A New Paradigm for Spectrum Allocation in Millimeter-Wave Systems

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Presented by
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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 50 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
- 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

- Problem Statement
- Scope
  - Proposed Technique
  - Major Concern and Possible Solution
    - Performance Evaluation
    - Conclusion
      - References

Problem Statement

Low spectrum utilization

- The **number of users** of one MNO differs from another and so does their required spectrum.
  - This causes an MNO with **more users to experience insufficiency** of spectrum, whereas the other with **fewer users to make wastage** of spectrum.
- Irrespective of the number of users of each MNO, the user traffic demand of one MNO varies much from another in **time and space.**

Scarcity of spectrum

- **Disproportionate** increase in the demand of mobile users (in terms of data rate and volume) and the available spectrum to serve these user demands allocated to an MNO.
- How the spectrum specified for a country is **allocated** to its MNOs.

Traditionally, a **portion** of the countrywide spectrum is allocated to each MNO exclusively in an equal amount and a static manner.

A significant amount of its spectrum may be either **unused or underutilized**.

Problem Statement

Such a **static and dedicated allocation of a portion** of the full spectrum specified for a country to each MNO is **no longer considered**

- **sufficient** to address its ever-increasing user demands, as well as
- **efficient** to utilize the allocated spectrum,

particularly in urban multistory buildings as most data is generated in such indoor environments.

Numerous approaches namely **spectrum aggregation, trading, sharing, and reusing** have been proposed in literature to increase the amount, as well as the utilization, of the spectrum.

But, above approaches **can be avoided** if

Countrywide full-spectrum is made available to each MNO unlike a portion in the static spectrum allocation

- to ensure large spectrum availability, as well as efficient utilization of the allocated spectrum,
- to serve a large volume of indoor data at high rates for the existing and upcoming mobile networks.

Scope

In addressing so, we

- **propose a new technique** for allocating the countrywide full millimeter-wave spectrum,
- **present major concerns** (e.g., co-channel interference) and **possible solutions** of the proposed technique, and
- **evaluate the performance** of the proposed technique with respect to the traditional static spectrum allocation technique.

Proposed Technique

We present a new idea for the millimeter-wave spectrum allocation called **countrywide full spectrum allocation (CFSA)** stated as follows.

Each MNO *of a country is allocated dynamically to the* ***full millimeter-wave spectrum*** *specified for the country to operate its in-building small cells subject to managing Co-Channel Interference (CCI) for a certain renewed-term* t_r*. The spectrum licensing fee for each MNO is updated in accordance with the number of its subscribers at each term.*

- ensures the **availability of a large amount of spectrum** by allocating the countrywide **full** (instead of a portion) millimeter-wave spectrum, whereas
- an **efficient spectrum utilization** by allowing **dynamic and flexible** (instead of static and dedicated) access to each MNO.
- Moreover, unlike bound to pay for the unused spectrum for an MNO with fewer users, an MNO can pay only for the amount of spectrum that it uses to serve user demands at t_r, resulting in **reducing the cost per unit capacity** (i.e., bps).

Major Concern and Possible Solution

CCI may generate when in-building small cells of more than one MNO attempt to access the same spectrum simultaneously.

CCI can be managed either in

- **Time**-domain,
- **Frequency**-domain, or
- **Power**-domain.

- In **time-and frequency-domain**, CCI can be avoided **(Fig.1(b))** by allocating small cells of different MNOs in a **different time** (e.g., a transmission time interval of 1 ms) and **frequency** (e.g., a resource block of 180 kHz) of the spectrum respectively

using techniques, such as time-domain and frequency-domain Enhanced Intercell Interference Coordination (**eICIC**).

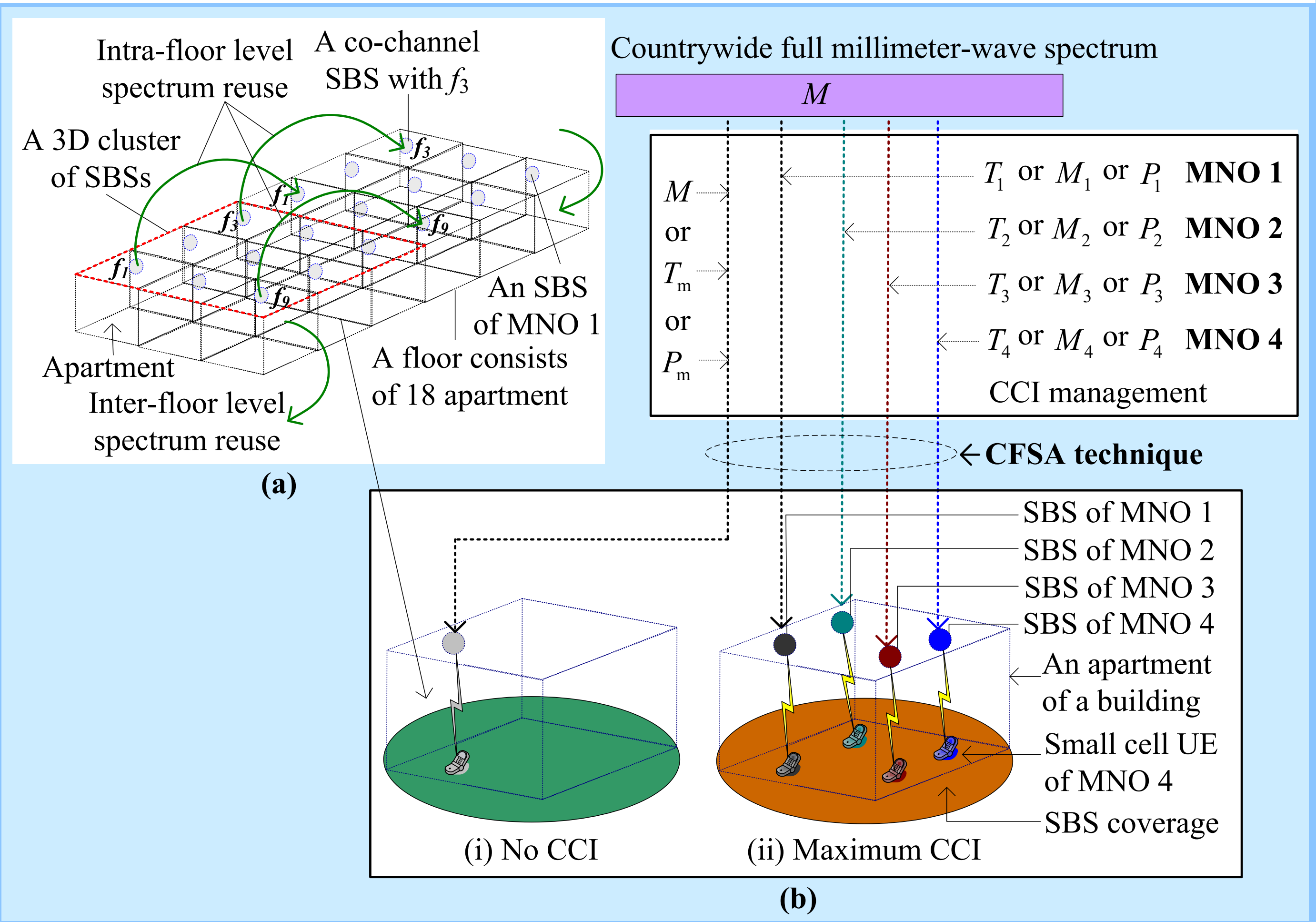

Figure 1. (a) A floor of a multistory building for 3D clustering of SBSs, (b) Illustration of the proposed CFSA technique.

Major Concern and Possible Solution

Since each MNO pays the spectrum licensing fee based on its number of subscribers, the **optimal value** of **time and frequency** for an SBS of an MNO *o* to serve its user traffic can be derived as the **ratio** of the number of of subscribers an MNO *o* to the sum of the total number of subscribers of MNOs $\boldsymbol{O}\backslash o$.

For example, in **time-domain eI**CIC, the number of transmission time intervals (TTIs) for an MNO at any Almost Blank Subframe (ABS) Pattern Period (APP) in TTIs is given by,

$$T_o = \left\lceil \left(\left(N_o \Big/ \sum_{o=1}^{O} \left(1_{\varphi_o}(N_o) \times N_o \right) \right) \times T_A \right) \right\rceil \qquad (1)$$

Following (1), we can find the **amount of spectrum** for MNO *o* in a TTI in **frequency-domain eICIC**.

In **power domain** (Fig.1(b)), using cognitive radio access, e.g.,

using **interweave spectrum access**, an SBS of an MNO *o* can be allowed to serve its user traffic **at the maximum power** so long as no UE of other MNOs $\boldsymbol{O}\backslash o$ exists in the same apartment.

Likewise, using **underlay spectrum access**, an SBS of an MNO *o* can transmit simultaneously on the full spectrum **by reducing its transmission power** if a UE of other MNOs $\boldsymbol{O}\backslash o$ exists in the same apartment as that of an SBS of MNO *o*.

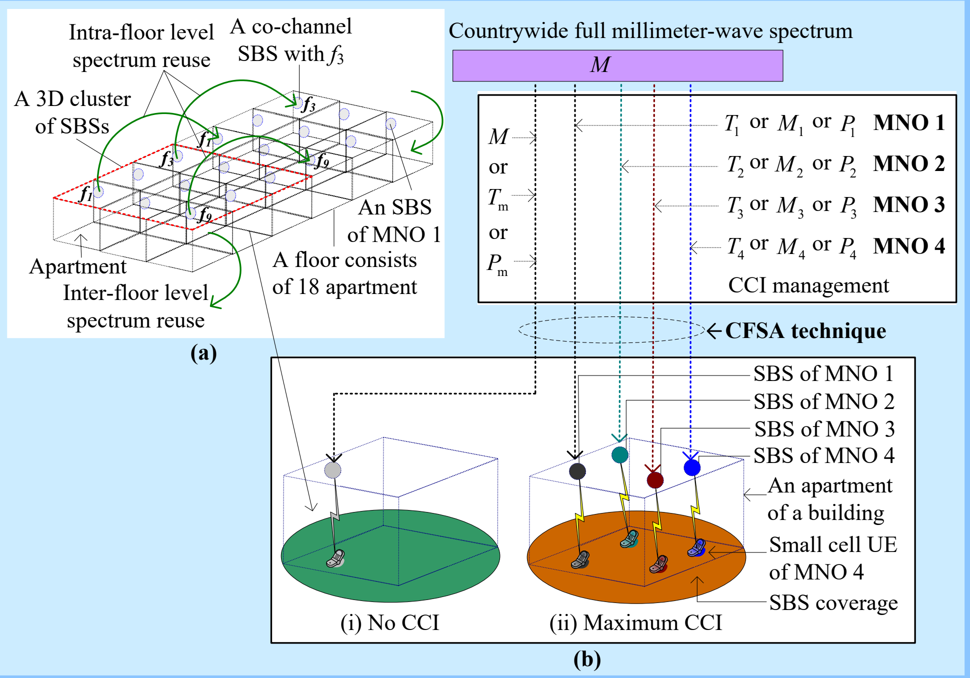

Figure 1. (a) A floor of a multistory building for 3D clustering of SBSs, (b) Illustration of the proposed CFSA technique.

Major Concern and Possible Solution

Hence, using a **hybrid interweave-underlay spectrum access**, CCI can be managed as follows.

$$P_o = \begin{cases} P_{\max}, & \text{for Interweave (if no UE of MNOs } \boldsymbol{O} \setminus o \text{ exists)} \\ P_{\text{red}}, & \text{for underlay (if a UE of MNOs } \boldsymbol{O} \setminus o \text{ exists)} \end{cases} \quad (2)$$

By exploiting the **spatial domain**, the countrywide full spectrum can be reused to in-building SBSs of an MNO o to increase the achievable capacity and spectrum utilization even further.

For example, by forming a **3-Dimensional (3D) cluster of SBSs** in a building of an MNO o subject to satisfying a minimum CCI threshold both in the intra-floor, as well as inter-floor, levels, the **same spectrum can be reused to each 3D cluster** as shown in **Fig.1(a)**.

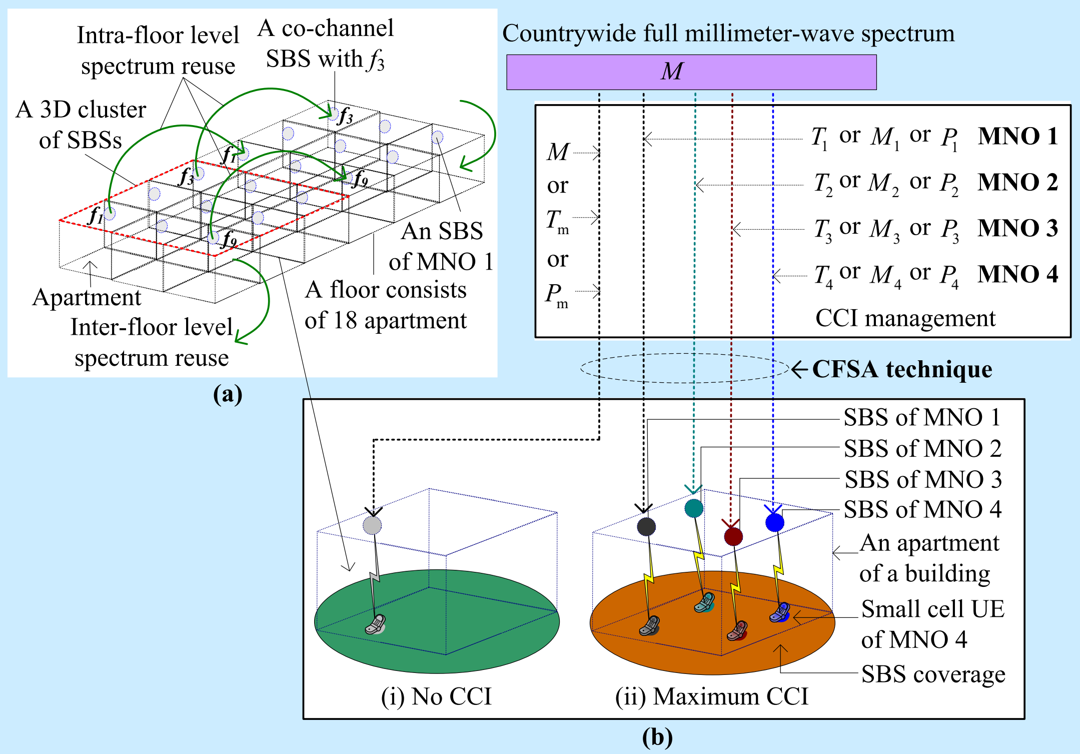

Figure 1. (a) A floor of a multistory building for 3D clustering of SBSs, (b) Illustration of the proposed CFSA technique.

Performance Evaluation

Example Problem

- Four MNOs are operating in a country such that with a subscriber base of 40%, 30%, 20%, and 10%, respectively of the total number of subscribers countrywide at t_r.
- Let M=200 MHz denote the countrywide full millimeter-wave spectrum, which is allocated to each MNO based on its aforementioned subscriber base.
- Considering applying the frequency-domain CCI avoidance, the spectra allocated to MNOs 1, 2, 3, and 4 are given respectively by 80 MHz, 60 MHz, 40 MHz, and 20 MHz.
- Assume that the millimeter-wave link quality of each UE is given by 3 bps/Hz.
- Consider that the total observation time T_m=8 TTIs where each TTI equals to 1 ms

Solution

- Now, using Shannon's capacity formula, the **capacity** and **Spectral Efficiency** (SE) of MNO 1 **when UEs of all MNOs** $\boldsymbol{O \backslash o=1}$ are present with a small cell in each apartment of MNO 1 are given by **1.728 Gbps and 3 bps/Hz**.
- Capacity and SE of MNO 1 are given by **4.32 Gbps** and **7.5 bps**/Hz, when **no UE** of MNOs $\boldsymbol{O}\backslash o=1$ is present.
- However, when applying the **Static Spectrum Allocation** (TSSA) technique, by assuming that each MNO is allocated to an equal amount of 50 MHz spectrum, the capacity and SE are given by **1.08 Gbps** and **3 bps/Hz**, respectively.

Findings

- These show **an outperformance in capacity and SE** of
  - 60% and 0% for the **maximum CCI**, and 300% and 150% for **no CCI** of CFSA over TSSA.
- Hence, CFSA improves the **capacity ranging from 60% to 300%,** whereas **the SE ranging from 0% to 150%**, over TSSA.
- Also, for **20** 3D clusters per building, the above capacity and SE are also increased by 20 times.

Conclusion

In this paper, we have presented **an idea of allocating a countrywide full millimeter-wave spectrum to each MNO** to increase the spectrum availability and utilization.

We have broadly detailed the proposed technique and **shown its outperformance in terms of capacity and spectral efficiency** over the traditional static spectrum allocation technique.

References

1. G. Yuan, X. Zhang, W. Wang, and Y. Yang, "Carrier Aggregation for LTE-Advanced Mobile Communication Systems," IEEE Communications Magazine, vol. 48, pp. 88-93, Feb. 2010, doi: 10.1109/MCOM.2010.5402669.
2. C. M. Park, H. B. Jung, S. H. Kim, and D. K. Kim, "System level performance evaluation of various carrier aggregation scenarios in LTE-advanced," Proc. The 2013 15th International Conference on Advanced Communications Technology (ICACT), IEEE Press, Jan. 2013, pp. 814-817.
3. Y. Xing, R. Chandramouli, and C. M. Cordeiro, "Price Dynamics in Competitive Agile Spectrum Access Markets," IEEE Journal on Selected Areas in Communications, vol. 25, pp. 613-621, Apr. 2007, doi: 10.1109/JSAC.2007.070411.
4. D. Niyato, E. Hossain, and Z. Han, "Dynamics of Multiple-Seller and Multiple-Buyer Spectrum Trading in Cognitive Radio Networks: A Game Theoretic Modeling Approach," IEEE Transactions on Mobile Computing, vol. 8, pp. 1009-1022, Aug. 2009, doi: 10.1109/TMC.2008.157.
5. R. K. Saha, "A Technique for Massive Spectrum Sharing with Ultra-Dense in-Building Small Cells in 5G Era," Proc. The 2019 IEEE 90th Vehicular Technology Conference (VTC2019-Fall), IEEE Press, Sept. 2019, pp. 1-7, doi: 10.1109/VTCFall.2019.8891437.
6. M. L. Attiah, A. A. M. Isa, Z. Zakaria, *et al.,* "A Survey of mmWave User Association Mechanisms and Spectrum Sharing Approaches: An Overview, Open Issues and Challenges, Future Research Trends," Wireless Networks, vol. 26, pp. 2487-2514, May 2020, doi.org/10.1007/s11276-019-01976-x.
7. S. K. Joshi, K. B. S. Manosha, M. Codreanu, and M. Latva-aho, "Dynamic Inter-Operator Spectrum Sharing via Lyapunov Optimization," IEEE Transactions on Wireless Communications, vol. 16, pp. 6365-6381, Oct. 2017, doi: 10.1109/TWC.2017.2722999.
8. R. K. Saha, "Modeling Interference to Reuse Millimeter-Wave Spectrum to In-Building Small Cells Toward 6G," (accepted) Proc. The 2020 IEEE 92nd Vehicular Technology Conference (VTC2020-Fall), IEEE Press, Oct. 2020, pp. 1-6.
9. R. K. Saha, "3D Spatial Reuse of Multi-Millimeter-Wave Spectra by Ultra-Dense In-Building Small Cells for Spectral and Energy Efficiencies of Future 6G Mobile Networks," Energies, vol. 13, Art. No. 1748, 2020, doi.org/10.3390/en13071748.

End of the Presentation

Thank You …