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

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Resume of the Presenter

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

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

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

Topics of Research Interests

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

Presentation Outline

- Background and Problem Statement
- System Architecture
  - Proposed DOSA Technique
  - Problem Formulation
    - Performance Result and Comparison
    - Conclusion
      - References

Background and Problem Statement (1)

PROBLEM

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.

EFFECT

- 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**.

OVERCOME

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**.

Background and Problem Statement (2)

RELATED WORK

Several research studies have addressed the spectrum allocation problem in CR systems. 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.

LIMITATION

However, both studies are limited by the assumption of **a specific number of MNOs in a country**.

CONTRIBUTION

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.

System Architecture

- 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.

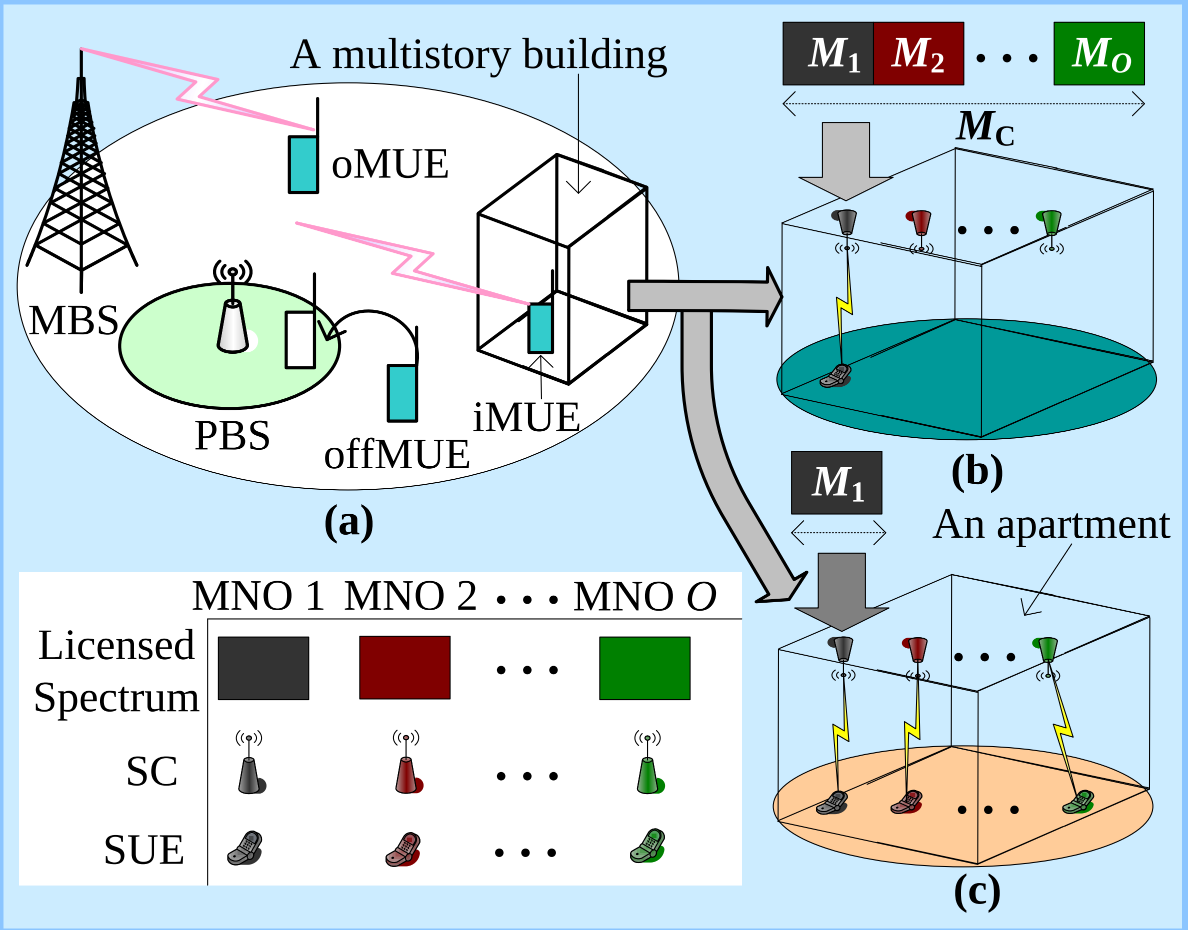

Figure 1. (a) System architecture of MNO 1 and SBSs of MNO 1 with the shared mmWave spectrum of other *O*-1 MNOs (b) maximum (c) none. oMUE, offMUE, and iMUE denote, respectively, outdoor, offloaded, and indoor macrocell UEs.

Proposed DOSA Technique

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 each MNO is allocated to an equal amount of 28 GHz, denoted as M in RBs where an RB=180 kHz.

Assume 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 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.

Problem Formulation

By Shannon's formula, a link throughput at RB i in TTI t in bps per Hz is given by [4],

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

The average capacity of an MBS

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

If **DOSA is employed** The capacity of SBS s of MNO o is given by [5],

$$\sigma_{\text{DOSA},o,s}=\sum_{t\in\boldsymbol{T}}\sum_{i=1}^{M}\sigma_{t,i,o}\left(\rho_{t,i,o}\right)+$$

$$\sum_{k=1}^{O-1}\mathbf{C}(O-1,k)\left(\sum_{t=1}^{\left(Q/2^{O-1}\right)}\sum_{i=1}^{kM}\sigma_{k,t,i,o}\left(\rho_{k,t,i,o}\right)\right)$$

Let each building has similar indoor characteristics, the countrywide average capacity, SE, and EE of MNOs O for L buildings are given, respectively, by,

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

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

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

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

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

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

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

Performance Result and Comparison

From Figure 2(a) **for *L*=1**:

- 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.

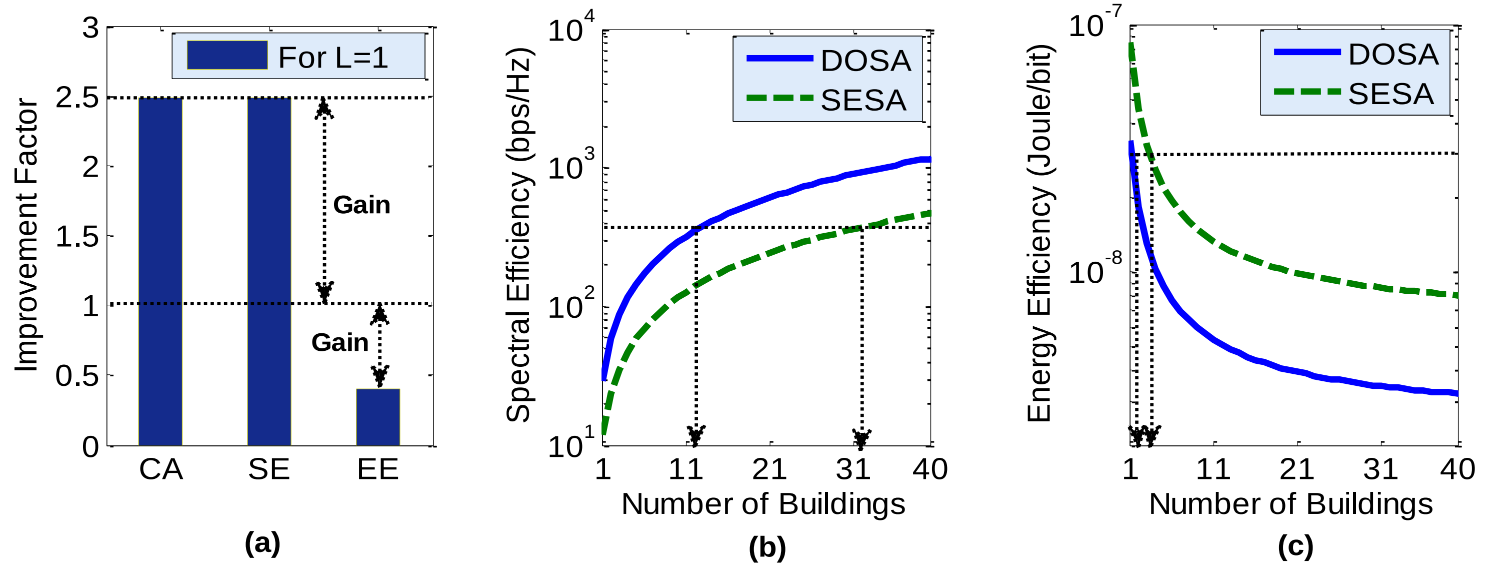

Figure 2. (a) Performance improvement factors, (b) SE, and (c) EE responses.

From Figures 2(b)-2(c) **for *L*>1**:

- SE increases linearly, whereas EE improves negative-exponentially, with an increase in *L*.
- DOSA technique **outperforms SESA** with a great margin in terms of SE and EE.

- 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]) **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.

Conclusion

We have presented a Dynamic and Opportunistic Spectrum Access (DOSA) technique 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.

We have then **derived** system-level Average Capacity (CA), Spectral Efficiency (SE), and Energy Efficiency (EE) performance metrics for an arbitrary number of NR MNOs.

Finally, we have **shown**, for an example case of four NR MNOs, **the outperformance of DOSA** in CA, SE, EE, as well as the **fulfilment** of both SE and EE requirements expected for the future 6G mobile networks, over that of SESA.

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End of the Presentation

Thank You …