Dynamic and Opportunistic Millimeter-Wave Spectrum Access in 5G New Radio Multi-Operator Cognitive Radio Networks

Rony Kumer Saha
Radio and Spectrum Laboratory
KDDI Research, Inc.
2-1-15 Ohara, Fujimino-shi, Saitama, Japan
email: ro-saha@kddi-research.jp

Abstract—**In this paper, we present a Dynamic and Opportunistic Spectrum Access (DOSA) technique that allows access to the static and equal licensed 28 GHz millimeter-wave (mmWave) spectrum of each Fifth-Generation (5G) New Radio (NR) Mobile Network Operator (MNO) to every other MNOs in a country to serve their respective in-building Small Cells (SCs) subject to avoiding Co-Channel Interference (CCI). We derive the system-level Average Capacity (CA), Spectral Efficiency (SE), and Energy Efficiency (EE) performance metrics for an arbitrary number of NR MNOs. With extensive simulation results and analyses for four MNOs, we show that the proposed DOSA can provide CA and SE 2.5 times and improve EE by about 60% as compared to that of the traditional Static and Equal Spectrum Access (SESA) technique. Moreover, DOSA can achieve both SE and EE requirements expected for the Sixth-Generation (6G) mobile networks by reusing the countrywide mmWave spectrum for 46.87% fewer buildings of SCs than that required by SESA.**

Keywords—5G; 28 GHz; in-building; small cell; millimeter-wave; multi-operator; new radio; dynamic spectrum access.

I. Introduction

Traditionally, the mobile radio spectrum specified for a country is allocated statically in an equal amount to each of its Mobile Network Operator (MNO) regardless of the inequality in the number of subscribers of one MNO from another. This uniform distribution of spectrum causes one MNO to allocate more spectrum than necessary, whereas the other MNO suffers from the lack of a sufficient amount of spectrum, resulting in low spectrum utilization. Due to this reason, such Static and Equal Spectrum Allocation (SESA) is no longer considered effective. Recently, Cognitive Radio (CR) has been considered an effective technology to address this issue. In CR, the spectrum is given access to the secondary User Equipment (UE) with the primary UE to use unused spectra of the primary UE opportunistically, resulting in improving spectrum utilization.

Several research studies have addressed the spectrum allocation problem in CR systems. For example, to address constraints with SESA, an underlay CR access technique in Saha [1] and an interweave shared-use model in Saha [2] have been presented to share the unused millimeter-wave (mmWave) spectrum of one MNO to another. However, both studies are limited by the assumption of a specific number of MNOs in a country. In this paper, we address this constraint by relaxing this assumption and present a Dynamic and Opportunistic Spectrum Access (DOSA) technique for an arbitrary number of MNOs to share the 28 GHz spectrum opportunistically with in-building Small Cells (SCs) of each Fifth-Generation (5G) New Radio (NR) MNO with that of other MNOs in a country.

The paper is organized as follows. In Section II, the system model, including the system architecture and the proposed DOSA technique, is presented. We formulate the problem in Section III. Section IV covers the performance results of the proposed technique where the Spectral Efficiency (SE) and Energy Efficiency (EE) performances are compared with that of the prospective Sixth-Generation (6G) mobile systems. We conclude the paper in Section V.

II. System Model

A. System Architecture

A system architecture consisting of an arbitrary O number of 5G NR MNOs in a country is considered. Each MNO comprises three Base Stations (BSs), including Macrocell BSs (MBSs), Picocell BSs (PBSs), and Small Cell BSs (SBSs). An SBS of each MNO is located in each apartment of any building, and each SBS can serve one Small Cell UE (SUE) at a time. SBSs operate in the 28 GHz, whereas MBSs and PBSs operate in the 2 GHz, bands. Assuming similar architecture of all MNOs, Figure 1 shows the system architecture of MNO 1.

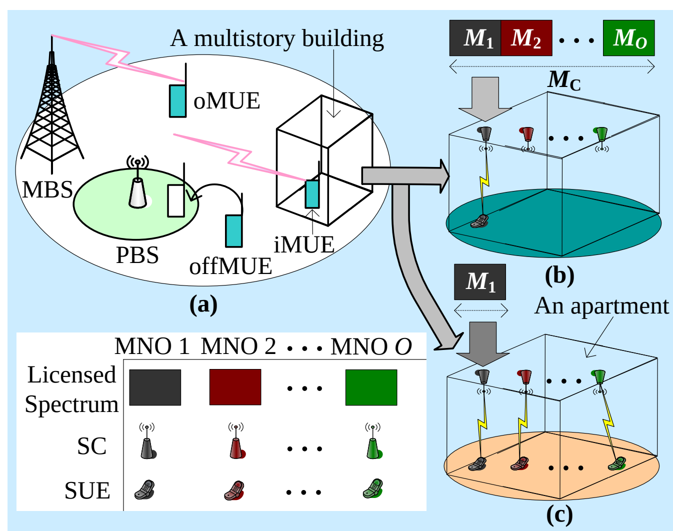

Figure 1. (a) System architecture of MNO 1 and SBSs of MNO 1 with the shared mmWave spectrum of other O-1 MNOs (b) maximum (c) none. oMUE, offMUE, and iMUE denote, respectively, outdoor, offloaded, and indoor macrocell UEs.

B. Proposed DOSA Technique

The proposed DOSA technique can be stated as follows. *Static allocation of an equal amount of mmWave spectrum to a*

5G NR MNO x in the primary level can be reallocated in the secondary level to SBSs of another MNO y in a building l as long as no UE of x exists within l to avoid Co-Channel Interference (CCI) between SBSs of x and y.

Let $\boldsymbol{O}$ denote a set of 5G NR MNOs in a country such that $o \in \{1, 2, ..., O\}$. Let each MNO is allocated to an equal amount of 28 GHz spectrum, denoted as M in Resource Blocks (RBs) where an RB=180 kHz. To analyze the performance, we consider that the occurrence (i.e., either presence or absence) of an SUE of each MNO within an apartment is equally likely over an observation period of $|\boldsymbol{T}| = Q$ such that any combination of the occurrence of SUEs of all MNOs happens with a probability of $Q/2^{O-1}$. The reallocated spectrum to an SUE of MNO o can be expressed as a set of $\{0, M, ..., (n \times M)\}$ with each component scaled by a Binomial coefficient $\mathbf{C}(n,k)$ of row $n = O-1$ of the left-justified Pascal's triangle [3] corresponding to $n \geq k \geq 0$. For example, the minimum reallocated spectrum of 0 and the maximum reallocated spectrum of $n \times M$ occur for an SUE of o, respectively, for no absence (Figure 1(c)) and no presence (Figure 1(b)) of SUEs of MNOs $\boldsymbol{O}\backslash o$ in an apartment of a building.

III. Problem Formulation

Let M_{C} denote the countrywide mmWave spectrum for all 5G NR MNOs. Let P_{MC}, P_{PC}, and P_{SC} denote the transmission power of an MBS, a PBS, and an SBS, respectively for each MNO o. Let each MNO has the same number of MBSs S_{M}, PBSs S_{P}, and SBSs S_{F} per building. By Shannon's formula, a link throughput at RB i in TTI t in bps per Hz is given by [4],

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

where β denotes implementation loss factor. Let M_o^{MC} in RBs denote the spectrum of an MBS of MNO o such that the average capacity of an MBS can be given as follows.

$$\sigma_o^{\mathrm{MC}} = \sum_{t \in \boldsymbol{T}} \sum_{i=1}^{M_o^{\mathrm{MC}}} \sigma_{o,t,i}\left(\rho_{o,t,i}\right) \quad (2)$$

where σ and ρ are responses of MNO o over M_o^{MC} RBs in $t \in \boldsymbol{T}$. For DOSA, the capacity of SBS s of MNO o is given by [5],

$$\sigma_{\mathrm{DOSA},o,s} = \sum_{t \in \boldsymbol{T}} \sum_{i=1}^{M} \sigma_{t,i,o}\left(\rho_{t,i,o}\right) + \sum_{k=1}^{O-1} \mathbf{C}(O-1,k)\left(\sum_{t=1}^{\left(Q/2^{O-1}\right)} \sum_{i=1}^{kM} \sigma_{k,t,i,o}\left(\rho_{k,t,i,o}\right)\right) \quad (3)$$

Assume that each building has similar indoor characteristics, so that by linear approximation, the countrywide average capacity, SE, and EE of MNOs O for L buildings of SBSs are given, respectively, by,

$$\sigma_{\mathrm{DOSA},O} = \sum_{o=1}^{O}\left(\sigma_o^{\mathrm{MC}} + L\sum_{s=1}^{S_{\mathrm{F}}} \sigma_{\mathrm{DOSA},o,s}\right) \quad (4)$$

$$\gamma_{\mathrm{DOSA},O} = \frac{\sigma_{\mathrm{DOSA},O}}{\left(\left(M_{\mathrm{C}} + \sum_{o=1}^{O} M_o^{\mathrm{MC}}\right) \times Q\right)} \quad (5)$$

$$\varepsilon_{\mathrm{DOSA},O} = \frac{O \times \left(L\, S_{\mathrm{F}} P_{\mathrm{SC}} + S_{\mathrm{P}} P_{\mathrm{PC}} + S_{\mathrm{M}} P_{\mathrm{MC}}\right)}{\left(\frac{\sigma_{\mathrm{DOSA},O}}{Q}\right)} \quad (6)$$

If DOSA is not employed, the system-level average capacity, SE, and EE of all MNOs for SESA are given, respectively, by,

$$\sigma_{\mathrm{SESA},O} = \sum_{o=1}^{O}\left(\sigma_o^{\mathrm{MC}} + L\sum_{s=1}^{S_{\mathrm{F}}} \sum_{t \in \boldsymbol{T}} \sum_{i=1}^{M} \sigma_{o,s,t,i}\left(\rho_{o,s,t,i}\right)\right) \quad (7)$$

$$\gamma_{\mathrm{SESA},O} = \frac{\sigma_{\mathrm{SESA},O}}{\left(\left(M_{\mathrm{C}} + \sum_{o=1}^{O} M_o^{\mathrm{MC}}\right) \times Q\right)} \quad (8)$$

$$\varepsilon_{\mathrm{SESA},O} = \frac{O \times \left(L\, S_{\mathrm{F}} P_{\mathrm{SC}} + S_{\mathrm{P}} P_{\mathrm{PC}} + S_{\mathrm{M}} P_{\mathrm{MC}}\right)}{\left(\frac{\sigma_{\mathrm{SESA},O}}{Q}\right)} \quad (9)$$

IV. Performance Result and Comparison

Selected parameters and assumptions are given in Table I. Detailed parameters and assumptions can be found in [1]-[2]. From Figure 2(a) for a single building of SBSs of all MNOs, it can be observed that the proposed DOSA can provide 2.5 times average capacity and SE as compared to that of the traditional SESA. The additional 1.5 times improvement in the performance of the capacity and SE comes from reallocating mutually the licensed mmWave spectrum of one NR MNO to another. Due to the same reason, DOSA improves EE by about 60% as compared to SESA.

TABLE I. DEFAULT PARAMETERS AND ASSUMPTIONS

Parameters and Assumptions	Value
Spectrum bandwidth per MNO	50 MHz (28GHz) and 10 MHz (2GHz)
Number of MNOs (O), Transmission direction	4, downlink
SBSs per building, UE per SBS	48, 1

Figures 2(b)-2(c) show SE and EE responses of DOSA and SESA techniques when reusing the same countrywide mmWave spectrum to more than one building of SBSs (i.e., L>1) located over the macrocell coverage. Note that SE increases linearly, whereas EE improves negative-exponentially, with an increase in L. This can be justified by the expressions of SE and EE in (8) and (9), respectively. Moreover, from Figures 2(b)-2(c), it can be found that the proposed DOSA technique outperforms SESA with a great margin in terms of SE and EE. Furthermore, it can be observed from Figures 2(b)-2(c) that the proposed DOSA technique can achieve both SE (10 times of 5G, i.e., 370 bps/Hz) and EE (10-100 times of 5G, i.e., 0.03µJ/bit) requirements ([6]-[9])

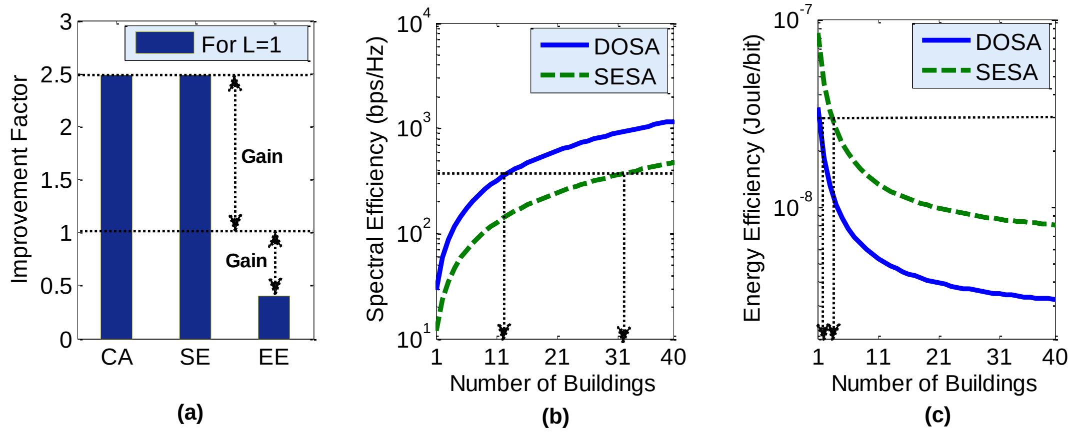

Figure 2. (a) Performance improvement factors, (b) SE, and (c) EE responses.

expected for the 6G mobile networks by reusing the countrywide mmWave spectrum for 46.87% less number of buildings of SBSs than that required by SESA.

V. Conclusion

A Dynamic and Opportunistic Spectrum Access (DOSA) technique has been presented to allow opportunistic and dynamic access to the static and equal licensed 28 GHz mmWave spectrum of one NR MNO to that of the other in a country to serve their in-building SCs. System-level Average Capacity (CA), Spectral Efficiency (SE), and Energy Efficiency (EE) performance metrics for an arbitrary number of NR MNOs are derived. For an example case of four NR MNOs, the outperformance of DOSA in CA, SE, EE, as well as satisfying both SE and EE requirements expected for the future 6G mobile networks, over that of SESA have been shown.

References

[1] R. K. Saha, "Underlay Cognitive Radio Millimeter-Wave Spectrum Access for In-Building Dense Small Cells in Multi-Operator Environments Toward 6G," Proc. 2020 23rd International Symposium on Wireless Personal Multimedia Communications (WPMC), Okayama, Japan, 2020, pp. 1-6, doi: 10.1109/WPMC50192.2020.9309471.

[2] R. K. Saha, "Interweave Shared-Use Model for Dynamic Spectrum Access in Millimeter-Wave Mobile Systems for 6G," Proc. 2020 IEEE 92nd Vehicular Technology Conference (VTC2020-Fall), Victoria, BC, Canada, 2020, pp. 1-6, doi: 10.1109/VTC2020-Fall49728.2020.9348671.

[3] G Kallós, "A Generalization of Pascal's Triangle using Powers of Base Numbers," Annales Mathematiques Blaise Pascal, vol. 13, pp. 1-15, 2006.

[4] J. Ellenbeck, J. Schmidt, U. Korger, and C. Hartmann, "A Concept for Efficient System-Level Simulations of OFDMA Systems with Proportional Fair Fast Scheduling," Proc. 2009 IEEE Globecom Workshops, Honolulu, HI, 2009, pp. 1-6, doi: 10.1109/GLOCOMW.2009.5360729.

[5] R. K. Saha, "Dynamic Allocation and Sharing of Millimeter-Wave Spectrum with Indoor Small Cells in Multi-Operator Environments Toward 6G" unpublished.

[6] Z. Zhang et al., "6G Wireless Networks: Vision, Requirements, Architecture, and Key Technologies," IEEE Vehicular Technology Magazine, vol. 14, pp. 28-41, 2019, doi: 10.1109/MVT.2019.2921208.

[7] S. Chen, Y. -C. Liang, S. Sun, S. Kang, W. Cheng, and M. Peng, "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, vol. 27, no. 2, pp. 218-228, April 2020, doi: 10.1109/MWC.001.1900333.

[8] C.-X. Wang et al., "Cellular Architecture and Key Technologies for 5G Wireless Communication Networks," IEEE Communications Magazine, vol. 52, no. 2, pp. 122-130, February 2014. doi: 10.1109/MCOM.2014.6736752.

[9] G. Auer et al., "How Much Energy is Needed to Run a Wireless Network?," IEEE Wireless Communications, vol. 18, no. 5, pp. 40-49, October 2011, doi: 10.1109/MWC.2011.6056691.

Copyright (c) IARIA, 2021. ISBN: 978-1-61208-878-5