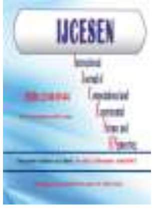
International Journal of Computational and Experimental Science and ENgineering
(IJCESEN)

Vol. 11-No.2 (2025) pp. 1803-1816
http://www.ijcesen.com



ISSN: 2149-9144

Research Article

Dynamic Licensed and Unlicensed Spectrum Assignment Technique for 6G Wireless Systems

Anita Patil [1], Sridhar Iyer[2*], Sidramayya Swamy Matad[3], Jagannath Jadhav[4]

[1]Assistant Professor, Department of ECE, S.G. Balekundri Institute of Technology affiliated to Visveswaraya Technological University, Karnataka, India - 590010.
Email: anitap@sgbit.edu.in - **ORCID:** 0000-0002-2604-6774

[2]Professor, Department of ECE, KLE Technological University Dr. MSSCET, Karnataka, India - 590008.
* **Corresponding Author Email:** sridhariyer1983@klescet.ac.in. - **ORCID**: 0000-0002-8466-3316

[3]Associate Professor, Department of ECE, S.G. Balekundri Institute of Technology affiliated to Visveswaraya Technological University, Karnataka, India - 590010.
Email: sidramayyam@sgbit.edu.in - **ORCID**: 0000-0003-1389-5475

[4]Professor and HOD, Department of ECE, KLE's College of Engineering and Technology, Karnataka, India - 591201
Email: jagannathjadhav3030@gmail.com - **ORCID:** 0000-0001-9238-4192

Article Info:

DOI: 10.22399/ijcesen.1271
Received : 30 November 2024
Accepted : 28 February 2025

Keywords :

6G wireless systems,
dynamic spectrum assignment,
licensed and unlicensed spectrum.

Abstract:

In this article, a dynamic licensed unlicensed spectrum assignment (DLUSA) technique is proposed enabling co-existence of 95GHz licensed Tera-Hertz (THz) spectrum and 60GHz unlicensed milli-meter (mm)-wave spectrum. In DLUSA, spectrum is assigned to small-cells (SCs) located on every floor of specific home/building of each mobile service provider (MSP) of country. Two cases are considered: (a) case 1: SCs operate only in licensed 95GHz spectrum with four MSPs, and (b) case 2: SCs operate in both, 95GHz spectrum with four MSPs and 60 GHz spectrum with an incumbent WiGig operator. Through DLUSA (i) for every MSP, required amount of 95GHz and 60GHz spectrum is found, and (ii) mean capacity (MC), spectral-efficiency (SE), energy-efficiency (EE), and cost-efficiency (CE) are evaluated. Simulations are conducted to (i) compare performance of DLUSA with static SA (SSA) technique, and (ii) evaluate MC, SE, EE, and CE for MSP1 under cases 1 and 2. The results demonstrate that DLUSA improves MC, SE, EE, and CE of MSP1 by 3 times, 1.7 times, 77%, and 65%, respectively, considering case 1; whereas, by 6.2 times, 5.3 times, 88%, and 86%, respectively, considering case 2. It is also observed that DLUSA meets SE and EE requirements of 6G wireless systems.

1. Introduction

The recent advancements in wireless technology towards deployment of fifth generation (5G) systems and conceptualization of the sixth generation (6G) systems have mandated need for efficient access, assignment and management of the enormous available spectrum [1]. This migration from 5G to 6G wireless systems demands higher capacity and data rates due to which the mobile service providers (MSPs) have had to re-think the design of the legacy systems. The key concern which has emerged is the cost and scarcity of the licensed spectrum which can be made available simultaneously incurring a lower transmission cost/bit. In this view, for the 6G wireless systems' operation, in addition to the 95GHz Tera-Hertz (THz) licensed spectrum, it is also proposed to utilize the unlicensed spectrum within the milli-meter (mm)-wave spectrum [2]. Specifically, the 60GHz unlicensed mm-wave spectrum band is attractive due to availability of wide contiguous bandwidth; however, the IEEE 802.11 enabled Wireless Gigabit (WiGig) also operates within this same band [3]. Hence, to operate in this unlicensed band without interfering with licensed THz band, it is required to introduce techniques which will ensure appropriate co-existence following regulatory restrictions on transmission power within this unlicensed spectrum band which requires the deployment of small-cells (SCs) in regard to indoor coverage [4]. Currently, to provision the increasing user demands for extremely high data rates and capacity, spectrum to the MSPs is assigned in a static manner which has resulted in immense scarcity of the spectrum. In fact, static spectrum assignment (SSA) leads to less spectrum utilization as majority of the spectrum which is allocated remains idle [5] and hence, for the licensed and unlicensed spectrum bands to co-exist, formulation of dynamic spectrum assignment (DSA) techniques are mandatory which is the focus of the current study.

Multiple studies have addressed various issues considering the co-existence of licensed and unlicensed spectrum bands. The authors in [6] reviewed state of art long term evolution (LTE) and Wi-Fi coexistence mechanisms and demonstrated the related incorporation within the industry standards. In [7], the authors studied the effective coexistence mechanism between LTE-Unlicensed (LTE-U) and Wi-Fi systems within the same unlicensed spectrum for enabling cellular network to utilize LTE-U simultaneously protecting the Wi-Fi access points (APs). The authors in [8] described the LTE-U Wi-Fi heterogeneous (HetNet) architecture and outlined various technical challenges for effective utilization of the unlicensed spectrum bands within LTE-U WiFi HetNets. In [9], the authors addressed the coexistence of 5G New Radio-Unlicensed (5G NR-U) and Wi-Fi within the 6 GHz spectrum band. The authors in [10] addressed the co-existence of Wi-Fi with beam-based 5G NR-U within the mm-wave spectrum bands. In [11], the author considered a 6G wireless system scenario which allows sharing of spectrum between links with spectrum license (6G license access) and which are unlicensed (Wi-Fi). A machine learning algorithm is formulated which considers both, medium access and physical layer parameters of APs and eNodeBs to (i) enable them to select sub-channels, and (ii) permit them to choose best sub-channel in a distributed manner. The results demonstrate that the (i) proposed method converges to ideal scenario, and (ii) throughput of both, licensed and unlicensed systems remains close to results obtained through a search which has been conducted exhaustively. From existing literature, it emerges that for addressing the issue of scarce spectrum availability, the 6G wireless systems will require to aggregate the 95GHz licensed THz spectrum and the 60 GHz unlicensed mm-wave spectrum [12]. Further, to improve the spectrum assignment, as opposed to SSA technique which assigns only a specific part of the aggregate or country-wide (CW) spectrum to every MSP, the entire CW spectrum must be assigned to the SCs of every MSP thereby, increasing the spectrum. Overall, a technique is must be formulated which can (i) aggregate the CW entire 95GHz licensed THz spectrum and the 60 GHz unlicensed mm-wave spectrum. However, such a technique which aims to increase the available spectrum bandwidth for serving on-demand high capacity and data rate does not appear in the existing literature. In this article, we formulate a CW dynamic licensed unlicensed spectrum assignment (DLUSA) technique which enables co-existence of the 95GHz licensed THz spectrum and the 60GHz unlicensed mm-wave spectrum. In DLUSA, spectrum is assigned to SCs which are considered to be located on every floor of a specific home/building of each MSP of a country (e.g., India). Through DLUSA (i) for every MSP, we evaluate the required amount of licensed 95GHz spectrum and unlicensed 60GHz spectrum, and (ii) we derive mean capacity (MC), spectral-efficiency (SE), energy-efficiency (EE), and cost-efficiency (CE). For simulations, we consider two cases viz., case 1: SCs operate in the licensed 95GHz spectrum considering four MSPs, and case 2: SCs operate in both, 95GHz licensed spectrum with four MSPs and 60 GHz unlicensed spectrum with an incumbent WiGig operator (WGO). We conduct extensive simulations to (i) compare performance of DLUSA with the traditional SSA technique, and (ii) evaluate MC, SE, EE, and CE for MSP1 under cases 1 and 2 considering the absence of co-channel interference. Lastly, we demonstrate that DLUSA is able to meet the SE and EE requirements of the 6G wireless systems.The rest of the article is organized as follows. In **Section 2**, the assumed system architecture, and details of the proposed DLUSA technique are presented. **Section 3** details the derivation of the various performance metrics. In **Section 4,** the obtained results are presented and discussed. Finally, **Section** 5 concludes the study.

2. System Architecture and Proposed DLUSA Technique

In the current study, a system architecture is assumed which comprises of MSPs and WGOs operating in a country (e.g., India). For every MSP, we consider the existence of a macro-cell base stations (MCBS), pico-cell BSs (PCBSs), and SCBSs [5]. It is assumed that SCBSs operate within the licensed 95GHz THz band and/or within the unlicensed 60GHz band whereas, MCBSs and PCBSs operate at lower frequencies (i.e., lower mm-wave). Further, SCBSs and PCBSs are located in a manner such that MCBSs of MSPs are able to provide coverage to them, and it is assumed that SCBSs are deployed within homes/buildings such that at any instance, they provision individual user equipment (UE). For all the MCBSs, either a

MCBS or a PCBS is assumed to provision UE for every MCBS.

Every MSP gets to access entire CW 95GHz licensed THz spectrum provided it is able to avoid co-channel interference. When the SCs operate in the unlicensed 60GHz spectrum, additional co-channel interference occurs due to presence of WiGig APs (WGAPs) of any incumbent WGO. Hence, in this case, an opportunistic carrier aggregation (CA) technique can be implemented by the SCs to operate in both, 95GHz licensed and 60GHz unlicensed spectrum bands thereby, extending the available spectrum bandwidth [2]. Additionally, considering that in every home/building the floor penetration loss will be high [13] due to which both, the licensed and the unlicensed signals will be significantly attenuated, it can be assumed that the co-channel interference effect from one floor of the home/building to the adjacent one will be negligible. The proposed DLUSA technique is detailed in the following sub-section.

2.1 DLUSA Technique

The proposed DLUSA technique assigns the entire 95GHz licensed THz spectrum to a country's every MSP which in turn operates the SCs deployed on every floor within a home/building such that there occurs no co-channel interference from one MSP to another. Additionally, DLUSA also reuses the assigned spectrum of every MSP to the SCs on every floor within home/building. Specifically, SCs of all the MSPs which are located on every floor within a home/building are considered to operate within the same CW 95GHz licensed THz spectrum. Hence, due to co-existence of all MSPs UEs on same floor, co-channel interference occurs if SC UEs of more than a single MSP are assigned to the licensed spectrum simultaneously. The co-channel interference is avoidable by assigning UEs of SCs on a floor in an orthogonal manner in the frequency domain such that UEs of MSPs which are located on same floor are assigned to different parts of the 95GHz licensed THz spectrum [14]. Therefore, SC UEs of not more than one MSP can be assigned to the same frequency during any time interval for transmission (TiT). Also, to avoid simultaneous same spectrum access, any conventional spectrum sensing technique can be implemented by the SC to detect the existence of an interfering UE [12]. Lastly, in regard to license fee, following the study in [15], the fee for complete CW spectrum could be distributed amongst all the MSPs by charging a fair fee to every MSP such that the spectrum licensing fee for any MSP updates as per variation in the consumers' amount during every license term of renewal (ToR) T_{TOR}. When SCs of a MSP operate in the unlicensed 60GHz mm-wave band, for a specific MSP, in addition to other MSPs, co-channel interference will also arise due to incumbent WGOs which needs to be taken into account. However, following the same technique of assigning UEs of SCs on a floor in an orthogonal manner in the frequency domain as for the licensed 95GHz THz band, co-channel interference from the SCs operating in the unlicensed 60GHz spectrum band can also be avoided under the consideration that all the WGOs and MSPs operate in every apartment on any floor of a home/building. Firstly, DLUSA aims to find the consumers' amount for every SC of a specific MSP msp in a particular apartment considering an observation time $T_{\max}$. At any given time T_{ToR}, the UEs amount which are provisioned by a SCBS sb of a specific MSP is denoted as $UE_{sb} \in UE_{sb} = \{0,1,2......UE_{sb,\max}\}$. Following [16], the call arrivals are modelled as a Poisson process which results in the activity of traffic for a SC UE which provisions a specific in-building SCBS to be modelled as an exponentially distributed continuous-time Poisson process. Further, with the current state known, the future state is not dependent on the past state and hence, activity of traffic of a specific UE is modelled as a two-state Markov chain. Specifically, transition rate of a UE from activity of traffic in the off-state to activity of traffic in the on-state, and transition rate of a UE from activity of traffic in the on-state to activity of traffic in the off-state is denoted as α and β, respectively. To find the active UEs amount UE_{sb} in any apartment, for a specific SCBS sb the corresponding on-state probability is denoted as $p(0), p(1), p(2),.........., p(U_{sb,\max})$ which can be evaluated by Birth-Death process [17]. Denoting the birth-rate and death-rate as α_{UE} and β_{UE}, respectively, these values are given as [18]

$$\alpha_{UE_{sb}} = \begin{cases} (UE_{sb,\max} - UE_{sb})\alpha, & 0 \le UE_{sb} \le UE_{sb,\max} \\ 0, & otherwise \end{cases}$$

…(1)

$$\beta_{UE_{sb}} = UE_{sb} \times \beta$$

Therefore, probability of a specific UE is evaluated as

$$p(UE_{sb}) = p(0)\left(\left(\frac{\alpha}{\beta}\right)^{UE_{sb}} \times \begin{pmatrix} UE_{sb,\max} \\ \\ UE_{sb} \end{pmatrix}\right)$$

…(2)

However,

$$\sum_{UE_{sb}=0}^{UE_{sb}=UE_{sb,\max}} p(UE_{sb})=1 \qquad \ldots(3)$$

Hence, from eq. (2) and eq. (3), the following can be evaluated

$$p(0)=\frac{1}{\left(1+\left(\frac{\alpha}{\beta}\right)\right)^{UE_{sb,\max}}} \qquad \ldots(4)$$

From the above equations, the probability of SCBS sb provisioning UEs amount UE_{sb} is evaluated as

$$p(UE_{sb})=\frac{UE_{sb,\max}!}{UE_{sb}!\left(UE_{sb,\max}-UE_{sb}\right)!}\times\left(\frac{\alpha}{\beta}\right)^{UE_{sb}}\times\frac{1}{\left(1+\left(\frac{\alpha}{\beta}\right)\right)^{UE_{sb,\max}}}$$

(5)

Finally, At any given time t, the expectation of UEs amount which are provisioned simultaneously is evaluated as

$$E[UE_{sb}]=\sum_{UE_{sb}=0}^{UE_{sb}=UE_{sb,\max}}(UE_{sb})\times p(UE_{sb}) \qquad \ldots(6)$$

It must be noted that in the SC UEs Poisson distribution, the UE_{sb} value is very small since arrival rate of UEs for a specific in-building SCBS sb is very less due to small coverage. Hence, occurrence of smaller UE_{sb} values are more probable compared to larger values. Therefore, in this study we assume $E[UE_{sb}]=1$ which implies that each SC sm_{msp} of a MSP msp provisions a maximum of one UE at any given time. Also, with this assumption, presence of interferer UEs amount within every apartment can be evaluated by following the same procedure. Specifically, we consider that $UE_I \in UE_I=\{0,1,2.....UE_{I,\max}\}$ denotes the interferer UEs amount which are provisioned by every SCBS of MSP msp during any TiT of a specific SCBS sb of MSP msp, where $UE_{I,\max}=MSP-1$. Hence, probability of UE_I interferer UEs amount for a specific SCBS sb of MSP msp within an apartment is evaluated as

$$p(UE_I)=\frac{UE_{I,\max}!}{UE_I!\left(UE_{I,\max}-UE_I\right)!}\times\left(\frac{\alpha}{\beta}\right)^{UE_I}\times\frac{1}{\left(1+\left(\frac{\alpha}{\beta}\right)\right)^{UE_{I,\max}}}$$

(7)

Therefore, the expected value of interferer UEs amount which are provisioned simultaneously during any time within an apartment for a specific SBS sb of MSP msp is evaluated as

$$E[UE_I]=\sum_{UE_I=0}^{UE_I=UE_{I,\max}}(UE_I)\times p(UE_I) \qquad \ldots(8)$$

From eq. (8), it is observed that the maximum spectrum amount is assigned to a specific MSP msp when there are no interferer UEs of the MSPs existing within an apartment on any floor i.e., $E[UE_I]=0$. Similarly, the minimum spectrum amount is assigned to a specific MSP msp when every interferer UE of a MSP exists within every apartment on any floor i.e., $E[UE_I]=UE_{I,\max}-1$. Secondly, DLUSA assigns the CW licensed and/or unlicensed spectrum to every MSP msp with an aim to increase the aggregate CW spectrum utilization. Let MSP denote the maximum number of MSPs in a country such that $msp\in MSP : MSP=\{1,2,3,\ldots\ldots,MSP\}$. Further, let S_{Total} denote the aggregate 95GHz licensed THz spectrum band and the 60GHz unlicensed spectrum band which is available in the form of spectrum blocks (SBs) where, every SB equals 180 kHz [5]. Further, the amount of SCs of a MSP msp is denoted as $SM_{Total,msp}$, and for a specific home/building $b\in B=\{1,2,3,\ldots\ldots B\}$, it is given as $sm_{msp}\in SM_{msp}=\{1,2,3,\ldots\ldots SM_{Total,msp}\}$. Let $C_{msp,T_{ToR}}$ denote the aggregate amount of customers in any MSP msp such that $\sum_{msp} C_{msp,T_{ToR}} \le C_{\max,T_{ToR}}$ where, $C_{\max,T_{ToR}}$ denotes the maximum customers amount in a country at any T_{ToR}. It is also fixed that the UEs of not more than a single MSP msp, which operate on the same floor, χ_{floor}, of a home/building, are provisioned by the same SB over any TiT. Therefore, at T_{ToR}, on χ_{floor} of a home/building b, the licensed and/or unlicensed spectrum which is assigned to the UEs of a MSP msp is evaluated as the ratio of $C_{msp,T_{ToR}}$ and $C_{T_{ToR}}^{b,\chi_{floor}}$ where, $C_{T_{ToR}}^{b,\chi_{floor}}$ denotes the aggregate customers' amount of all the MSPs which operate on the same floor χ_{floor} of a building b over any TiT at a specific T_{ToR}. With the above, and considering that every MSP will aim to minimize the licensed spectrum cost simultaneously maintaining the desired quality of service (QoS), we formulate DLUSA as a minimization problem to assign the CW licensed and unlicensed spectrum to every MSP with an aim of enhancing the overall CW spectrum utilization. Therefore, at a specific T_{ToR}, the problem of finding the optimum 95GHz licensed THz spectrum and/or 60GHz unlicensed mm-wave spectrum amount $S^{b,\chi_{floor}}_{msp,T_{ToR}}$ in terms of SBs, for any MSP $msp \in MSP$ on a specific floor χ_{floor} of a home/building *b* over a TiT, can be formulated as

$$\underset{msp\in MSP}{\min imize} \qquad S^{b,\chi_{floor}}_{msp,T_{ToR}} \quad \ldots(9)$$

$$considering \quad \frac{C_{msp,T_{ToR}}}{C^{b,\chi_{floor}}_{T_{ToR}}} = \frac{S^{b,\chi_{floor}}_{msp,T_{ToR}}}{S_{Total}}$$

and subjected to

$$\forall msp \forall T_{ToR} \sum_{msp}^{MSP} C_{msp,T_{ToR}} \le C_{\max,T_{ToR}}$$

The solution to the optimization problem in eq. (9) can be found considering that, at any T_{ToR}, the customers' amount of all the MSPs is not the same and hence, the constraint in eq. (9) is satisfied assuming that, at T_{ToR}, $C_{1,T_{ToR}} > C_{2,T_{ToR}} > \ldots\ldots > C_{msp,T_{ToR}}$.

Further, considering that the UE for any MSP over the TiT may not be existing on any of the floors χ_{floor} of a home/building *b* of SCs of a specific MSP msp, $C^{b,\chi_{floor}}_{T_{ToR}}$ can be evaluated as

$$C^{b,\chi_{floor}}_{T_{ToR}} = \sum_{msp=1}^{MSP} K_{\psi}\left(C_{msp}\right) \times C_{msp} \qquad \ldots(10)$$

where $\psi = \{C_1, C_2, C_{3,\ldots\ldots\ldots,} C_{msp}\}$, and value of K is '1' if C_{msp} is included in set ψ, else it is '0'. Using eq. (10), the CW 95GHz or 60GHz spectrum can be reused to the SCs of every MSP $msp \in MSP$ on a specific floor χ_{floor} of a home/building *b* to improve the CW spectrum utilization. Further, with the constraint on SBs being an integer value only, the optimal value of $S^{b,\chi_{floor}}_{msp,T_{ToR}}$ using eq. (10) and the constraint in eq. (9) is evaluated as

$$S^{b,\chi_{floor}}_{msp,T_{ToR}} = \left\lfloor \left(\frac{C_{msp}}{\sum_{msp=1}^{MSP} K_{\psi}\left(C_{msp}\right) \times C_{msp}} \right) \times S_{Total} \right\rfloor \qquad (11)$$

It must be noted that if UE for any MSP over the TiT on any of the floors χ_{floor} of a home/building *b* does not exist then, in eq. (10), $C^{b,\chi_{floor}}_{T_{ToR}} = C_{msp}$ which leads to $S^{b,\chi_{floor}}_{msp,T_{ToR}} = \lfloor S_{Total} \rfloor$ in eq. (11) implying that the entire CW 95GHz licensed THz spectrum or 60GHz unlicensed mm-wave spectrum is available for assignment over all TiT to the UEs of SCs of a specific MSP on any of the floors χ_{floor} of a home/building *b*. In view of avoiding co-channel interference, this process is implemented for all the MSPs $msp \in MSP$ at every T_{ToR} for updating $S^{b,\chi_{floor}}_{msp,T_{ToR}}$ during any TiT. Lastly, we highlight that with higher customers amount C_{msp} of a specific MSPs msp during T_{ToR}, larger will be the $S^{b,\chi_{floor}}_{msp,T_{ToR}}$ value of spectrum available for assignment to MSP msp over the TiT on any of the floors χ_{floor} of a home/building *b* at T_{ToR}.

3. Derivation of Performance Metrics

Initially, we consider the case when only the 95GHz licensed THz spectrum band is utilized for the operation by SCs of all the MSPs. We assume that SM_{MC} and SM_{PC} denote the amount of macro-cells and the amount of pico-cells of a MSP msp, respectively.

Let the execution time of the simulation experiments be denoted as T such that $T \in \{1,2,3,\ldots\ldots T_{\max}\}$. For a MSP msp, the power transmitted via a macro-cell, pico-cell and a SC be denoted as PO_{MC}, PO_{PC}, and PO_{SC}, respectively. From the study in [5], considering a MSP msp, at any T_{ToR}, throughput of link (in bits per second per Hz), at any instant T for a $SB = sb$, and the availability of signal to interference noise ratio (SINR) is evaluated as

$$\xi^{T_{ToR}}_{T,sb,msp}\left(SINR_{T,sb,msp}\right)=\begin{cases}0, & SINR_{T,sb,msp}<-10\,dB\\ \lambda\log_2\left(1+10^{\left(SINR_{T,sb,msp}(dB)/10\right)}\right) & ,-10dB\leq SINR_{T,sb,msp}\leq 22\,dB\\ 4.4 & ,SINR_{T,sb,msp}>22\,dB\end{cases}\tag{12}$$

where, λ is the factor denoting the loss in implementation, and $\xi \; and \; SINR$ represent the reaction of all the macro UEs over the SBs of $S_{MCBS,msp}$ which denotes for a $msp \in MSP$, available spectrum (in terms of SBs) within a macro-cell. Hence, for a $msp \in MSP$, at any T_{ToR} for $SB = sb$, aggregate capacity of UEs in a macro-cell is given as

$$\xi_{MCBS,msp}=\sum_{T=1}^{T_{\max}}\sum_{sb=1}^{S_{MCBS,msp}}\xi_{T,sb,msp}\left(SINR_{T,sb,msp}\right)\tag{13}$$

where, $S_{MCBS,msp}$ denotes the spectrum (in terms of SBs) of a MCBS within a $msp \in MSP$, and ξ and $SINR$ are evaluated considering $S_{MCBS,msp}$ SBs over T for a specific $msp \in MSP$. Considering that all the SCBSs $sb_{\chi_{floor},msp}$ over any floor χ_{floor} within a home/building b of a specific $msp \in MSP$ provisions at the same time over all TiT within the 95GHz licensed spectrum, the total capacity at a certain T_{ToR} provisioned by a specific SCBS due to all the SCBSs in every floor χ_{floor} and on all floors χ_{FLOOR} is, respectively evaluated as

$$\xi_{95,msp,SM_{Total}}=\sum_{t\in T_{\max}}\sum_{sb=1}^{S^{b,\chi_{floor}}_{msp,T_{ToR}}}\xi_{t,sb,msp}\left(SINR_{t,sb,msp}\right)\tag{14}$$

$$\xi^{b,\chi_{floor}}_{95,msp,\chi_{floor,msp}}=\sum_{SM_{Total}=1}^{\chi_{floor,msp}}\xi^{b,\chi_{floor}}_{95,msp,SM_{Total}}\tag{15}$$

$$\xi^{b,\chi_{FLOOR}}_{95,msp,\chi_{floor,msp}}=\sum_{\chi_{floor}=1}^{\chi_{FLOOR}}\xi^{b,\chi_{floor}}_{95,msp,\chi_{floor}}\tag{16}$$

Considering the fact that the (i) distance between the UE of a SC and the SCBS is short, and (ii) SCBS transmits at low power, at a certain T_{ToR}, the same characteristics for propagating within indoor scenarios can be assumed for all the B buildings in every macro cell for a specific MSP msp. Hence, at a certain T_{ToR}, for all $b = B$, applying a linear approximation, the system level MC, SE, and EE for all MSPs msp which operate within the 95GHz CW licensed spectrum band is evaluated as

$$\xi^{MC}_{95,MSP}(B)=\sum_{msp=1}^{MSP}\xi_{MCBS,msp}+\left(B\times\xi^{b,\chi_{FLOOR}}_{95,msp}\right)\approx\sum_{msp=1}^{MSP}\left(B\times\xi^{b,\chi_{FLOOR}}_{95,msp}\right),\sin ce\left(B\times\xi^{b,\chi_{FLOOR}}_{95,msp}\right)>>\xi_{MCBS,msp}\tag{17}$$

$$\xi^{SE}_{95,MSP}(B)=\frac{\xi^{MC}_{95,MSP}(B)}{\left(\left(S_{Total}+\sum_{msp=1}^{MSP}S_{MCBS,msp}\right)\times T_{\max}\right)}\tag{18}$$

$$\xi^{EE}_{95,MSP}(B)=\frac{\left(\sum_{msp=1}^{MSP}\left(B\times SM_{Total,msp}\times PO_{SC}\right)+\left(SMP_{Total,msp}\times PO_{PC}\right)+\left(SMM_{Total,msp}\times PO_{MC}\right)\right)}{\xi^{MC}_{95,MSP}(B)\Big/T_{\max}}\tag{19}$$

where, $SM_{Total,msp}, SMP_{Total,msp}, SMM_{Total,msp}$ denote the aggregate SCBS, PCBS, and MCBS, respectively within any specific home/building l for MSP msp.Next, we consider the case when only the 60GHz unlicensed mm-wave spectrum band is utilized for the operation by SCs of all the MSPs. In this case, within a home/building, the maximum operator's amount is the total of MSPs which operate in the 95GHz licensed THz band and the WGOs operating in the 60GHz unlicensed mm-wave spectrum band. However, the value of MSP remains the same and hence, equations (17)-(19) can be used to evaluate $\xi^{MC}_{60,MSP}(B)$, $\xi^{SE}_{60,MSP}(B)$, and $\xi^{EE}_{95,MSP}(B)$, respectively for SCs of all MSPs which operate in the 60GHz unlicensed mm-wave spectrum band. It must be noted though that within a home/building, if any WGAP is present simultaneously with the SCs of MSPs, the unlicensed spectrum amount which is assigned to the WGAPs as per the customers amount percentage of WGOs with respect to that of all MSPs MSP is evaluated as

$$S^{b,\chi_{floor}}_{msp,T_{ToR}} = \left[\left(\frac{C_{msp}}{\sum_{msp=1}^{MSP} K_{\psi}\left(C_{msp}\right)\times C_{msp}}\right)\times S_{Total}\right] \tag{20}$$

From eq. (20), it is evident that the existence of a WGAP prevents assignment of the complete CW unlicensed spectrum SM_{Total} to the MSPs MSP as a percentage of unlicensed spectrum gets assigned to the WGAPs. However, following eq. (2), DLUSA ensures that irrespective of the UEs amount, the MSPs and WGOs are assigned an even unlicensed spectrum amount. In this study, it is also assumed that DLUSA mutes SCs transmission over unlicensed spectrum so that only WGAPs or WGOs transmit thereby ensuring fair access of the unlicensed spectrum and avoiding any unexpected blockages. In the case when SCs of all the MSPs utilize both, the 95GHz licensed THz spectrum band and the 60GHz unlicensed mm-wave spectrum band for operation, by implementing a CA technique which enables the SCs of MSP to operate in both the bands, the MC value from eq. (17) will be the total of the capacities which are achievable by both the spectrum bands. In regard to SE, when SCs operate in both, the licensed and the unlicensed bands, the effective spectrum will correspond to the 95GHz licensed THz band since a fee is paid for this band only and not for the unlicensed band. Hence, the values of MC, SE and EE, respectively are evaluated as

$$\xi^{MC}_{95+60,MSP}(B) = \xi^{MC}_{95,MSP}(B) + \xi^{MC}_{60,MSP}(B)$$
…(21)

$$\xi^{SE}_{95+60,MSP}(B) = \frac{\xi^{MC}_{95+60,MSP}(B)}{\left(\left(S_{Total} + \sum_{msp=1}^{MSP} S_{MCBS,msp}\right)\times T_{\max}\right)} \tag{22}$$

$$\xi^{EE}_{95+60,MSP}(B) = \frac{\left(\sum_{msp=1}^{MSP}\left(B\times SM_{Total,msp}\times PO_{SC}\right)+\left(SMP_{Total,msp}\times PO_{PC}\right)+\left(SMM_{Total,msp}\times PO_{MC}\right)\right)}{\xi^{MC}_{95+60,MSP}(B)\big/T_{\max}}$$
(23)

$$\xi^{MC}_{SSA,MSP}(B) = \sum_{msp=1}^{MSP}\xi_{MCBS,msp} + \left(B\times\sum_{\chi_{floor}=1}^{\chi_{floor}}\ \sum_{sb_{\chi_{floor}}=1}^{sb_{\chi_{floor}}}\ \sum_{sb=1}^{S_{Total}}\sum_{t\in T}\xi^{\chi_{floor}}_{sb_{\chi_{floor}},t,sb,msp}\left(SINR^{\chi_{floor}}_{sb_{\chi_{floor}},t,sb,msp}\right)\right)$$
$$\xi^{MC}_{SSA,MSP}(B) \approx \sum_{msp=1}^{MSP}\left(B\times\sum_{\chi_{floor}=1}^{\chi_{floor}}\ \sum_{sb_{\chi_{floor}}=1}^{sb_{\chi_{floor}}}\ \sum_{sb=1}^{S_{Total}}\sum_{t\in T}\xi^{\chi_{floor}}_{sb_{\chi_{floor}},t,sb,msp}\left(SINR^{\chi_{floor}}_{sb_{\chi_{floor}},t,sb,msp}\right)\right) \tag{24}$$

The proposed DLUSA technique is dynamic in nature and in this study, we compare its performance with the SSA method in which a fixed chunk of licensed spectrum, ‘S’ in terms of SBs, is assigned to all the MSPs without considering the actual requirement of the MSPs. Hence, when the spectrum sharing (SS) method is implemented, for SCs of all MSPs MSP CW which operate in the 95GHz licensed spectrum band, at T_{ToR} for $b = B$ the corresponding MC, SE and EE is evaluated as

$$\xi^{SE}_{SSA,MSP}(B) = \frac{\xi^{MC}_{SSA,MSP}(B)}{\left(\left(S_{Total} + \sum_{msp=1}^{MSP} S_{MCBS,msp}\right)\times T_{\max}\right)}$$

(25)

$$\xi^{EE}_{SSA,MSP}(B) = \frac{\left(\sum_{msp=1}^{MSP}\left(B\times SM_{Total,msp}\times PO_{SC}\right)+\left(SMP_{Total,msp}\times PO_{PC}\right)+\left(SMM_{Total,msp}\times PO_{MC}\right)\right)}{\xi^{MC}_{SSA,MSP}(B)\Big/T_{\max}}$$

(26)

As the use of 95GHz licensed THz spectrum band will incur cost/fee, we also evaluate the cost-efficiency (CE) defined as the cost which is required to be paid per unit achieved MC (i.e., in bits per second). For utilizing the CW licensed spectrum S_{Total}, the cost incurred is denoted as κ_{cost}. At any T_{ToR}, a specific MSP msp incurs the cost depending on the customers amount $C_{msp,T_{ToR}}$ in relation to the customers $C_{\max,T_{ToR}}$ of all the MSPs. Then, with the assumption that a specific MSP msp pays a fee κ_{cost} which corresponds to $C_{msp,T_{ToR}}$ at T_{ToR}, κ_{cost} is evaluated as

$$\kappa_{msp} = \frac{C_{msp,T_{ToR}}}{C_{\max,T_{ToR}}}\times\kappa_{\cos t}$$

… (27)

Hence, when SCs are operating in the 95GHz licensed THz spectrum, at any T_{ToR}, the CE is evaluated as

$$\eta^{CE}_{95,MSP} = \frac{\kappa_{\cos t}}{\xi^{MC}_{95,MSP}(B)}$$

… (28)

When the SSA technique is implemented, CE is evaluated as

$$\eta^{CE}_{SSA,MSP} = \frac{\kappa_{\cos t}}{\xi^{MC}_{SSA,MSP}(B)}$$

… (29)

For the case when SCs operate only in the 60GHz unlicensed mm-wave spectrum, no fee is incurred. However, when the SCs operate in both, the licensed and the unlicensed spectrum bands, CE is evaluated as

$$\eta^{CE}_{90+60,MSP} = \frac{\kappa_{\cos t}}{\xi^{MC}_{90+60,MSP}(B)}$$

… (30)

With the above, considering SC operation in the 95GHz licensed THz spectrum, improvement factor (IF) for CE, SE, EE and CE, respectively is evaluated as

$$\gamma^{MC}_{90,MSP} = \frac{\xi^{MC}_{90,MSP}(B)}{\xi^{MC}_{SSA,MSP}(B)}$$

… (31)

$$\gamma^{SE}_{90,MSP} = \frac{\xi^{SE}_{90,MSP}(B)}{\xi^{SE}_{SSA,MSP}(B)}$$

… (32)

$$\gamma^{EE}_{90,MSP} = \frac{\xi^{EE}_{90,MSP}(B)}{\xi^{EE}_{SSA,MSP}(B)}$$

… (33)

$$\gamma^{CE}_{90,MSP} = \frac{\xi^{CE}_{90,MSP}(B)}{\xi^{CE}_{SSA,MSP}(B)}$$

… (34)

Next, when SCs operate in both, the licensed and the unlicensed spectrum bands, using eq. (31)-(33), the IF for CE is evaluated as

$$\gamma^{CE}_{90+60,MSP} = \frac{\xi^{CE}_{90+60,MSP}(B)}{\xi^{CE}_{SSA,MSP}(B)}$$

… (35)

It must be noted that for the case when SCs operate in only the 60GHz unlicensed mm-wave band, no cost is incurred thereby resulting in no improvement of CE as this is an ideal case.

Performance comparison of DLUSA and SSA techniques

In this sub-section, we show that the proposed DLUSA technique outperform the SSA method under all the considered parameters. We demonstrate the improved performance of DLUSA by considering an example in which we consider four MSPs which are assigned number of customers from aggregate amount of consumers as follows: $MSP_1 = 40\%$, $MSP_2 = 30\%$, $MSP_3 = 20\%$, and $MSP_4 = 10\%$. Considering that for any MSP msp, the spectrum is assigned based on customers amount, following eq. (2), the spectrum assigned to the four MSPs is

$$
\begin{aligned}
S_{1,t}^{b,\chi_{floor}} &= \left(0.4 \times S_{Total}\right) \\
S_{2,t}^{b,\chi_{floor}} &= \left(0.3 \times S_{Total}\right) \\
S_{3,t}^{b,\chi_{floor}} &= \left(0.2 \times S_{Total}\right) \\
S_{4,t}^{b,\chi_{floor}} &= \left(0.1 \times S_{Total}\right)
\end{aligned}
\quad \ldots (36)
$$

Therefore, using DLUSA, the aggregate spectrum amount used to provision the demands of users of all MSPs is evaluated as

$$
\begin{aligned}
S_{MSP,t}^{b,\chi_{floor},user} &= \left(0.4 \times S_{Total}\right) + \left(0.3 \times S_{Total}\right) + \left(0.2 \times S_{Total}\right) + \left(0.1 \times S_{Total}\right) \\
S_{MSP,t}^{b,\chi_{floor},user} &= S_{Total}
\end{aligned}
\qquad (37)
$$

When the SSA method is implemented, every MSP msp is assigned with the same spectrum amount of $\left(0.25 \times S_{Total}\right)$.

However, as the customers' amount for the four considered MSPs is not same, every MSP does not require the same spectrum amount. As the spectrum amount depends on the customers' amount, in this case the spectrum assigned to the four MSPs is

$$
\begin{aligned}
S_{1,t}^{b,\chi_{floor}} &= \left(0.25 \times S_{Total}\right) \\
S_{2,t}^{b,\chi_{floor}} &= \left(0.25 \times S_{Total}\right) \\
S_{3,t}^{b,\chi_{floor}} &= \left(0.2 \times S_{Total}\right) \\
S_{4,t}^{b,\chi_{floor}} &= \left(0.1 \times S_{Total}\right)
\end{aligned}
\quad \ldots (38)
$$

Therefore, using SSA, the aggregate spectrum amount used to provision the demands of users of all MSPs is evaluated as

$$
\begin{aligned}
S_{MSP,t}^{b,\chi_{floor},user1} &= \left(0.25 \times S_{Total}\right) + \left(0.25 \times S_{Total}\right) + \left(0.2 \times S_{Total}\right) + \left(0.1 \times S_{Total}\right) \\
S_{MSP,t}^{b,\chi_{floor},user1} &= 0.8 \times S_{Total}
\end{aligned}
\qquad (39)
$$

From eq. (37) and eq. (39), it can be observed that $S_{MSP,t}^{b,\chi_{floor},user} > S_{MSP,t}^{b,\chi_{floor},user1}$.

Since capacity which can be achieved is directly proportional to spectrum, the following holds

$$
\xi_{MSP,t}^{b,\chi_{floor},user} > \xi_{MSP,t}^{b,\chi_{floor},user1} \quad \ldots (40)
$$

where, $\xi_{MSP,t}^{b,\chi_{floor},user}$ and $\xi_{MSP,t}^{b,\chi_{floor},user1}$ denotes the spectrum in eq. (37) and eq. (39) when DLUSA and SSA techniques are implemented, respectively. Since SE varies proportionally with the capacity which can be achieved, from eq. (18) and eq. (25) it is observed that DLUSA outperforms SSA in terms of SE. In regard to EE and CE which show an inverse proportionality trend with capacity, eq. (19) and eq. (26), and eq. (28) and eq. (29), respectively show that DLUSA outperforms SSA in regard to these parameters also. Overall, DLUSA demonstrates the following advantages over the SSA method: (i) in comparison to SSA which assigns only a portion of CW spectrum, DLUSA makes available a large spectrum amount by assigning CW complete licensed and/or unlicensed spectrum to every MSP, (ii) DLUSA ensures effective use of spectrum as it allows every MSP to dynamically and flexibly access the CW spectrum as opposed to SSA which implements static and dedicated spectrum assignment, and (iii) DLUSA minimizes the cost for every unit capacity as it requires a specific MSP to pay the spectrum fee based on customers amount during any T_{ToR}. It must also be noted that implementing DLUSA will require that the MSPs and WGOs continuously update and share utilization of the licensed and/or unlicensed spectrum with one another. This mandates coordination among the SCBSs of multiple MSPs in regard to the management of co-channel interference and use of appropriate spectrum sensing techniques. We do not focus on this aspect in the current article as it is out of scope of this study; however, we suggest the use of centralized, distributed or a hybrid coordination method depending on the characteristics of the proposed architecture [19].

4. Simulation Results and Discussions

For simulation experiments and performance evaluation of the proposed DLUSA technique, the key multiple parameters, detailed in Table 1 [5, 20-23], are considered. Using the performance metrics derived for arbitrary MSPs from Section 3, for simulations, the existence of four MSPs is assumed. For modelling the existence of the MSP UEs within every apartment, the traffic arrival is assumed to follow a Poisson process. The 95GHz licensed and 60GHz unlicensed spectrum bands are assumed to provision very high data rates for short distances considering the availability of large bandwidth and favourable characteristics of indoor signal propagation. Hence, we assume similar signal propagation characteristics within the same home/building, and between the adjacent homes/buildings. Further, the SCBSs are assumed to operate within the 95GHz licensed THz band and/or within the 60GHz unlicensed band under the large scale signal propagation model whereas, the MCBSs and PCBSs are assumed to operate at lower mm-wave frequencies of 2GHz. It is considered that each SC sm_{msp} of a MSP msp provisions a maximum of one UE at any given time i.e., $E\lfloor UE_{sb,msp}\rfloor = 1$. Lastly, negligible co-channel interference is assumed between the SCBSs of one home/building to adjacent homes/building. We compare performance of the proposed DLUSA technique with that of the existing SSA method considering the two cases of spectrum operation viz., case 1: SCs operate in the 95GHz licensed spectrum considering four MSPs, and case 2: SCs operate in both, 95GHz licensed spectrum with four MSPs and 60 GHz unlicensed spectrum with an incumbent WGO. In case 1, during T_{ToR}, the four MSPs which are assigned customers amount from total number of customers follows: $MSP_1 = 40\%$, $MSP_2 = 30\%$, $MSP_3 = 20\%$, and $MSP_4 = 10\%$. For case 2, in addition to the four MSPs, one WGO is also assumed to co-exist in every apartment. Hence, it is assumed that the WGO is assigned 20% of the customers amount which results in the four MSPs being assigned the customers amount as $MSP_1 = 30\%$, $MSP_2 = 25\%$, $MSP_3 = 15\%$, and $MSP_4 = 10\%$. Further, to provision the traffic at all times, a complete buffer model for traffic is assumed, and in view of ensuring trade-off which is balanced between the fairness and throughput performances, a proportional fair scheduler is considered. Lastly, from recent literature it is evident that the 6G wireless systems will require a mean SE and EE of approximately 350 bps/Hz and 0.4×10^{-6} Joules/bit, respectively [24-27]; hence, in the simulations we obtain results keeping this aspect into consideration. The results are obtained via a simulator designed on the MATLAB R2023b platform.

Firstly, we demonstrate the performance improvement achieved by implementing the proposed DLUSA technique as opposed to when SSA is implemented considering the various parameters viz., MC, SE, EE, and CE. To obtain the results, we consider a variation in the co-channel interferer UEs amount of MSP1 over every apartment on an individual floor for MSP 1 UEs when 4 MSPs and one WGO exists. In the simulations, two extreme cases are considered viz., (i) $Z_{\text{int}\,erference} = 0$ which denotes the non-existence of co-channel interference when UEs of other MSPs are not present, and (ii) $Z_{\text{int}\,erference} = 3$ which denotes the presence of maximum co-channel interference when UEs of other MSPs are present on a specific floor within a home/building. The SCs are assumed to operate in (i) only the 95GHz licensed THz band, and (ii) in both, the 95GHz licensed THz band and the 60GHz unlicensed mm-wave band. When there exists no co-channel interferer i.e., $Z_{\text{int}\,erference} = 0$ within an apartment, maximum 95GHz licensed THz spectrum is assigned to the SCBSs of MSP 1 over every floor during all TiT. With increase in $Z_{\text{int}\,erference}$, the assigned spectrum amount for MSP1 decreases. Specifically, for $Z_{\text{int}\,erference} = 3$, over every floor of the apartment, SCBSs of MSP 1 are assigned 40% and 30% of the CW spectrum in case 1 and case 2, respectively. Therefore, compared to $Z_{\text{int}\,erference} = 3$ for $Z_{\text{int}\,erference} = 0$, the 95GHz licensed THz spectrum and 60Hz unlicensed spectrum amount assigned to SCBSs of MSP 1 are 2.5 times and 3.33 times more, respectively.

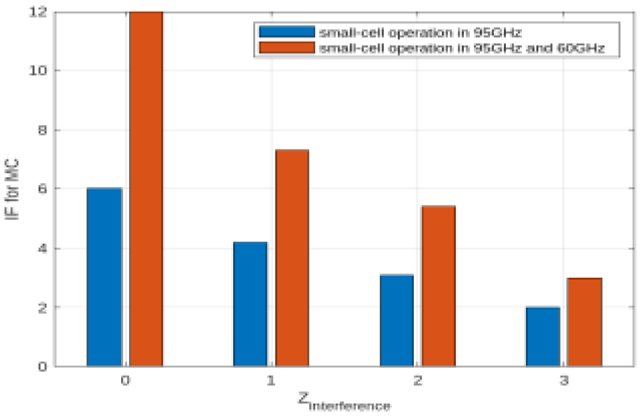
In Figure 1 we demonstrate that the largest and smallest values of MC, SE, EE and CE for MSP 1 can be obtained corresponding to $Z_{\text{int}\,erference} = 0$ and $Z_{\text{int}\,erference} = 3$, respectively.

These values can be obtained for both the cases since the capacity which can be achieved is dependent on the available spectrum amount. From Figure 1 it can be observed that in comparison to when $Z_{\text{int}\,erference} = 3$, the values of

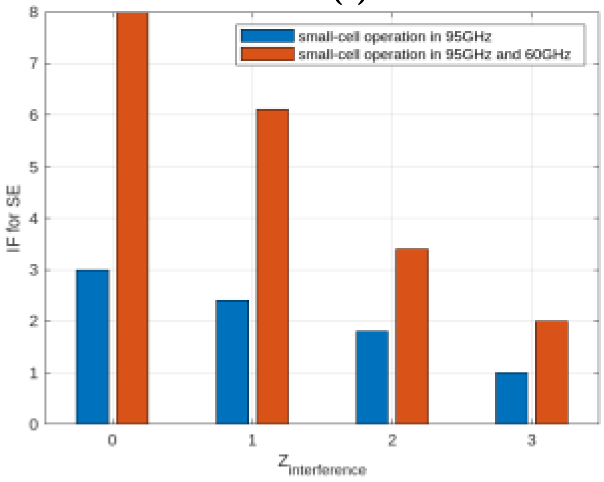
Table 1. *Simulation Parameters considered in study [20-23].*

Parameters	**Value**
95 GHz licensed THz spectrum and 60 GHz unlicensed mm-wave spectrum	1000 MHz each
Aggregate number of MSPs, WGOs and customers	4
Aggregate number of WGOs	1
Aggregate number of consumers	$C_{\max}$
Assigned customers amount from total customers amount for MSPs 1, 2, 3, 4, respectively	40%, 30%, 20%, and 10% of $C_{\max}$ for 95GHz licensed THz spectrum use only 30%, 25%, 15%, 10%, and 20% (for WGO) of $C_{\max}$ for both, 95GHz licensed THz spectrum and 60GHz unlicensed mm-wave spectrum use
Number of cells	2 macrocells, 4 picocells, 560 small cells every home
Total transmit power (dBm) of the BS	48 dBm – macrocell 39 dBm - picocells, 21 dBm - small cells operating at 95GHz licensed THz spectrum 30 dBm - small cells operating at 60GHz unlicensed mm-wave spectrum
Path Loss (PL) in dB	MCBS and UE $PL = 15.3 + 37.6\log_{10} D$ D has the unit of m
	PCBS and UE $PL = 140.7 + 36.7\log_{10} D$ D is in km
	SCBS and user equipment $PL = 61.38 + 17.97\log_{10} D$ D is in m
Antenna configuration, and channel state information	Single Input Single Output for all the base stations and UEs, Ideal
Pattern of the antenna	Directional for MCBS, and omni-directional for PCBS and SCBS
Gain of the Antenna (dBi)	15 for MCBS, 6 for PCBS, 6 for SCBS
UE antenna gain (dBi), noise dB), and speed (km/hr)	8, 12, 5
Type of small cell, scheduler and traffic model	Femtocells, proportional fair, and full buffer
Coverage of pico-cell, aggregate macro cell UEs, and macro cell user equipments offloaded to all pico-cells	50m in radius, 35, 3/18
Indoor macro cell UEs	40%
Time interval for transmission and Simulation execution time	2ms, and 10ms

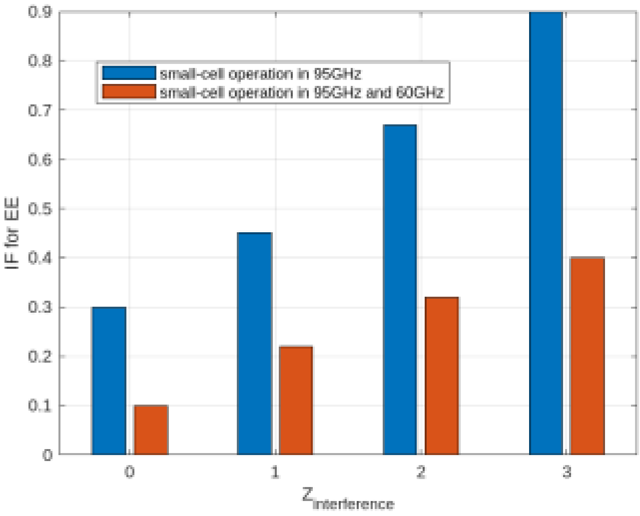
MC, SE, EE and CE improve for $Z_{interference} = 0$ by 3 times and 4 times in case 1 and case 2, respectively. Further, in comparison to when the SSA method is implemented, for MSP1 and $Z_{interference} = 0$, the proposed DLUSA technique improves MC, SE, EE and CE by 3 times, 1.7 times, 77%, and 65%, respectively for case 1, and by 6.2 times, 5.3 times, 88%, and 86%, respectively for case 2. It can also be seen from Figure 1 that, in comparison to the operation in case 1, when the operation is in case 2, the network performance shows significant improvements of 2 times for MC, 2.67 times for SE, 33.33% for EE, and 40% for CE. This implies that for the current and the next-generation wireless systems, operation must involve the simultaneous use of both, the licensed and the unlicensed spectrum bands. It can also be inferred from Figure 1 that the co-channel interference has a key role in the MSP performance irrespective of SBCS operation under case 1 or case 2. This is due to the observed decreasing trend of IFs with increase in $Z_{interference}$ value which is independent of the operational spectrum bands' type and amount.



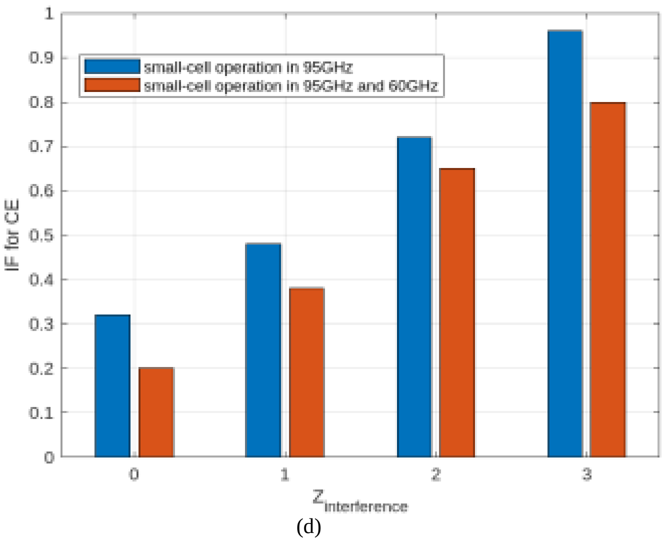
(a)



(b)



(c)



(d)

Figure 1. *Performance improvement of DLUSA when compared to SSA in terms of (a) MC, (b) SE, (c) EE, and (d) CE.*

Next, we investigate whether the proposed DLUSA technique is able to satisfy this requirement of the 6G wireless systems. Specifically, for every apartment over every floor of a specific home/building of MSP1, considering both cases 1 and 2 in the implementation of DLUSA and SSA, we vary the values of χ_{FLOOR} and B for $Z_{interference}=0$ and $Z_{interference}=3$. The obtained results are shown in Table 1 from which it can be observed that the SE and EE value which is required to meet the 6G wireless system requirement is function of the product of χ_{FLOOR} and B $(\chi_{FLOOR}\times B)$. It can also be seen from Table 2 that under the operation of SCs of MSP1 in case 1, to meet the 6G wireless system requirements, DLUSA uses approximately (i) 64.28% lesser single floor ($\chi_{FLOOR}=1$) homes/buildings ($B=10$) for $Z_{interference}=0$, and (ii) 10.71% lesser single floor homes/buildings ($B=25$) for $Z_{interference}=3$, as compared to SSA which requires $B=28$. Further, when SCs of MSP1 operate under case 2, the results are encouraging i.e., DLUSA uses approximately (i) 85.71% lesser single floor ($\chi_{FLOOR}=1$) homes/buildings ($B=4$) for $Z_{interference}=0$, and (ii) 57.14% lesser single floor homes/buildings ($B=12$) for $Z_{interference}=3$, as compared to SSA which requires $B=28$. Therefore, it can be inferred that operation of SCs in case 2 achieves better performance as compared to operation in case 1 due to reuse of spectrum for the SCBSs by 60% ($B=4$) lesser single floor (i.e. $\chi_{FLOOR}=1$) homes/buildings for $Z_{interference}=0$, whereas by 52% ($B=12$) for $Z_{interference}=3$ than that required by case 1 by reusing the same spectrum for the SCBSs of $B=10$ single floor homes/buildings amount for $Z_{interference}=0$ and $B=25$ single floor homes/buildings amount for $Z_{interference}=3$.

Table 2. *The values of* χ_{FLOOR} *and* B *required for DLUSA and SSA to meet the SE and EE requirements for 6G wireless systems.*

Case	χ_{FLOOR}	Value of B required by DLUSA with $Z_{interference}=0$		Value of B required by DLUSA with $Z_{interference}=3$		Value of B required by SSA	
		SE	EE	SE	EE	SE	EE
1	2	10	1	25	1	28	1
1	8	2	1	4	1	7	1
2	2	4	1	12	1	28	1
2	8	1	1	2	1	7	1

5. Conclusion

In the current article, we proposed the DLUSA technique which enables co-existence of 95GHz licensed THz spectrum and the 60GHz unlicensed mm-wave spectrum. In DLUSA, spectrum is assigned to SCs located on every floor of a specific home/building of each MSP of a country. Two cases are considered: (a) case 1: SCs operate only in licensed 95GHz spectrum with four MSPs, and (b) case 2: SCs operate in both, 95GHz licensed spectrum with four MSPs and 60 GHz unlicensed spectrum with an incumbent WGO. Through DLUSA (i) for every MSP, required amount of licensed 95GHz spectrum and unlicensed 60GHz spectrum is found, and (ii) MC, SE, EE, and CE are evaluated. Simulations have been conducted to (i) compare performance of DLUSA with SSA technique, (ii) and evaluate MC, SE, EE, and CE for MSP1 under cases 1 and 2, considering absence of co-channel interference.The obtained results demonstrate that DLUSA improves MC, SE, EE, and CE of MSP1 by 3 times, 1.7 times, 77%, and 65%, respectively, considering case 1; whereas, by 6.2 times, 5.3 times, 88%, and 86%, respectively, considering case 2. It is also observed that in comparison to the SC operation in case 1, when operation is in case 2, system performance shows significant improvements of 2 times for MC, 2.67 times for SE, 33.33% for EE, and 40% for CE. Additionally, it is observed that (i) DLUSA performance for both cases significantly depends on co-channel interference, operation within 60GHz unlicensed spectrum band, and (ii) DLUSA meets SE and EE requirements of 6G wireless systems. As a scope for future research, we will aim to investigate the effect of spectrum reuse on the considered performance metrics. 6G wireless systems is studied and reported in the literature [28-30].

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
- **Acknowledgement:** The authors declare that they have nobody or no-company to acknowledge.
- **Author contributions:** The authors declare that they have equal right on this paper.
- **Funding information:** The authors declare that there is no funding to be acknowledged.
- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

References

[1] Pärssinen, M. Alouini, M. Berg, T. Kuerner, P. Kyösti, M. Leinonen, M. Matinmikko-Blue, E. McCune, U. Pfeiffer, P. Wambacq, (Eds.). (2020), White Paper on RF Enabling 6G – Opportunities and Challenges from Technology to Spectrum, *White paper, 6G Research Visions, No. 13. 6G Flagship, University of Oulu, Finland,* 2021. http://urn.fi/ urn:isbn:9789526228419

[2] S. Tripathi, N.V. Sabu, A.K. Gupta, and H.S. Dhillon, (2021). Millimeter-Wave and Terahertz Spectrum for 6G Wireless. In: et al. 6G Mobile Wireless Networks, *Computer Communications and Networks.* https://doi.org/10.1007/978-3-030-72777-2_6

[3] P. Wang, B. Di and L. Song, (2020). Unlicensed Spectrum Sharing with WiGig in Millimeter-wave Cellular Networks in 6G Era, *in Proc. IEEE Global Communications Conference (IEEE GLOBECOM), Taipei, Taiwan,* 2020, pp. 1-6, doi: 10.1109/GLOBECOM42002.2020.9322110.

[4] M. Matinmikko-Blue, S. Yrjölä, and P. Ahokangas, (2020). Spectrum Management in the 6G Era: The Role of Regulation and Spectrum Sharing, in Proc. *IEEE 2nd 6G Wireless Summit (6G SUMMIT), Levi, Finland,* 2020, pp. 1-5, doi: 10.1109/6GSUMMIT49458.2020.9083851.

[5] S. Iyer, (2023). Performance Analysis of a Dynamic Spectrum Assignment Technique for 6G,

The Institution of Electronics and Telecommunication Engineers (IETE) Journal of Research, 69(11);7695-7703.

[6] Y. Huang, Y. Chen, Y. T. Hou, W. Lou, and J.H. Reed, (2018). Recent advances of LTE/WiFi coexistence in unlicensed spectrum, *IEEE Network*, 32(2);107–113.

[7] K. Bairagi, N. H. Tran, W. Saad, Z. Han, and C. S. Hong, (2019). A game-theoretic approach for fair coexistence between LTE-U and wi-fi systems, *IEEE Transactions on Vehicular Technology*, 68(1);442–455.

[8] M. Ali, S. Qaisar, M. Naeem, W. Ejaz, and N. Kvedaraite, (2020). LTE-U WiFi HetNets: enabling spectrum sharing for 5G/beyond 5G systems, *IEEE Internet of Things Magazine*, 3(4);60–65.

[9] G. Naik, J.M. Park, J. Ashdown, and W. Lehr, (2020). Next generation wi-fi and 5G NR-U in the 6 GHz bands: opportunities and challenges, *IEEE Access*, 8;153027–153056.

[10] S. Lagen, L. Giupponi, S. Goyal et al., (2020). New radio beam-based access to unlicensed spectrum: design challenges and solutions, *IEEE Communications Surveys & Tutorials*, 22(1);8–37.

[11] S. Iyer, (2024). Machine Learning enabled Dynamic Spectrum Access for 6G Wireless Networks, *Journal of Applied Security Research*, 19(2);330-350.

[12] Patil, S. Iyer, O.L.A. López, R.J. Pandya, K. Pai, A. Kalla, and R. Kallimani, (2024). A Comprehensive Survey on Spectrum Sharing Techniques for 5G/B5G Intelligent Wireless Networks: Opportunities, Challenges and Future Research Directions, *Computer Networks*, 253.

[13] L. Carneiro de Souza, C.H. de Souza Lopes, R. de Cassia Carlleti dos Santos, A. Cerqueira Sodré Junior, and L.L. Mendes, (2022). A Study on Propagation Models for 60 GHz Signals in Indoor Environments, *Front. Comms. Net*, 2;757-842, 10.3389/frcmn.2021.757842

[14] Calhan and M. Cicioglu, (2020). Handover scheme for 5G small cell networks with non-orthogonal multiple access, *Computer Networks*, 183.

[15] S.F. Ennis, "Advantages of License-Exempt Spectrum: Allocation Versus Auctions for Upper 6Ghz Spectrum", http://dx.doi.org/10.2139/ssrn.4349180

[16] A.O. Almagrabi, R. Ali, D. Alghazzawi, A. AlBarakati, and T. Khurshaid, (2021). A Poisson Process-Based Random Access Channel for 5G and Beyond Networks, *Mathematics*, 9(5);508. https://doi.org/10.3390/math9050508

[17] Y. Liu, Y. Deng, M. Elkashlan, A. Nallanathan, J. Yuan and R. K. Mallik, (2021). RACH in Self-Powered NB-IoT Networks: Energy Availability and Performance Evaluation, *IEEE Transactions on Communications*, 69(3);1750-1764.

[18] L. Kleinrock, Queueing Systems: Meory, *Wiley, Hoboken*, NJ, USA, 1975.

[19] R.H. Tehrani, S. Vahid, D. Triantafyllopoulou, H. Lee, and K. Moessner, (2016). Licensed spectrum sharing schemes for mobile operators: a survey and outlook, *IEEE Communications Surveys & Tutorials*, 18(4);2591–2623.

[20] 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*, (2007). Available online: https://portal.3gpp.org/desktopmodules/Specifications/Specification Details.aspx?specificationId=2592

[21] Simulation assumptions and parameters for fdd henb rf requirements. Document TSG RAN WG4 (Radio) Meeting #51, R4-092042, 3GPP, 2009. Available online: https://www.3gpp.org/ftp/tsg_ran/WG4_Radio/TSGR4_51/Documents/

[22] Guidelines for evaluation of radio interface technologies for IMT-2020. Report ITU-R M.2412-0 (10/2017), Geneva, 2017. Available online: https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2412-2017-PDF-E.pdf

[23] G.R. Maccartney, T.S. Rappaport, S. Sun, and S. Deng, (2015). Indoor office wideband millimeter-wave propagation measurements and channel models at 28 and 73 ghz for ultra-dense 5G wireless networks, *IEEE Access*, 3;2388-2424.

[24] 'The Vision of 6G: Bring the next hyper-connected experience to every corner of life', *Samsung, White Paper*, 2020.

[25] S. Chen, S. Sun, S. Kang, W. Cheng, M. Peng, and M. Peng, (2020). Vision, requirements, and technology trend of 6G: how to tackle the challenges of system coverage, capacity, user data rate and movement speed, *IEEE Wireless Communications*, 27(2);218–228.

[26] S. Ali et al., (2020). White Paper on Machine Learning in 6G Wireless Communication Networks 6G Flagship, *University of Oulu, Finland*, 2020. [Online]. Available: http://jultika.oulu.fi/files/isbn9789526226736.pdf

[27] White Paper on 6G Networking, White Paper, 6G Flagship, 2020.

[28] Mansi Joshi, & S. Murali. (2025). An Efficient Smart Flood Detection and Alert System based on Automatic Water Level Recorder Approach using IoT. *International Journal of Computational and Experimental Science and Engineering*, 11(1). https://doi.org/10.22399/ijcesen.717

[29] Kosaraju Chaitanya, & Gnanasekaran Dhanabalan. (2024). Precise Node Authentication using Dynamic Session Key Set and Node Pattern Analysis for Malicious Node Detection in Wireless Sensor Networks. *International Journal of Computational and Experimental Science and Engineering*, 10(4). https://doi.org/10.22399/ijcesen.613

[30] S. Praseetha, & S. Sasipriya. (2024). Adaptive Dual-Layer Resource Allocation for Maximizing Spectral Efficiency in 5G Using Hybrid NOMA-RSMA Techniques. *International Journal of Computational and Experimental Science and Engineering*, 10(4). https://doi.org/10.22399/ijcesen.665