Coverage Probability Optimisation by Utilizing Flexible Hybrid mmWave Spectrum Slicing–Sharing Access Strategy for 5G Cellular Systems

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***Abstractt*—Spectrum and infrastructure sharing among multiple mobile network operators is a vital solution to substantially and sustainably improves cost and network efficiency. However, such approach may face several challenges, such as the imposed restrictions on the independence of operators, the complexity of spectrum management policies and the mutual interference issues among operators. Therefore, in this study, we propose a flexible hybrid spectrum access strategy, namely, hybrid millimetre wave (mmWave) spectrum slicing–sharing access (HMSSSA), to optimise the coverage probability via distributing the spectrum in a hybrid manner. Accordingly, the interference problem can be addressed, and the coverage probability can be improved. In the proposed strategy, the spectrum splits into three different classes: (i) exclusive right assigned to all of the operators, (ii) semi-pooled among all the operators and (iii) fully pooled (shared) as open access among all the operators with the ultra-flexibility feature. Adaptive hybrid multi-state mmWave cell selection (AHMMC-S) scheme is adopted to optimally associate a typical user to the mmWave base station (mBS) that offers high signal-to-interference plus noise ratio. Numerical results demonstrate that our proposed strategy reduces the outage probability significantly, provides a degree of freedom to the subscribers to optimally select mBS with high signal quality and maintains an acceptable level of mBS densification.**

***Index Terms*—Hybrid mmWave Spectrum Sharing Strategy; Spectrum Slicing; 5G; Hybrid mmWave Cell.**

I. INTRODUCTION

The spectrum usage measurements conducted by the Federal Communications Commission Spectrum Policy Task Force [1] indicated that significant amount of the allocated spectrum, which was auctioned off exclusively, lies idle or is used sporadically [2],[3]. The spectrum management policy mainly concerns the spectrum shortage rather than spectrum scarcity. Consequently, extensive research efforts have been conducted to ensure efficient usage of the exclusively allocated (dedicated) spectrum. Such research efforts have revealed that the use of dynamic spectrum access (DSA) is an indispensable choice to solve the inefficient utilisation of resources [4]–[7]. In this context, cognitive radio (CR) technology, which supports the viability of the DSA approach, has been developed to address the problem of spectrum scarcity through four main functions [8],[9]:(i) spectrum sensing, (ii) spectrum management, (iii) spectrum mobility and (iv) spectrum sharing.

Recently, given the rapid increase in spectrum demand driven by the unprecedented growth in the number of devices and connections that can be attributed to various advances in the technology [10],[11], the combination of the aforementioned promising technologies (DSA and CR) is insufficient to effectively fuel the drastic future demands and reach the desired end. Therefore, the use of large chunks of underutilised spectrum in the extremely high frequencies (millimetre wave (mmWave) frequencies) is recently attracting significant interest to take place in the next-generation cellular communication (5G) [12]–[14]. Moreover, the diversity of the future service requirements such as satellite and fixed services [15] along with the necessity of fair manner to license the mmWave bands to multiple mobile network operators (MMNOs) require an adaptive way to share the allocated mmWave spectrum among them. Thus, harvesting considerable benefit and exploiting high degree of freedom to enrich the user experience in a cost-effective manner.

Consequently, the future cellular communication era will necessitate a paradigm shift to accommodate the diverse set of sectors, domains, and applications that require various types of requirements [16]–[19]. In the midst of the paradigm shifts, several aspects must be examined, such as performance metrics (e.g., outage probability and average rate), topology, cell association strategy, downlink vs. uplink, mobility, backhaul and interference management [20]. Overcoming the spectrum underutilisation issue is another challenge that needs to be seriously considered because such issue can occur significantly in the mmWave bands if either no efficient planning is available or when a significant amount of the spectrum is exclusively granted to the single mobile network operator (MNO) [15]. In this context, many studies have addressed various spectrum access paradigms in the conventional frequency bands (below 6 GHz). Examples of such paradigms are exclusive (licensed) spectrum access, license-exempt (unlicensed) spectrum access [21] and spectrum pooling access, which is a compromise between the aforementioned spectrum access paradigms [22],[23]. The spectrum pooling access paradigm is a subcase of the spectrum sharing paradigm and is an optimal option according to operators and regulators as it can attain high spectrum utilisation while maintaining an acceptable interference threshold to guarantee the high quality of service (QoS) [24].

In the mmWave frequencies, a few studies have been conducted to identify the optimal spectrum management strategy. In [25], the possibility of an authorisation regime that enables sharing of the wide spectrum available in the frequencies of 32 and 73 GHz among multiple operators is discussed. The spectrum pooling is found to be a suitable choice to facilitate an efficient resource sharing rather than the conventional regime in which the spectrum is allocated exclusively to single operators. In the meantime, the expected interference phenomenon between multiple operators that are deployed in overlapping area is alleviated through a coordination context-based spectrum sharing scheme as proposed in [26]. The relationship between the system performance and the spectrum cost is investigated in [15], [27]–[30], since, different usage cases have been studied to mimic the expected realistic environment in the future spectrum sharing paradigms. In particular, the authors in [15] and [28] revealed that the spectrum pooling paradigm provides considerable gain in terms of user experience with respect to the two mmWave frequencies (28 and 73 GHz) even without any coordination among the co-located operators. The economic implication of the spectrum sharing paradigm is addressed in [31], and the results clarify that resource sharing is beneficial for network service providers (NSPs) that operate at mmWave and microwave cellular networks. However, this feature is not necessarily translated to significantly maximising their own profits but may only encourage additional subscribers to occupy the shared spectrum. Furthermore, mandated sharing increases the low-end NSP profits and may encourage them to stay in the market, thereby improving consumer surplus relative to a monopoly.

In this work, we extend the prior studies in [15],[27]–[30] by considering new assumptions with regard to the use of hybrid spectrum sharing access strategy and different path loss models (commonly used) and enhancing the flexibility of the operators with a low number of mBSs. We also suggest two access models be adopted by MMNOs. The first model uses an equal amount of spectrum (1 GHz) for 28 and 73 GHz, and the second uses 1 GHz for 28 and 1.5 GHz for 73 GHz. The allocated spectrum for models 1 and 2 are sliced equally to four parts at the carrier frequency of 28 GHz, each with 250 MHz. In the high carrier frequency of 73 GHz, the total spectrum is divided into two parts, each with 500 MHz. The first part of the 1 GHz spectrum (500 MHz) is fully pooled among all operators (OP1, OP2, OP3, and OP4). The second part of 1 GHz (500 GHz) is sliced into two parts, and each part is semi-pooled/shared only by two operators (e.g., OP1, OP4 or OP2, OP3). Eventually, our work aims to optimise the system performance with respect to the signal-to-interference plus noise ratio (SINR), a topic that is not mainly addressed in the recent studies.

II. SYSTEM MODEL AND SIMULATION SET UP

We divide our proposed framework into the following four key parts to accurately simulate and apply the baseline and our proposed spectrum sharing strategy configurations.

A. Network Model

To serve a popular geographical area, we consider two tiers of hybrid MMNOs given by X, and each operator x is granted a shared or is exclusively assigned a certain amount of the available bandwidth W^{XC}.

Let J_x be the set of mBSs of operator x and $J = J_1 \cup J_1 \ldots \cup J_X$ be the set of all mBSs in the network. However, all operators have their own mBSs J_x that can operate optionally at two mmWave carrier frequencies (28 and 73 GHz) given by C. Notably, all mBSs are densely deployed in an overlapping area that provides high coverage and QoS to a large number of UEs, such that the simulation area is 1.2 Km^2. Without loss of generality, we use I to denote the set of all UEs. Each operator x has a set of outdoor users I_x that are served by a certain mBS J_x that belongs to the same or different operator depending on the spectrum allocation and the quality of the signal.

For a given association, we utilise our proposed scheme, namely, adaptive hybrid multi-state cell selection scheme, to select the serving mBS that offers a link with high signal quality adaptively. In practice, the user association and cell selection operation can be implemented by using either master cell-decision making scheme or user-decision making scheme. All mBSs that are owned by MNOs and their UEs are assumed to be powered by multi-antenna systems. Specifically, for simplicity, we assume that the transmit antenna is an omni-directional antenna with some assumption of beamforming technology, since, only a single beam from other base stations can interfere the receiver of interest that operates at the same frequency band of the served mBS J.

B. Mathematical Models

We consider two types of mathematical models: the models that are related to basic mobile communications and those that are related to the mmWave communication system. They are rewritten and developed to meet the baseline and the proposed strategy requirement optimally. In this context, capturing one or more snapshots through the implementation of the whole simulation helps determine the special behaviour of the overall hybrid mmWave system.

To calculate the received signal power at the receiving antenna, we consider the commonly used close-in reference distance path loss model [32]–[35].

$$PL(d_{ij})^{XC} = PL_{fs}(d_o) + 10 \times \gamma \times log_{10}\left(\frac{d_{ij}}{d_o}\right) + x_{\sigma}, \quad (1)$$

where $PL(d_{ij})^{XC}$ denotes the average path loss in dB for a specific user/terminal i with respect to j mBS that operates at mmWave carrier frequency C and owned by operator X. The separation distance is d_{ij} in meters. d_o denotes the close-in free space reference distance (1 m), $PL_{fs}(d_o)$ denotes the close-interference free space path loss in dB as identified in Equation (2), γ denotes the average path loss exponent and x_{σ} denotes zero mean Gaussian random variable with σ as a standard deviation in (dB) given that 10 dB shadowing margin is used in our work.

$$PL_{fs}(d_o) = 20 \times log_{10}\left(\frac{4 \times \pi \times d_o}{\lambda}\right), \quad (2)$$

where λ stands for the wavelength of the carrier frequency. The parameters of this model and those of the mmWave frequencies (28 and 73 GHz) are listed in Table 1.

Table 1
Statistical Path-loss Parameter [32], [35], [36]

Frequency Band	γ[dB]	λ[mm]
28GHz	3.4	10.71
73GHz	3.3	4.106

Typically, to calculate the average received signal power at the receiver, we first compute the path loss attenuation with Equation (1) and then execute Equation (3) as follows:

$$\mathrm{Pr} = P_t + G_t + G_t - PL, \tag{3}$$

To meet the assumptions of the utilisation of hybrid mBS deployment, we rewrite Equation (3) again as depicted below:

$$\mathrm{Pr}_{ij}{}^{\mathrm{XC}} = \mathrm{P_t}{}^{\mathrm{XC}} + G_t{}^{XC} + G_r{}^{XC} - PL_{ij}{}^{XC}, \tag{4}$$

where $\mathrm{Pr}_{ij}{}^{\mathrm{XC}}$ and $\mathrm{P_t}{}^{\mathrm{XC}}$ are the received and transmitted power of mBS j_X , respectively, which is owned by operator X and operated at mmWave carrier frequency C; $G_t{}^{XC}$ and $G_r{}^{XC}$ are the linear gains of the transmitter and the receiver antennas in dBi, respectively; $PL_{ij}{}^{XC}$ is the average path loss in dB.

In characterising the performance of each operator of the hybrid MMNOs, we consider the outage probability as an indicator to assess the feasibility of the proposed strategy based on $SINR$. We assume that the threshold value of the SINR of a user I_X served by an operator x is in outage status if it is below zero. For example, a user I_X associates with mBS j_X that is owned by operator x who is shared or exclusively granted a certain amount of spectrum in the carrier frequency C of either 28 or 73 GHz. Then, the SINR of user I_X can be calculated with Equation (5) [37].

$$\xi_{ij}{}^{\mathrm{XC}} = \frac{\mathrm{Pr}_{ij}{}^{\mathrm{XC}}}{\sum_{\mathrm{n=1}}^{\mathrm{N}} \mathrm{I}_{ij}{}^{\mathrm{XC}} + \eta^{\mathrm{XC}}}, \tag{5}$$

where $\xi_{ij}{}^{\mathrm{XC}}$ denotes the SINR; $\sum_{\mathrm{n=1}}^{\mathrm{N}} \mathrm{I}_{ij}{}^{\mathrm{XC}}$ denotes the interference received by the receiver i from all neighbouring mBSs that operate at the same frequency band and owned by operator x except the serving mBS J. Specifically, we assume that only a single beam comes from mBS J that interferes the receiver I_X ; η^{XC} denotes the additive white noise power of operator X for a carrier frequency C and is given by [38]

$$\eta^{XC} = 10 \times \log_{10}(KT_{sys}) + 10 \times \log_{10} W^{XC} + NF^{XC}, \tag{6}$$

where $10 \times \log_{10}(\mathrm{KT_{sys}})$ for a given system temperature (17 °C) equal to −174 dBm/Hz; $\mathrm{NF}^{\mathrm{XC}}$ denotes the noise figure with a value of 6 dB.

C. *Hybrid Millimetre Wave Spectrum Slicing–Sharing Access Models*

We address the most important considerations of our proposed hybrid mmWave spectrum slicing–sharing Access (HMSSSA) strategy and its models meticulously. Four hybrid millimetre MNOs (HMMNOs) are considered. All of them are distributed throughout the simulation area of 1.2 Km^2 following the grid-based cell deployment. We propose two access models to be adopted by the aforementioned operators. Each operator X grants exclusively a certain amount of the spectrum supplied by a certain carrier frequency to its subscribers or shares it with other operator's subscriber, as detailed below:

1. **Model 1**: we assume that the total amount of spectrum at the low and high frequencies (28 and 73 GHz) is 1 GHz. In this model, the 28 GHz spectrum is sliced evenly to four parts, each with 250 MHz. Each operator X grants exclusive rights of 250 MHz of the available spectrum supplied by the low carrier frequency of 28 GHz to only its subscribers I_X while avoiding co-channel interference with other adjacent operators. Each operator is assigned a bandwidth of $\mathrm{W}^{\mathrm{XC}} = \mathrm{W}^{\mathrm{TOTAL}}/4$ = 250 MHz. Meanwhile, in the high carrier frequency 73 GHz, the total spectrum is divided into two parts, each with 500 MHz. The first part of the 1G Hz spectrum (500 MHz) is pooled/shared among all operators in which each operator is assigned a bandwidth $\mathrm{W}^{\mathrm{XC}} = \mathrm{W}^{\mathrm{TOTAL}} =$ 500 MHz. The second part of 1 GHz (500 MHz) is sliced into two parts, and each part is assigned as semi-pooled/shared only by two operators. Thus, $\mathrm{W}^{\mathrm{XC}} = \mathrm{W}^{\mathrm{TOTAL}}/2$ = 250 MHz (e.g. t,he first part (250 GHz) is granted to OP1 and OP4, and the second part (250 GHz) is granted to OP2 and OP3. In this case, co-channel interference exists between OP1and OP4 and between OP2 and OP3 as depicted in Figure 1.

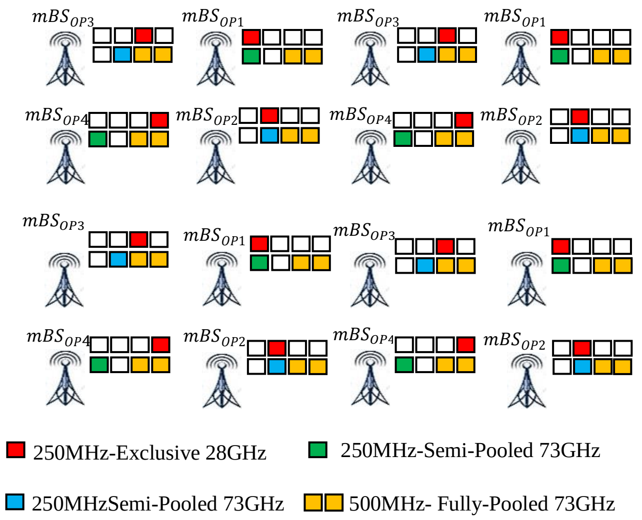

Figure 1: HMSSA Model 1

2. **Model 2**: we assume that we have two different sets of the spectrum: 1G Hz at the low frequency of 28 GHz and 1.5 GHz at the high frequency of 73 GHz. In this model, the spectrum assignment is similar to that in model 1 for 28 GHz band. However, the allocated amount of the 1 GHz spectrum at the carrier frequency of 73 GHz is available for exclusive access. Each operator X grants exclusive rights of 250 MHz of the available spectrum to only its subscribers $\mathrm{I_X}$. Furthermore, each operator is assigned a bandwidth $\mathrm{W}^{\mathrm{XC}} = \mathrm{W}^{\mathrm{TOTAL}}/4$ = 250 MHz. In this assignment, the co-channel interference is non-

existent. The remaining amount of the 1.5 GHz spectrum at 73 GHz (500 MHz) is shared among the different operators. Each operator is assigned a bandwidth $W^{C} = W^{TOTAL} = 500$ MHz. Thus, co-channel interference exists between all adjacent operators as depicted in Figure 2.

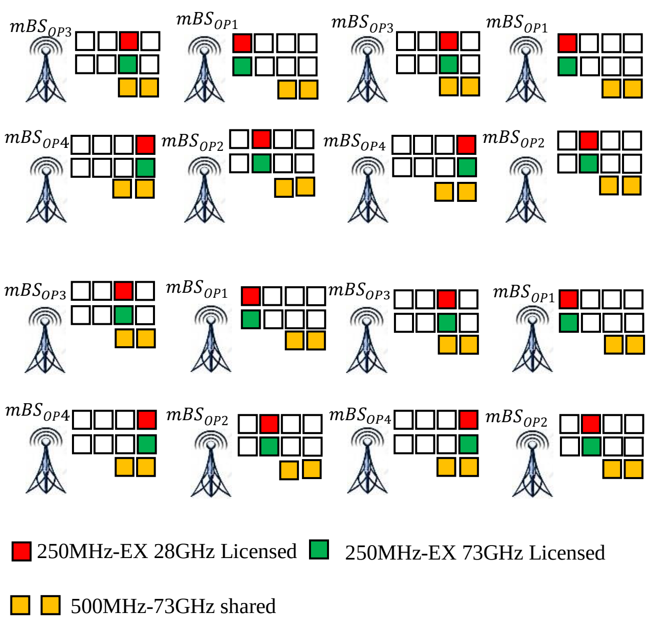

Figure 2: HMSSSA Model 2

D. mBSs distribution and AHMMC–S scheme

In our proposed network architecture, mBSs that belong to the four operators can be deployed in two modes. The first mode is mBSs deployed independently with the rental option of part of its infrastructure and resources to another operator. The second mode is co-located-based mBS mode. In the first mode, the operator has its own distinct mBSs with their infrastructure and allocated resources that are available to its subscribers. At the same time, such operator can rent part of its infrastructure and allocate resources among the adjacent operators. In the second mode, the operator has its own mBSs that are co-located with other mBSs that belong to other operators. In the proposed access strategy under model 1, the UEs that subscribed to OP1 have three options to associate with any mBS that belongs to that operator or to another operator that has cooperation with its operator depending on the above-mentioned modes (rent or co-located mode) with respect to the quality of signal offered by such mBS. The three options can be summarised as follows:

1. UEs of (OP1) can associate with mBS (OP1) that offers exclusive right access of 250 MHz at 28 GHz.
2. UEs of (OP1) can associate with mBS that belong to (OP4) that offer semi-pooled access of 250 MHz at 73 GHz to only the UEs of (OP1) and the same for UEs of (OP4). Hence, the UEs of OP1 and OP4 can associate to one other but in an opposite way.
3. UEs of (OP1) can associate with mBSs that belong to OP1, OP2, OP3 or OP4 that offers fully shared/pooled access of 500 MHz of the spectrum and the same for other operator's users.

In model 2, the UEs that are subscribed to operator X have the right to associate with mBS J that belongs to that operator via three options as follows:

1. UEs of (OP1) can associate with mBS (OP1) that offers exclusive right access of 250 MHz at 28 GHz and so on for other operators.
2. UEs of (OP1) can only associate with mBS (OP4) that offers exclusive right access of 250 MHz at 73 GHz, and vice versa. UEs of (OP2) can associate with mBS of (OP3) under the same assignment and carrier frequency. In this case, the interference will be lower than those in model 1 that utilises semi-pooled spectrum access.
3. UEs of (OP1) can associate with mBSs that belong to OP1, OP2, OP3 or OP4 that offers fully shared/pooled access of 500 MHz of the spectrum and the same for other operator's users.

The user and cell association decision is performed by using our proposed scheme, namely, adaptive hybrid multi-state mmWave cell selection (AHMMC-S), which relies on providing optimal cell selection based on the offered signal quality as a function of $SINR$. For example, UE I_X s located somewhere close to the four mBSs (mBS_{OP1}, mBS_{OP2}, mBS_{OP3} and mBS_{OP4}) (Figures. 3a and 3b). $I_{mBS_{OP2}}$ associates adaptively to the mBS that utilises its carrier frequency and provides high $SINR$ (link with high signal quality) to the user.

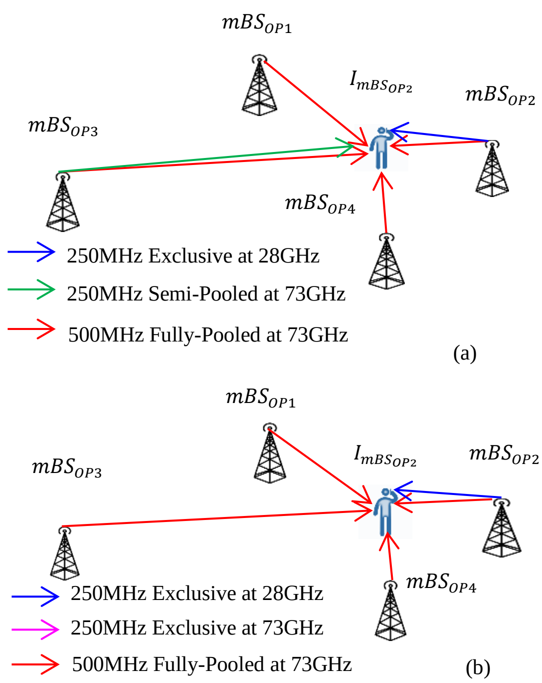

Figure 3: HMSSSA Models (a) Model 1(b) Model 2

III. SIMULATION RESULTS AND DISCUSSION

We evaluate the performance of the proposed HMSSSA strategy in a typical mmWave scenario that supports two hybrid access models based on the distribution and allocation spectrum. We consider that we have an equal amount of 1 GHz spectrum for the carrier frequencies of 28 and 73 GHz in model 1. In model 2, we have two different amounts of the spectrum: 1 GHz for the carrier frequency of 28 GHz and 1.5 GHz for the carrier frequency of 73 GHz. However, the main goal of HMSSSA is to optimise the coverage range and thus reduce the number of mBSs while maintaining an acceptable level of mBS densification. Accordingly, outage probability (as a function of SINR) is considered the key performance metric to assess the effectiveness of the proposed strategy with the two models (the discussion will be provided in the following sections).

The simulation settings of parameters, such as simulation area and a number of users, are all listed in Table 2.

Table 2
Simulation Parameter settings

Parameter	Settings
mmWave Base Station Layout	Grid-based Cell Deployment
mmWave Base Station Density	16
Number of Operator	4
UE Layout	Uniform random distribution
UE Density	160 Users
Area of Simulation	1.2Km2
Inter-Site Distance (ISD)	300m
mBS Carrier Frequency	28GHz and 73GHz
mBS Transmit Power	30dB
Noise Figure (BS)	5dB
Variant of White Gaussian Noise	-174 dBm/Hz
Noise Figure (MS)	7dB
mBS Bandwidth	Model1:1GHz for 28GHz and 73GHz Model2:1GHz for 28GHz and 1.5GHz for 73GHz

A. *HMSSSA results and discussion (model 1)*

Figure 4 shows the SINR distributions of the four operators (OP1, OP2, OP3, and OP4) in HMSSSA under model 1. Such SINR distributions are averaged over a sufficient number of iterations to achieve the desired accuracy. A typical user i which associates with mBS J_x belongs to the same operator based on the exclusive right of spectrum access (250MHz) at 28GHz carrier frequency (represented by the cyan bar) has higher SINR (lower outage) than the semi-pooled and fully-pooled spectrum access at 73GHz carrier frequency (represented by yellow and blue color respectively). The reason behind that such semi-pooled and fully-pooled spectrum accesses are semi-open or fully open access. The amount of interference in the semi-pooled and fully pooled access is larger than that in the exclusive right assignment of the spectrum. Since, the number of adjacent mBSs that are operated by the two aforementioned access strategies (semi-pooled and fully pooled) are 7 and 15 respectively; by contrast, only 3 mBSs operate in the exclusive right access except for the serving mBS, as shown in Figure. 1. However, the location of a user i in terms of mBS j plays a dominant role in reducing the outage probability, since; we found that the SINR distribution bar of the fully pooled spectrum access outperforms that of the semi-pooled spectrum access in some iterations. This, will happen when the users are closer to mBSs j that belongs to other operator in which only one choice for those users to associate with such mBS J. For instance, user i that subscribes to OP1 that is located extremely close to mBSs J_x owned by OP2 and OP3, will be only one choice for user i to associate with mBS j that offers fully-pooled spectrum access. Therefore, the outage probability will be reduced accordingly.

In our proposed HMSSSA strategy under model 1 extra flexible degree of freedom is utilized to bring advantages from all the available mBSs that operate at the different carrier frequency and spectrum assignments. Therefore, the outage probability reduces significantly with SINR value more than 3 dB for the cell-edge users, which outperforms the state of arts [15], [27]–[30]. This result can be translated to an enhancement in the performance of the cell-edge users. Hence, the coverage and data rate can be improved, and the number of mBSs can be decreased because only 16 mBSs are needed to be deployed through 1.2 Km^2 with good coverage. The outage probability percentages (black bars) of all operators (OP1, OP2, OP3 and OP4) are zeros (0%) with our proposed strategy, as shown in Figure 4.

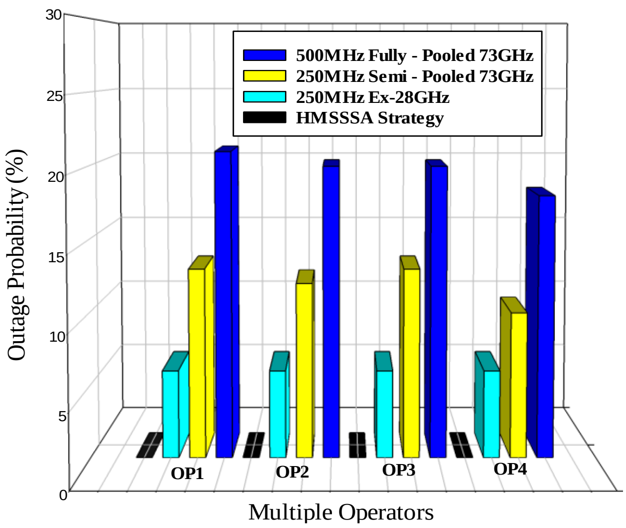

Figure 4: Overall Outage Probability Percentages of the four operators (model 1)

B. *HMSSSA results and discussion (model 2)*

Similar to HMSSSA (model 1) strategy two millimeter wave frequencies have been adopted (28GHz and 73GHz) for model 2. However, the allocated amount of the spectrum in model 1 and model 2 is different. Additionally, in model 2 each user can be associated with any mBS belongs to the same operator or to different operator based on one of the two choices, either based on exclusive right access of 250MHz at 28GHz and fully shared/pooled access of 500MHz of the spectrum at 73GHz carrier frequency or exclusive right access of 250MHz at 73GHz and fully shared/pooled access of 500MHz of the spectrum at 73GHz carrier frequency. This extra degree of freedom provided by in model 2 helps to achieve considerable improvements in terms of the outage probability, since the SINR distributions (black bars) of our strategy of all operators (OP1, OP2, OP3, and OP4) are kept zero (0%) with some improvement in the SINR distributions (>6dB). This improvement widens the gap with other spectrum access strategies (exclusive right, fully-pooled) adding 3dB to the cell-edge users (as compared to model 1), as illustrated in Table 3. The reason is that the extra amount of spectrum at the carrier frequency of 73 GHz reduces the interference between the mBSs that operate at such frequency owing to the reduction in the number of adjacent mBSs that operate in the same bands (exclusive right access of 250 MHz). Since, the number of adjacent mBSs that are operated by the fully pooled access strategy is 15, whereas only 3 adjacent mBSs are operated by exclusive right access at the carrier frequencies of 28 and 73 GHz for each operator except the serving mBS, as depicted in Figure 2.

Table 3
HMSSSA Strategy (Model 1 and Model 2)

HMSSSA Strategy	Spectrum amount	SINR value for each i	Outage Probability %
Model 1	1GHz at 28GHz 1GHz at 73GHz	> 3dB	0%
Model 2	1GHz at 28GHz 1.5GHz at 73GHz	> 6dB	0%

After extensive iteration, the SINR distribution of all operators with exclusive right access at the carrier frequency of 28 GHz (cyan bar) is not necessarily better than the SINR distribution of exclusive right access at the carrier frequency of 73 GHz (yellow bar). Furthermore, the SINR distribution of exclusive right access at the carrier frequency of 73 GHz (yellow bar) is not necessarily better than that of fully pooled access strategy (blue bar). These observations lead us to the fact that the user's location plays an important role in shaping the system performance.

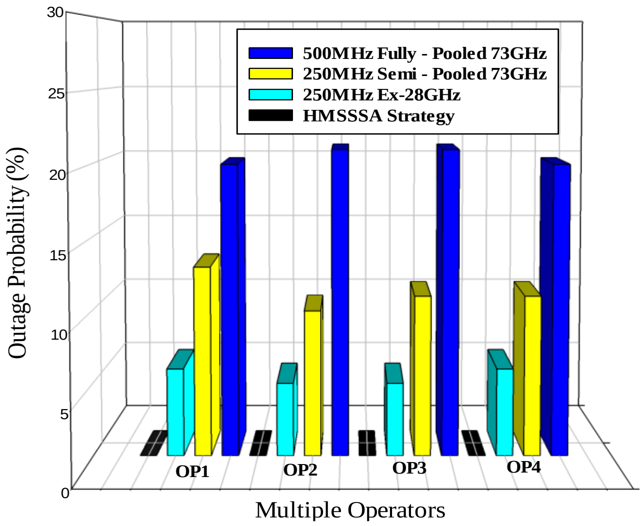

Figure 5: Overall Outage Probability Percentages of the four operators (model 2)

Notably, our proposed strategy achieves a great success in terms of equity in resource allocation and relatively efficient mBS planning, as shown in Figures 4 and 5. The figures show that the outage probability percentages of all operators are relatively extremely close to one other. Thus, operators are encouraged to rely on such strategy as it has proven its fairness in terms of resource allocation and outage probability. Accordingly, the competition between multiple operators in terms of delivering the services will be conducted in a fair manner with the existence of hybrid spectrum sharing represented by our proposed HMSSSA strategy.

C. *mBS- Density Evaluation*

In our proposed 5G network architecture, the density of mBSs that (HMSSSA) strategy depends on the mode that the operator relies on (e.g., rent mode or co-located mode) and the used models (model 1 or model 2). Regarding the rent mode in our proposed network architecture, the number of millimeter wave base stations that belong to operator X are four mBSs for each operator as illustrated in Figure. 6. Their locations are chosen carefully to guarantee the hybrid distribution of such mBSs. While, in the collocated mode the number of mBSs follows the mBSs density Equation (6) which can only be implemented in Grid-based mBSs deployment and the simulation area must be as a multiplication of the inter-site-distance (ISD).

$$\Gamma^{X} = \left(\frac{\mathbb{R}^{2}{}_{[seq-area]}}{\Theta_{[mWBSs_{ISD}]}}\right)^{2}, \quad (6)$$

where Γ_J^X denotes the total number of mBSs J that belong to operator X, $\mathbb{R}^2{}_{[\mathrm{seq-area}]}$ denotes the simulation area and $\Theta_{[\mathrm{mWBs_{ISD}}]}$ denotes the inter-site- distance (ISD) of the mBSs.

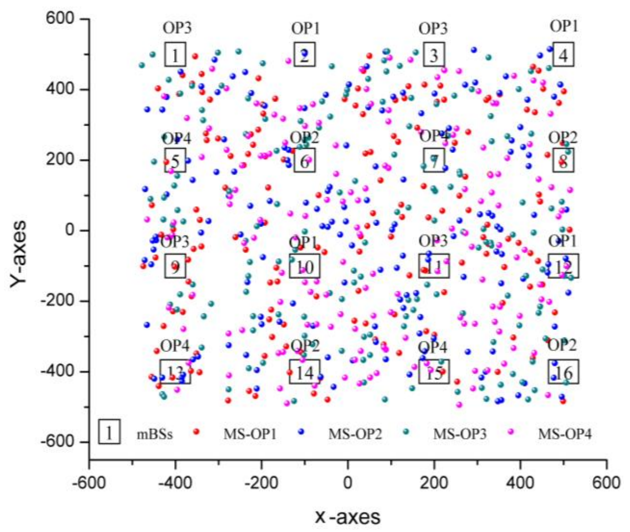

Figure 6: Illustration of the network deployment with of 4 operators each with 4 mBSs and its own mobile stations

The density of mBSs that adopt HMSSSA strategy and with the simulation area of 1.2 Km2 is 16 mBSs, which account less than the state of the arts (Table 4). When the number of mBSs decreases, the operating expenses, and capital expenditures decreases. Consequently, the environmental issue is also alleviated towards achieving a green communication, which is an important 5G requirement.

Table 4
MBSs Density Comparison

Ref	Simulation area/Cell range	SINR	#No. mBSs
[15]	0.3Km^2	Starting from≈ -4dB with outage 3%	60
[28]	103m	Starting from ≈ -10dB with outage 5%	30
[29]	1Km^2	Starting from ≈ -15dB with outage 3%	30
HMSSA Strategy (model 1)	1.2Km^2	Starting from ≈ 3dB with outage 0%	16
HMSSA Strategy (model 2)	1.2Km^2	Starting from ≈ 6dB with outage 0%	16

IV. CONCLUSION

In this paper, a flexible HMSSSA strategy has been presented. In particular, we have developed an optimisation framework that enables operators to harvest the gains from several considerations, such as hybrid spectrum integration strategy, resource and infrastructure sharing and user-cell association. Our results show that the hybrid spectrum (exclusive, semi-pooled and fully pooled) integration strategy can provide a considerable solution to overcome the mutual interference issues and thus reduce the outage probability and the number of mBSs. In case of resource and infrastructure, our results show that relying on HMSSSA strategy guarantees cost and technical efficiency for HMMNOs. Specifically, even with pooled and semi-pooled spectrum access, the interference amount diminishes significantly because of the efficient mBS distribution and the utilisation of AHMMC-S scheme that ensures optimal mBS and user association with respect to the best QoS.

Our current work considers various aspects to mimic the envisioned 5G scenarios. However, some limitations are found and are summarised as follows. Firstly, we consider stand-alone mmWave frequencies (28 and 73 GHz). Some extension in terms of employing lower frequencies (below 6 GHz) will be necessary to take advantage of the available features. Secondly, the decision of user-cell association is rendered on the basis of high link quality (maximum SINR). Thus, we may need to explore other realistic scheduling algorithms that are expected to occur in the fifth generation of cellular communications. This topic will be the focus of attention in the future work.

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