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On Operating 5G New Radio Indoor Small Cells in the 60 GHz Unlicensed Band

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IARIA

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.

Dr. Saha served as a member of the Fronthaul Working Group, xRAN Forum, USA. He also served as a TPC member of the 2020 ICSNC and 2018 IEEE Global Communications Conference Workshops. Furthermore, he also served as the Session Chair for two sessions, namely Radio Resource Management and Aerial Networks at 2019 IEEE VTC-Fall, Hawaii, USA, as well as the 2019 IEEE International Symposium on Dynamic Spectrum Access Networks Newark, NJ, USA, for the session Spectrum Sharing in 5G. Since early 2019, he has been serving as an Associate Editor of the Engineering Journal, Thailand. He served as a Reviewer of a number of recognized journals, including IEEE Transactions on Vehicular Technology, IEEE Access, Elsevier Physical Communication, Wiley International Journal of Communication Systems, MDPI Sensors Journal, MDPI Symmetry Journal, Hindawi Mobile Information Systems, and MDPI Sustainability Journal.

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
- System Architecture
  - Time-Domain Coexistence
  - Performance Metrics Estimation
    - Performance Result and Evaluation
    - Conclusion
      - References

Background and Problem Statement (1)

PROBLEM

Introduction of the Fifth-Generation (5G) New Radio (NR) to serve a large volume of data traffic has increased the **burden** on the licensed spectrum of a Mobile Network Operator (MNO) [1].

SOLUTION AND EFFECT

- An **effective solution** to address this problem is to serve data traffic in the **unlicensed bands** along with the existing licensed bands.
- However, technologies such as the **IEEE 802.11 based WiFi** have already been in operation globally over a wide range of unlicensed bands, including 2.4 GHz, 5 GHz, and 60 GHz bands [3].

This necessitates **developing a technique** that can allow both cellular networks and incumbent WiFi networks to coexist.

Background and Problem Statement (2)

RELATED WORK

To address the coexistence between WiFi and cellular systems, **several studies proposed** to apply the **Almost Blank Subframe (ABS)** based Enhanced Intercell Interference Coordination **(eICIC) technique**. For example,

- using the concept of ABS, the authors **in [6] proposed a scheme** to coexist LTE with WiFi systems in an unlicensed band.
- the authors **in [7] proposed the LTE muting mechanism** to mute the transmission of LTE in *a* certain number of subframes of every 5 subframes during which the channel can be used by WiFi users.
- **an ABS-based coexistence scheme** to avoid co-channel interference between small cells and WiFi systems was presented by the authors **in [8]**.

SCOPE

To address the **transmission power requirement** in the unlicensed bands, 5G NR-U is expected to be operated in the **small cells deployed indoors**. In this regard, **60 GHz unlicensed band** is considered an attractive unlicensed band for NR-U [5] [9] due to its wider contiguous bandwidth availability.

However, **studies on the NR-U** operating in both the licensed and unlicensed mmW spectra for in-building small cells are in the early stage, and

detailed analysis and evaluation of major performance metrics, including capacity, Spectral Efficiency (SE), and Energy Efficiency (EE), for NR-U is yet to be addressed.

Background and Problem Statement (3)

In doing so, we **present a time-domain coexistence technique** to avoid co-channel interference by **modifying** the concept of ABS.

CONTRIBUTION

We **derive and evaluate average capacity, SE, and EE** responses of in-building 5G NR-U small cells that are considered coexisting with the IEEE 802.11ad/ay, also termed as Wireless Gigabit (WiGig), where each small cell operates in both the 28 GHz licensed and the 60 GHz unlicensed bands.

A **system-level performance** analysis is carried out for **several variants of 5G NR**, including

- **5G NR Standalone** operating **only** in the 28 GHz band,
- **5G NR-U Standalone** operating **only** in the 60 GHz band, and
- **5G NR-U Anchored** operating in **both** the 28 GHz and 60 GHz bands.

System Architecture

Figure 1 shows the system architecture consisting of a 5G NR-U operator and a WiGig operator.

- Each NR-U operator has **three types of base stations** (BSs), namely macrocell BSs (MBSs), picocell BSs (PBSs), and small cell BSs (SBSs).
- We assume that all SBSs and WiGig Access Points (APs) are deployed only **within a building**, one per apartment per operator.
- An SBS or a WiGig Access Point (WiAP) serves only one User Equipment (UE) at a time.
- Each **SBS is dual-band enabled** such that the 28 GHz licensed band operates at its transceiver 1, and the 60 GHz unlicensed band operates at its transceiver 2.
- Each **WiAP** operates at the 60 GHz band.
- **Any MBS or any PBS** of the NR-U operates in the 2 GHz band.

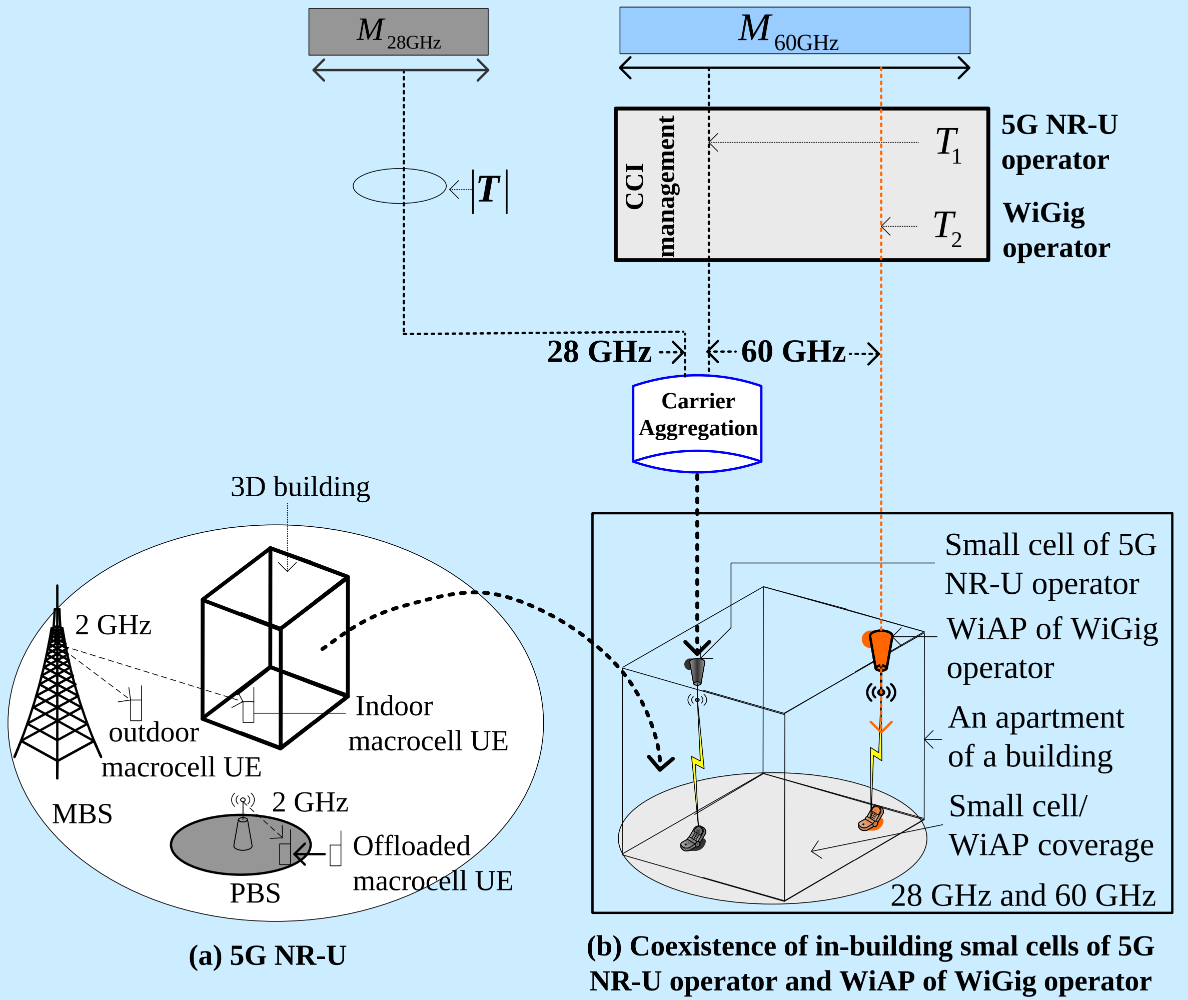

Figure 1. System architecture for the coexistence of small cells of a 5G NR-U operator with WiAPs of a WiGig operator.

Time-Domain Coexistence

Since both SBSs and WiAPs operate in the 60 GHz unlicensed band, co-channel interference is generated. To coexist both SBSs and WiAPs in the 60 GHz unlicensed band, we present the following coexistence technique.

An SBS can share the 60 GHz spectrum with an incumbent WiAP by allocating them in different time slots to avoid simultaneous access by either the SBS or the WiAP to the 60 GHz spectrum using the well-established concept termed as ABS in LTE.

Modifying ABSs to avoid transmitting control signals during ABSs results in **Fully Blank Subframes (FBSs)** as shown in **Figure 2**.

An **optimum value** of the number of FBSs over an FBS pattern period (FPP) T_{FPP} of 5G NR-U operator can be given as follows.

$$T_1 = \left\lceil \left(\lambda_1 / (\lambda_1 + \lambda_2)\right) T_{FPP} \right\rceil \qquad (1)$$

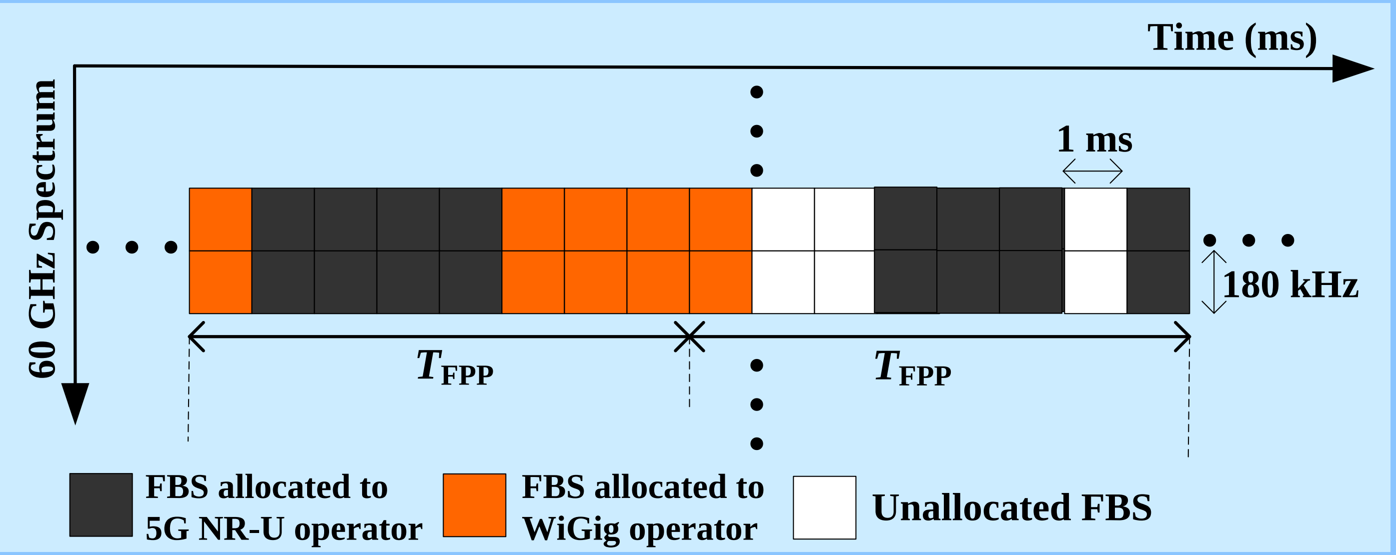

Figure 2. CCI avoidance in time-domain using FBSs.

λ_1 and λ_2 are, respectively, mean values of the Poisson arrival processes of UEs of NR-U and WiGig operators.

Since UEs of NR-U and WiGig operators are allocated orthogonally in the time-domain, i.e., in different TTIs, no collision from simultaneous transmissions from UEs of both occurs.

Time-Domain Coexistence

(1) can be **generalized** for any arbitrary number of NR-U and WiGig operators as follows:

Let X_1 and X_2 be the maximum number of NR-U operators and WiGig operators, respectively such that

$x_1 \in \{0,1,\ldots,X_1\}$ corresponds to $\lambda_{n,x_1} \in \{0,\lambda_{n,1},\ldots,\lambda_{n,X_1}\}$

$x_2 \in \{0,1,\ldots,X_2\}$ corresponds to $\lambda_{w,x_2} \in \{0,\lambda_{w,1},\ldots,\lambda_{w,X_2}\}$ and

Also $T_{\mathrm{FPP}} = \left(\sum_{x_1=0}^{X_1} T_{n,x_1} + \sum_{x_2=0}^{X_2} T_{w,x_2}\right)$

Then, for NR-U operators $T_{n,x_1} = \left\lceil \left(\lambda_{n,x_1} \middle/ \left(\sum_{x_1=0}^{X_1} \lambda_{n,x_1} + \sum_{x_2=0}^{X_2} \lambda_{w,x_2} \right) \right) T_{\mathrm{FPP}} \right\rceil$

And for WiGig operators $T_{w,x_2} = \left\lceil \left(\lambda_{w,x_2} \middle/ \left(\sum_{x_1=0}^{X_1} \lambda_{n,x_1} + \sum_{x_2=0}^{X_2} \lambda_{w,x_2} \right) \right) T_{\mathrm{FPP}} \right\rceil$

Performance Metrics Estimation

Signal-to-Noise-Plus-Interference Ratio (SINR) is given by [11],

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

The capacity of macrocell UEs of NR-U operator

$$\sigma_{2\mathrm{GHz}}=\sum_{t=1}^{Q}\sum_{i=1}^{M_{2\mathrm{GHz}}}\sigma_{t,i}\left(\rho_{t,i}\right)$$

Transceiver 1 of all SBSs in the building operates at the 28 GHz spectrum in $t\in\boldsymbol{T}$. The capacity served by transceiver 1 of all SBSs in the building

$$\sigma_{28\mathrm{GHz}}^{\mathrm{Trans}\ 1}=\sum_{s=1}^{S_{\mathrm{F}}}\sum_{t\in\boldsymbol{T}}\sum_{i=1}^{M_{28\mathrm{GHz}}}\sigma_{s,t,i}\left(\rho_{s,t,i}\right)$$

Transceiver 2 of all SBSs in the building operates at the 60 GHz spectrum in $t_1\in\boldsymbol{T}_1$. The capacity served by transceiver 2 of all SBSs of NR-U

$$\sigma_{60\mathrm{GHz}}^{\mathrm{Trans}\ 2}=\sum_{s=1}^{S_{\mathrm{F}}}\sum_{t_1\in\boldsymbol{T}_1}\sum_{i=1}^{M_{60\mathrm{GHz}}}\sigma_{s,t,i}\left(\rho_{s,t,i}\right)$$

So, the total capacity served by transceivers 1 and 2 of all SBSs in the building of operator NR-U

$$\sigma_{\mathrm{MB}}=\sigma_{28\mathrm{GHz}}^{\mathrm{Trans}\ 1}+\sigma_{60\mathrm{GHz}}^{\mathrm{Trans}\ 2}$$

Due to a short distance between a UE and its SBS and a low transmission power of an SBS, we assume similar indoor signal propagation characteristics for both mmWs of the NR-U operator.

System-level average aggregate capacity for the 5G NR-U Anchored

$$\sigma_{\mathrm{cap}}^{\mathrm{NR\text{-}U,Anch}}=\sigma_{2\mathrm{GHz}}+\sigma_{\mathrm{MB}}$$

Performance Metrics Estimation

SE is then given by

$$\sigma_{\mathrm{SE}}^{\text{NR-U,Anch}} = \sigma_{\text{cap}}^{\text{NR-U,Anch}} \Big/ \left(\left(M_{\text{2GHz}} + M_{\text{28GHz}} \right) \times Q \right)$$

EE is given by

$$\sigma_{\mathrm{EE}}^{\text{NR-U,Anch}} = \left(\begin{array}{l} \left(L \times S_{\mathrm{F}} \times \left(P_{\text{28GHz}} + P_{\text{60GHz}} \right) \right) + \\ \left(S_{\mathrm{P}} \times P_{\text{2GHz,PC}} \right) + \left(S_{\mathrm{M}} \times P_{\text{2GHz,MC}} \right) \end{array} \right) \Big/ \left(\sigma_{\text{cap}}^{\text{NR-U,Anch}} / Q \right)$$

Now, 5G NR Standalone and 5G NR-U Standalone operate only in the licensed and unlicensed bands, respectively. The system-level average capacity for NR Standalone and NR-U Standalone

$$\sigma_{\text{cap}}^{\text{NR,Std}} = \sigma_{\text{2GHz}} + \sigma_{\text{28GHz}}^{\text{Trans 1}}$$

$$\sigma_{\text{cap}}^{\text{NR-U,Std}} = \sigma_{\text{2GHz}} + \sigma_{\text{60GHz}}^{\text{Trans 2}}$$

Following SE and EE of NR-Anchored, SE and EE can be expressed for NR Standalone and for NR-U Standalone.

Performance Result and Evaluation

Table II shows selected simulation parameters and assumptions. Detailed parameters and assumptions can be found in [12] [13].

TABLE II. SIMULATION PARAMETERS AND ASSUMPTIONS

Parameters and Assumptions			Value
Number of 5G NR-U and WiGig operators, respectively			1, 1
Spectrum bandwidth of 5G NR-U operator		2 GHz	10 MHz (for an MBS and PBSs)
		28 GHz	50 MHz (for transceiver 1 of all SBSs)
		60 GHz	100 MHz (for transceiver 2 of all SBSs and WiAPs)
Number of cells	Macrocells, picocells, and small cells		1, 2, and 48
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
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
3D multistory building and SBS models (square-grid apartments)			A single building, 6 floors, 8 apartments per floor, 1 SBS and 1 WiAP per apartment, and 10×10 m^2 area of an apartment
Scheduler, traffic model[2], Type of SBSs			Proportional Fair, full buffer, and 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 [1]from [12], [2]from [13].

Performance Result and Evaluation

We vary the transmission time (i.e., the number of allocated FBSs) per FPP (including 50% and 75% of FPP) of small cells of a 5G NR operator coexisting with a single WiGig operator within a building. From Figure 3, the followings an be summarized.

- For **5G NR Standalone**, there is no change in capacity, SE, and EE occur with a change in the number of FBSs over an FPP.
- For **5G NR-U Standalone**, the capacity, SE, and EE responses increase with an increase in the transmission time due to having more time to transmit by the small cells.
- For **5G NR-U Anchored**, with an increase in the transmission time, the average capacity increases more than that of NR Standalone, as well as NR-U Standalone, operators due to operating in both the 28 GHz licensed and the 60 GHz unlicensed spectra.

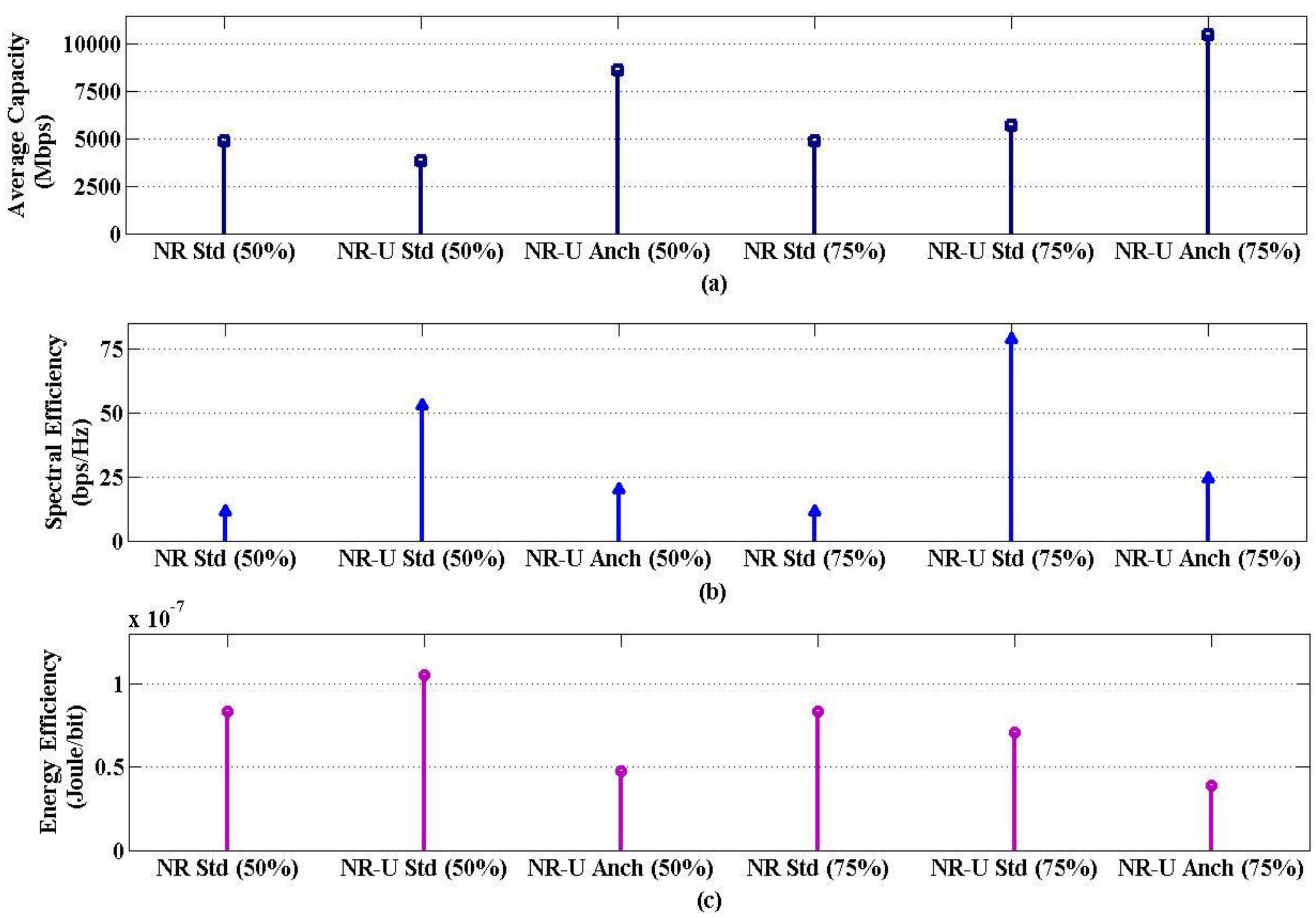

Figure 3. Average capacity, spectral efficiency and, energy efficiency responses of small cells of a single operator of 5G NR Standalone (Std), 5G NR-U Std, and 5G NR-U Anchored (Anch) with the variation of the number of FBSs (i.e., its transmission time) per FPP, including 50% and 75% of FPP, which coexists with a single WiGig operator in a building of small cells. (a) average capacity, (b) spectral efficiency, and (c) energy efficiency.

Performance Result and Evaluation

- **SE** for the 5G NR-U Anchored does not improve proportionately with its achievable **capacity** as the transmission time increases from 50% FPP to 75% FPP. Rather, **5G NR-U Standalone** achieves the maximum SE due to requiring the least amount of the effective licensed spectrum.
- Since **EE** is a function of transmission energy (Joule/bit), as well as achievable capacity (bits/s), the increase in the achievable capacity due to increasing the transmission time from 50% FPP to 75% FPP is significant enough to exceed the increase in the transmission energy for the NR-U Anchored as given by (9) in the same duration. This results in the minimum average energy required per bit transmission for the **NR-U Anchored**.

- Overall, **NR-U Anchored** can achieve the **maximum average capacity and EE**,
- Whereas, **NR-U Standalone** can achieve the maximum SE when coexisting with a WiGig operator.

Because in NR-U standalone, as well as NR-U Anchored, the 60 GHz unlicensed spectrum plays a role, this **implies the importance of operating the 5G NR operator in the unlicensed bands.**

Conclusion

In this paper, we have presented **a time-domain coexistence technique** for small cells of a **5G NR** located within a building to coexist with a **WiGig** operator in the 60 GHz band **to divide the air time in the 60 GHz band between the incumbent WiGig APs (WiAPs) and small cells.**

- We have **derived** average capacity, Spectral Efficiency (SE), and Energy Efficiency (EE) performance metrics for in-building small cells of the NR-U.
- With **system-level simulation** results, by varying the number of allocated FBSs per FPP the 5G NR operator, the average capacity, SE, and EE responses for three variants of the 5G NR, namely 5G NR Standalone, 5G NR-U Standalone, and 5G NR-U Anchored (Anch) have been evaluated.

It has been shown that **NR-U Anchored can achieve the maximum average capacity and EE**, whereas **NR-U Standalone can achieve the maximum SE** when coexisting with a WiGig operator.

Because the 60 GHz unlicensed band is present in both schemes, this signifies **the importance of operating a 5G NR operator in the unlicensed bands.**

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End of the Presentation

Thank You …