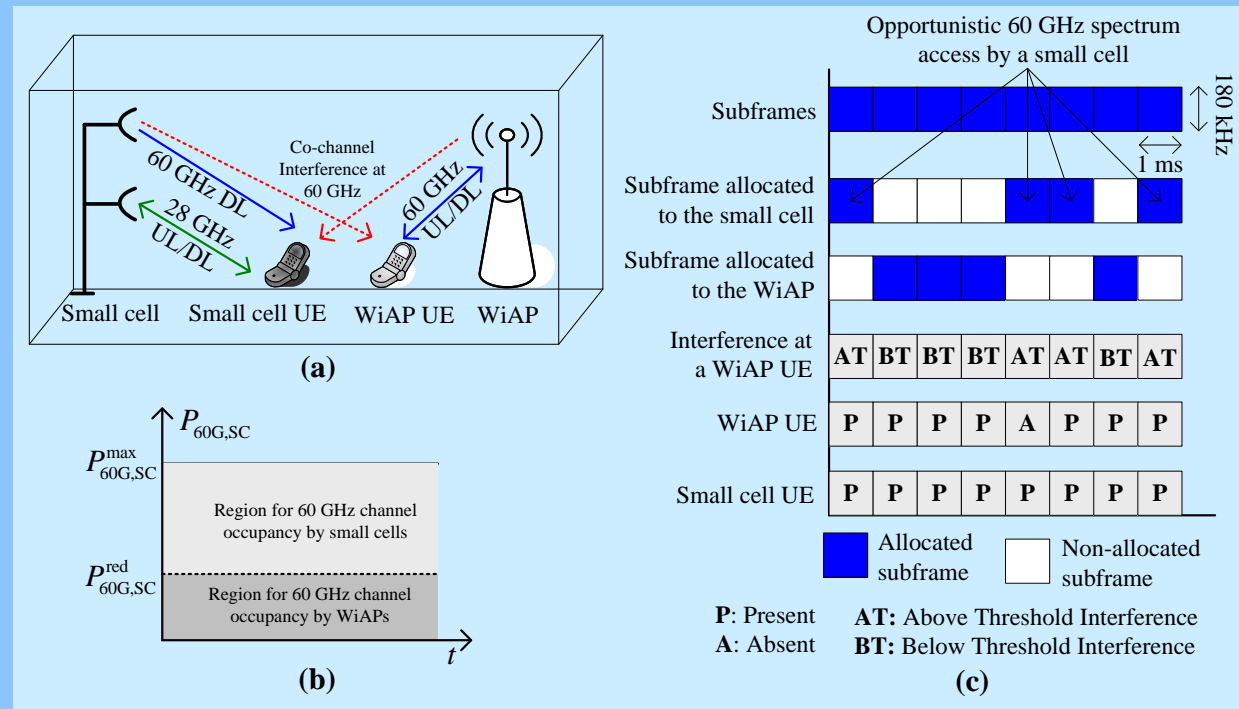


Figure 1. (a) Coexistence of a small cell and a WiAP in an apartment of a building. (b) Small cell transmission power control technique. (c) An example of opportunistic 60 GHz spectrum access by a small for a number of subframes.

System Architecture and Proposed Coexistence Mechanism

The presence of a UE of a small cell can be sensed by the WiAP by detecting and measuring the 60 GHz channel energy, whereas *the transmission of a WiAP can be identified either by the small cell using its transceiver operating at the 28 GHz or by the UE of the small cell in the uplink at the 28 GHz band.*

Note that the WiAP stops the transmission due to its inherent CSMA/CA protocol to avoid collision with the small cell. *An example of opportunistic subframe allocation to small cells to coexist with WiAPs in the 60 GHz spectrum band by employing the proposed power control technique is shown in Figure 1(c) and is described in detail in the following.*

System Architecture and Proposed Coexistence Mechanism

A subframe in the 60 GHz is allocated to **either a small cell or a WiAP** depend on the presence of their UEs at any time, as well as the level of interference experienced by the UE of the WiAP as compared to that of its threshold interference.

More specifically, **given that a UE of the small cell is present in an apartment**, *a subframe is allocated to a small cell only under the following conditions:*

- *when no UEs of the WiAP is present.*
- *when a UE of the WiAP is present, and the interference experienced by the WiAP UE is above the threshold interference.*

However, if the interference experienced by the UE of the WiAP is below the threshold interference in a subframe, no collision can be detected by the CSMA/CA protocol of the WiAP, and hence, the corresponding subframe is allocated to the WiAP.

Mathematical Analysis

Hence, the **amount of time** in terms of the number of Transmission Time Intervals (TTIs) that 5G NR small cells and WiAPs in a building serve their corresponding UEs in Q can be expressed, respectively, as follows.

$$T_{\text{NR}} = \left[\left(\frac{\lambda_{\text{NR}}}{(\lambda_{\text{NR}} + \lambda_{\text{WiG}})} \right) \times Q \right]$$

the transmission power of a small cell when operating at 60 GHz can be expressed as follows.

$$P_{60\text{G,SC}} = \begin{cases} P_{60\text{G,SC}}^{\text{max}}, & \text{if } I_{60\text{G,SC}} = 0 \\ P_{60\text{G,SC}}^{\text{red}}, & \text{if } I_{60\text{G,SC}} \neq 0 \end{cases}$$

Now the received Signal-to-Interference-Plus-Noise Ratio (SINR) at RB= i in TTI= t at a UE of a small cell is given by

$$\rho_{t,i} = \left(\frac{P_{t,i}}{(N_{t,i}^s + I_{t,i})} \right) \times H_{t,i}$$

Shannon's capacity formula, a link throughput at RB= i in TTI= t for an MNO o in bps per Hz is given by

$$\sigma_{t,i}(\rho_{t,i}) = \begin{cases} 0, & \rho_{t,i} < -10 \text{ dB} \\ \beta \log_2 \left(1 + 10^{(\rho_{t,i}(\text{dB})/10)} \right), & -10 \text{ dB} \leq \rho_{t,i} \leq 22 \text{ dB} \\ 4.4, & \rho_{t,i} > 22 \text{ dB} \end{cases}$$

The average capacity of all macrocell UEs of a 5G NR can be given by

$$\sigma_{2\text{G}} = \sum_{t=1}^Q \sum_{i=1}^{M_{2\text{G}}} \sigma_{t,i}(\rho_{t,i})$$

Now, the average capacity served by transceivers 1 and 2 of all small cells in the building is given by,

$$\sigma_{28\text{G}}^{\text{Tr 1}} = \sum_{s=1}^{S_{\text{F}}} \sum_{t \in \mathcal{T}} \sum_{i=1}^{M_{28\text{G}}} \sigma_{s,t,i}(\rho_{s,t,i})$$

$$\sigma_{60\text{G}}^{\text{Tr 2}} = \sum_{s=1}^{S_{\text{F}}} \sum_{t \in \mathcal{T}_{\text{NR}}} \sum_{i=1}^{M_{60\text{G}}} \sigma_{s,t,i}(\rho_{s,t,i})$$

the total average capacity served by both transceivers of all small cells in the building is given by,

$$\sigma_{\text{Dual Band}}^{\text{Tr 1+Tr 2}} = \sigma_{28\text{G}}^{\text{Tr 1}} + \sigma_{60\text{G}}^{\text{Tr 2}}$$

Mathematical Analysis

By linear approximation, the system-level average capacity, SE, and EE, respectively, for all small cells of a 5G NR is given by,

$$\sigma_{\text{Sys}}^{5\text{G NR}} = \sigma_{2\text{G}} + \sigma_{\text{Dual Band}}^{\text{Tr 1+Tr 2}}$$

$$\gamma_{\text{Sys}}^{5\text{G NR}} = \frac{\sigma_{\text{Sys}}^{5\text{G NR}}}{((M_{2\text{G}} + M_{28\text{G}}) \times Q)}$$

$$\epsilon_{\text{Sys}}^{5\text{G NR}} = \frac{\left(\left(\left(L \times S_{\text{F}} \times (P_{28\text{G,SC}} + P_{60\text{G,SC}}) \right) + \right) \times Q \right)}{\sigma_{\text{Sys}}^{5\text{G NR}}} \left((S_{\text{P}} \times P_{\text{PC}}) + (S_{\text{M}} \times P_{\text{MC}}) \right)$$

Performance Evaluation and Comparison

The simulation parameters and assumptions used to evaluate the performances of the proposed technique can be found in Table I.

Figure 2 shows SE and EE responses of small cells in a building due to the variation in the interference threshold at a WiAP

As the interference threshold requirement increases, i.e. the value of $I_{60G,WiG}^{th}$ decreases, both SE and EE performances of small cells of 5G NR improve nonlinearly.

This is because, with an increase in $I_{60G,WiG}^{th}$ small cells can increase the transmission power in the 60 GHz band, resulting in improving the capacity logarithmically following (4). This, however, causes a corresponding reduction in the capacity, and hence the SE and EE performances of WiAPs.

Moreover, using (7), an increase in the transmission time T_{NR} of small cells increases the overall capacity, and hence the SE and EE of small cells.

In summary, T_{NR} and $I_{60G,WiG}^{th}$ play considerable role in trading-off the coexistence performances, in terms of the average capacity, SE, and EE, of both small cells of a 5G NR network and WiAPs of a WiGig network.

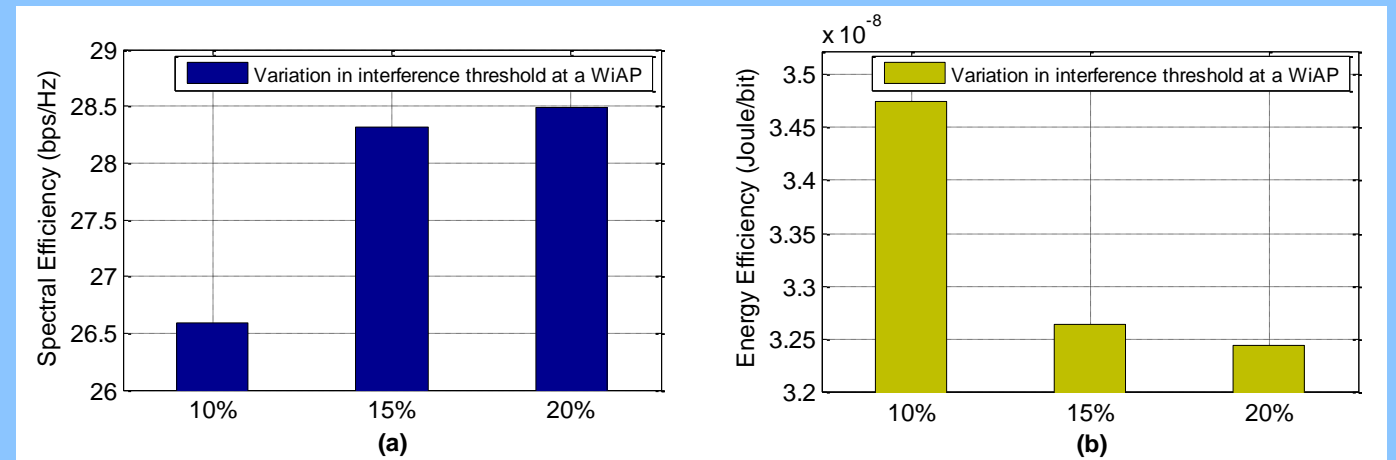


Figure 2. SE and EE responses of 5G NR small cells due to the variation in the interference threshold in the percentage of $P_{60G,SC}^{max}$

Performance Evaluation and Comparison

Table I. Simulation parameters and assumptions

Parameters and Assumptions		Value	
Number of 5G NR-U and WiGig operators, respectively		1, 1	
Spectrum bandwidth of NR	2 GHz (Non-LOS), 28 GHz (LOS), and 60 GHz (LOS), respectively	10 MHz, 50 MHz, and 100 MHz	
Number of cells	Macrocells, picocells, and small cells	1, 2, and 9	
Interference threshold, $I_{60G,WiG}^{th}$		10%, 15%, and 20% $P_{60G,SC}^{max}$	
Cellular layout ² , inter-site distance (ISD) ^{1,2} , transmission direction		Hexagonal grid, dense urban, 3 sectors per macrocell site, 1732 m, downlink	
Total base station transmit power (dBm)	Macrocell ¹ and picocell ¹	46 and 37	
	Small cell operating in 28 GHz ¹	19	
	Small cell operating in 60 GHz ¹	17.3	
Co-channel small-scale fading model ¹	2 GHz	Frequency selective Rayleigh	
	28 GHz	no small-scale fading effect	
	60 GHz	no small-scale fading effect	
Path loss	MBS and a UE ¹	Outdoor macrocell UE	$PL(dB)=15.3 + 37.6 \log_{10}R$, R is in m
		Indoor macrocell UE	$PL(dB)=15.3 + 37.6 \log_{10}R + L_{ow}$, R is in m and $L_{ow}=20$ dB
	PBS and a UE ¹		$PL(dB)=140.7+36.7 \log_{10}R$, R is in km
	SBS and a UE ^{1,2}	28 GHz	$PL(dB)=61.38+17.97 \log_{10}R$, R is in m
60 GHz		$PL(dB)=68+21.7\log_{10}(R)$, R in m	
Lognormal shadowing standard deviation (dB)	MBS ² and PBS ¹	8 and 10	
	SBS in 28 GHz and 60 GHz ²	9.9 and 0.88	
Antenna configuration		Single-input single-output for all BSs and UEs	
Antenna pattern (horizontal)		Directional (120°) for MBS ¹ , omnidirectional for PBS ¹ and SBS ¹	

Performance Evaluation and Comparison

Table I. Simulation parameters and assumptions

Antenna gain plus connector loss (dBi)	MBS ² , PBS ¹ , and SBS ¹	14, 5, and 5
UE antenna gain ²	2 GHz, 28 GHz, and 60 GHz (Biconical horn)	0 dBi, 5 dBi, and 5 dBi
UE noise figure ² , UE speed ¹ , and indoor macrocell UE ¹		9 dB (for 2 GHz) and 10 dB (for 28 GHz and 60 GHz), 3 km/hr, and 35%
Picocell coverage ¹ , the total number of macrocell UEs, and macrocell UEs offloaded to all picocells ¹		40 m (radius), 30, 2/15
3D multistory building and SBS models (square-grid apartments)	Number of buildings	1
	Number of floors per building	1
	Number of apartments per floor	9
	Number of SBSs per apartment	1
	Area of an apartment	10×10 m ²
Scheduler and traffic model ²		Proportional Fair and full buffer
Type of SBSs		Closed Subscriber Group femtocell BSs
TTI ¹ , FPP, and PF scheduler time constant (t _c)		1 ms, 8 ms, and 100 ms
Total simulation run time		8 ms

taken ¹from [15], ²from [16].

Conclusion

In this paper, we have presented a transmission power control technique for LBT-free 5G NR small cells to coexist with WiAPs in the 60 GHz band within a building.

With system-level simulation results, it has been shown that the proposed technique can improve the average capacity, SE, and EE of small cells of a 5G NR while ensuring fair coexistence with WiAPs.

More specifically, an increase in the interference threshold of WiAPs results in a nonlinear increase in the SE and EE of small cells while decreasing the SE and EE of WiAPs. However, an increase in the transmission time of either small cells or WiAPs causes a corresponding linear increase in the SE and EE.

Hence, the transmission time and the interference threshold of WiAPs play noticeable roles in trading-off the coexistence performances of small cells of a 5G NR and WiAPs of a WiGig.

References

1. M. Alhulayil and M. Lopez-Benitez, "Coexistence Mechanisms for LTE and Wi-Fi Networks Over Unlicensed Frequency Bands," Proc. 2018 11th International Symposium on Communication Systems, Networks & Digital Signal Processing (CSNDSP), Budapest, Hungary, 2018, pp. 1-6, doi: 10.1109/CSNDSP.2018.8471826.
2. R. Zhang et al., "LTE-Unlicensed: The Future of Spectrum Aggregation for Cellular Networks," IEEE Wireless Communications, vol. 22, no. 3, pp. 150-159, June 2015, doi: 10.1109/MWC.2015.7143339.
3. R. Kwan, et al., "Fair Co-Existence of Licensed Assisted Access LTE (LAA-LTE) and Wi-Fi in Unlicensed Spectrum," Proc. 2015 7th Computer Science and Electronic Engineering Conference (CEECE), pp. 13-18, 2015.
4. F. S. Chaves et al., "LTE UL Power Control for the Improvement of LTE/Wi-Fi Coexistence," Proc. 2013 IEEE 78th Vehicular Technology Conference (VTC Fall), Las Vegas, NV, USA, 2013, pp. 1-6, doi: 10.1109/VTCFall.2013.6692275.
5. S. Lagen et al., "New Radio Beam-Based Access to Unlicensed Spectrum: Design Challenges and Solutions," Proc. IEEE Communications Surveys & Tutorials, vol. 22, no. 1, pp. 8-37, Firstquarter 2020, doi: 10.1109/COMST.2019.2949145.
6. E. Almeida et al., "Enabling LTE/WiFi coexistence by LTE blank subframe allocation," Proc. 2013 IEEE International Conference on Communications (ICC), Budapest, 2013, pp. 5083-5088, doi: 10.1109/ICC.2013.6655388.
7. T. Nihtilä et al., "System Performance of LTE and IEEE 802.11 coexisting on a Shared Frequency Band," Proc. 2013 IEEE Wireless Communications and Networking Conference (WCNC), Shanghai, 2013, pp. 1038-1043, doi: 10.1109/WCNC.2013.6554707.
8. H. Zhang, X. Chu, W. Guo, and S. Wang, "Coexistence of Wi-Fi and Heterogeneous Small Cell Networks Sharing Unlicensed Spectrum," IEEE Commun. Mag., vol. 53, no. 3, pp. 158-164, March 2015, doi: 10.1109/MCOM.2015.7060498.
9. Y. Huang, Y. Chen, Y. T. Hou, W. Lou, and J. H. Reed, "Recent Advances of LTE/WiFi Coexistence in Unlicensed Spectrum," IEEE Network, vol. 32, no. 2, pp. 107-113, March-April 2018, doi: 10.1109/MNET.2017.1700124.
10. S. Sagari, S. Baysting, D. Saha, I. Seskar, W. Trappe and D. Raychaudhuri, "Coordinated Dynamic Spectrum Management of LTE-U and Wi-Fi Networks," Proc. 2015 IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN), Stockholm, Sweden, 2015, pp. 209-220, doi: 10.1109/DySPAN.2015.7343904.
11. D. Hang, M. Yang, Z. Yan, and B. Li, "Power Control Based Spatial Reuse for LAA and WiFi Coexistence." In: Lin YB., Deng DJ. (eds) Smart Grid and Internet of Things. SGIoT 2020. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol 354. Springer, Cham., pp. 363-384, doi.org/10.1007/978-3-030-69514-9_29
12. P. Xia, Z. Teng, and J. Wu, "How Loud to Talk and How Hard to Listen-Before-Talk in Unlicensed LTE," Proc. 2015 IEEE International Conference on Communication Workshop (ICCW), London, UK, 2015, pp. 2314-2319, doi: 10.1109/ICCW.2015.7247526.
13. J. D. Chimeh, M. Hakkak, and S. A. Alavian, "Internet Traffic and Capacity Evaluation in UMTS Downlink," Proc. FGCN, December 2007, pp. 547-552.
14. R. K. Saha "Spectrum Allocation and Reuse in 5G New Radio on Licensed and Unlicensed Millimeter-Wave Bands in Indoor Environments," Mobile Information Systems Journal, vol. 2021, art. ID 5538820, pages 21, 2021. doi: 10.1155/2021/5538820
15. Evolved Universal Terrestrial Radio Access (E-Utra); Radio Frequency (rf) System Scenarios. Document 3GPP TR 36.942, V.1.2.0, 3rd Generation Partnership Project, Jul. 2007. Available online: <https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=2592> [retrived: February, 2021].
16. Simulation Assumptions and Parameters For FDD HeNB RF Requirements. document TSG RAN WG4 (Radio) Meeting #51, R4-092042, 3GPP, May 2009. [retrived: February, 2021].
17. Y. Huang, Y. Chen, Y. T. Hou, W. Lou, and J. H. Reed, "Recent Advances of LTE/WiFi Coexistence in Unlicensed Spectrum," IEEE Netw., vol. 32, no. 2, pp. 107-113, March-April 2018 .

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Thank You ...