On Evaluating Spectrum Allocation Techniques in Millimeter-Wave Systems using Indoor Smalls for 5G/6G

Rony Kumer Saha

Presented by
Rony Kumer Saha, Ph.D.
Radio and Spectrum Laboratory
KDDI Research, Inc. JAPAN
2-1-15 Ohara, Fujimino-shi, Saitama, 356-8502
Email: ro-saha@kddi-research.jp

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 and Mathematical Analysis
  - Problem Formulation
  - Performance Evaluation
    - Conclusion
    - References

Problem Statement

Spectrum allocations have a significant impact on the **efficient utilization** of radio spectrum.

SESA: Traditionally, each MNO in a country is allocated statically and exclusively to **an equal amount of the licensed spectrum,** termed as **Static and Equal Spectrum Allocation (SESA)**, for a long term, irrespective of the demand of its users.

However, **SESA suffers** from a **low spectrum utilization** since

- a great portion of the allocated spectrum to an MNO may be either **unused or underutilize**d,
- while the other MNO **suffers from an insufficient** amount of spectrum,

due to the variation in user demands of MNOs with time and locations.

This raises concerns over **how to allocate the spectrum among MNOs** such that required **user demand can be served** while ensuring an **efficient countrywide spectrum utilization**.

- One way to address is to **allocate spectrum flexibly** to an MNO **in accordance with its number of subscribers**.

- **FUSA**: Since the number of subscribers of an MNO is usually **different** from that of others, such a flexible and on-demand spectrum allocation technique allocates an unequal amount of spectrum to MNOs, termed as **Flexible and Unequal Spectrum Allocation** (FUSA).

Problem Statement

- **CFSA: Another** key technique is to **allow access to the countrywide full spectrum to each MNO** subject to managing Co-Channel Interference (CCI) from one MNO to another, termed as **Countrywide Full Spectrum Allocation** (CFSA).
- CFSA takes advantage of **allocating a large amount of spectrum** to each MNO to address the required QoS, as well as the **dynamic allocation of the spectrum** to each MNO.

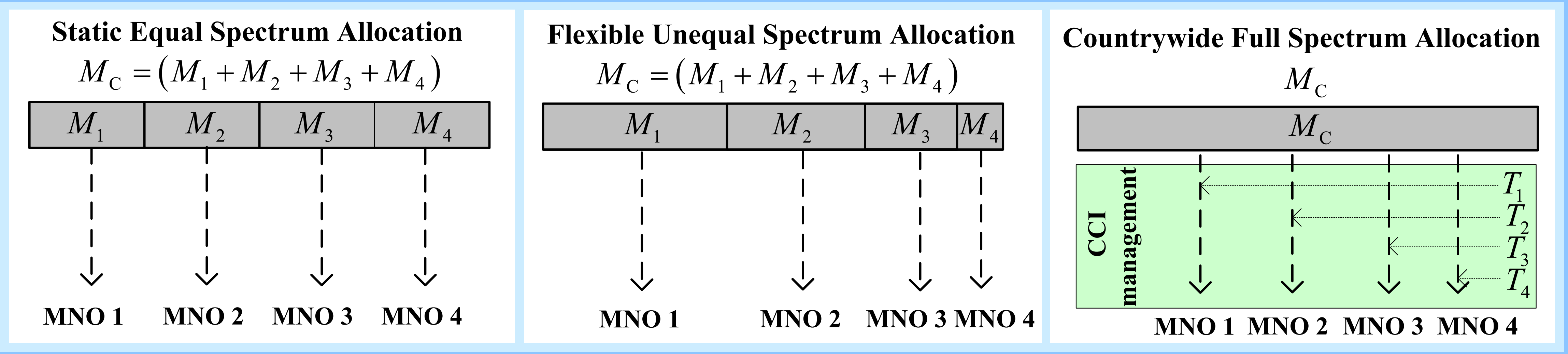

Figure 1. An illustration of SESA, FUSA, and CFSA techniques at any term t_r.

- To address the high bandwidth availability for an MNO indoors, the **28 GHz band has been considered as a potential mmWave band** due to its favorable indoor characteristics to address a high data rate and capacity demand within a short distance.

Scope and Mathematical Analysis

Hence, we intend to evaluate **SESA, FUSA, and CFSA techniques indoors** for 28 GHz spectrum in terms of Spectral Efficiency (SE), Energy Efficiency (EE), and Cost Efficiency (CE).

The amount of allocated spectrum to an MNO o in **SESA** at any term

$$M_{o,t_{\mathrm{r}}} = M : o \in \boldsymbol{O}$$

The amount of allocated spectrum to an MNO o in FUSA at term

$$M_{o,t_{\mathrm{r}}} = \left(N_{o,t_{\mathrm{r}}} \times M_{\mathrm{C}} \right) / N_{\mathrm{C}} : o \in \boldsymbol{O}$$

In CFSA, the amount of spectrum allowed to access by each MNO

$$M_{o,t_{\mathrm{r}}} = M_{\mathrm{C}} : t \in \boldsymbol{T}^{\mathrm{nA}}_{\boldsymbol{o},\boldsymbol{t}_{\mathrm{r}}} \wedge o \in \boldsymbol{O}$$

The number of non-ABSs to use the full countrywide spectrum using **CFSA**

$$T^{\mathrm{nA}}_{o,t_{\mathrm{r}}} = \left\lceil \left(\left(N_{o,t_{\mathrm{r}}} \Big/ \sum_{o=1}^{O} \left(1_{\mathrm{v}_o} \left(N_{o,t_{\mathrm{r}}} \right) N_{o,t_{\mathrm{r}}} \right) \right) \times T_{\mathrm{APP}} \right) \right\rceil$$

To avoid CCI in time-domain for CFSA, we consider **time orthogonality** in allocating the full spectrum to small cell User Equipments (UEs) of all MNOs such that in any TTI t Small cell UEs (SUs) of **only one MNO in a building can be scheduled using techniques**, such as the Almost Blank Subframe (ABS) based Enhanced Intercell Interference Coordination (eICIC).

Problem Formulation

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

For outdoor macrocell UEs

$$\sigma_{\text{MBS},o}^{t_r}=\sum_{t=1}^{Q}\sum_{i=1}^{M_{\text{MBS},o}}\sigma_{t,i,o}^{t_r}\left(\rho_{t,i,o}^{t_r}\right)$$

$$\sigma_{S_F,o}^{t_r}=\sum_{s=1}^{S_F}\sum_{t}\sum_{i=1}^{M_{o,t_r}}\sigma_{t,i,o}^{t_r}\left(\rho_{t,i,o}^{t_r}\right)$$

Define Cost Efficiency (CE) as the cost required per unit achievable average capacity (i.e., per bps)

System-level average aggregate capacity, SE, EE, and CE for all MNOs

$$\sigma_{\text{cap},O}^{\text{sys},t_r}=\sum_{o=1}^{O}\left(\sigma_{\text{MBS},o}^{t_r}+\sigma_{S_F,o}^{t_r}\right)$$

$$\sigma_{\text{SE},O}^{\text{sys},t_r}=\sigma_{\text{cap},O}^{\text{sys},t_r}\Big/\left(\sum_{o=1}^{O}\left(M_{\text{MBS},o}+M_{o,t_r}\right)\times Q\right)$$

$$\sigma_{\text{EE},O}^{\text{sys},t_r}=\left(O\left(S_F P_S+S_P P_P+S_M P_M\right)\right)\Big/\left(\sigma_{\text{cap},O}^{\text{sys},t_r}/Q\right)$$

$$\varsigma_{\text{CE},O}^{\text{sys},t_r}=\varepsilon_C\Big/\sigma_{\text{cap},O}^{\text{sys},t_r}$$

where

$$t\in\begin{cases}\boldsymbol{T}, & \text{for SESA}\\ \boldsymbol{T}, & \text{for FUSA}\\ \boldsymbol{T}_{o,t_r}^{\text{nA}}, & \text{for CFSA}\end{cases}$$

$$M_{o,t_r}=\begin{cases}M, & \text{for SESA}\\ \left(N_{o,t_r}M_C\right)/N_C, & \text{for FUSA}\\ M_C, & \text{for CFSA}\end{cases}$$

Performance Evaluation

Performance Results

From Figure 2, It can be found that

FUSA improves SE by 22.8%, EE by 18.56%, and CE by 18.56%, whereas

CFSA improves SE by 164.27%, EE by 74.77%, and CE by 59.64% in comparison with that of SESA.

Hence, **CFSA provides the best** SE, EE, and CE performances of all techniques.

Table I. Default Parameters and Assumptions

Parameters and assumptions	Value
Countrywide 28 GHz spectrum, MNOs, and subscribers	200 MHz; 4; N_C
Number of subscribers for MNOs 1, 2, 3, and 4	20%, 30%, 20% and 10% of N_C
E-UTRA simulation case	3GPP case 3
Small cell model	A building with square-grid apartments
Number of small cells	48
Observation time	8 ms

Issues with CFSA implementation

- CCI Management Systems
- Countrywide Spectrum Manager
- Spectrum Licensing Fees

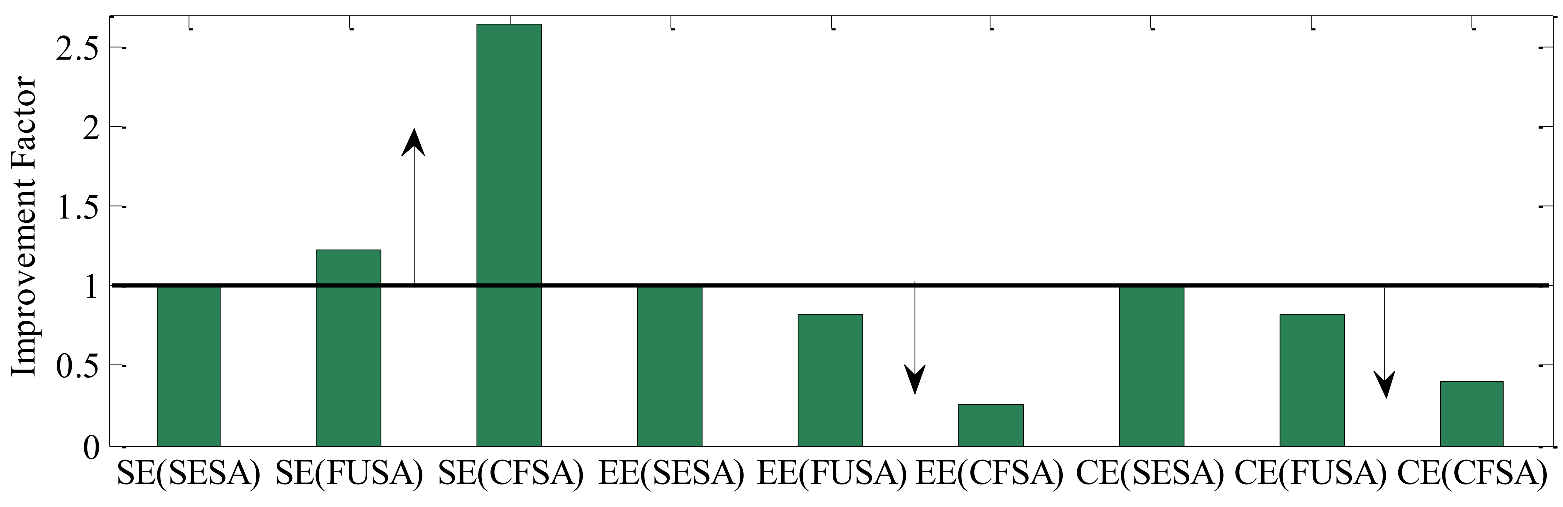

Figure 2. Performances of FUSA and CFSA with respect to SESA.

Conclusion

- We have presented **three spectrum allocation techniques**, namely SESA, FUSA, and CFSA, and

- shown that CFSA **outperforms** SESA and FUSA techniques in SE, EE, and CE such that

- **CFSA can be considered as a potential spectrum allocation** technique for Fifth Generation (5G)/Sixth Generation (6G) mobile networks.

References

1. S. J. Kim, E. C. Kim, S. Park, and J. Y. Kim, "Dynamic Spectrum Allocation with Variable Bandwidth for Cognitive Radio Systems," Proc. The 2009 9th International Symposium on Communications and Information Technology, IEEE Press, Sept. 2009, pp. 106-109, doi: 10.1109/ISCIT.2009.5341278.
2. R. K. Saha, "On Exploiting Millimeter-Wave Spectrum Trading in Countrywide Mobile Network Operators for High Spectral and Energy Efficiencies in 5G/6G Era," Sensors, vol. 20, Art. No. 3495, 2020, doi.org/10.3390/s20123495.
3. R. K. Saha, "A Countrywide Licensed Full Spectrum Allocation Method for Millimeter-Wave Mobile Systems for 6G," (accepted) Proc. The 2020 IEEE 92nd Vehicular Technology Conference (VTC2020-Fall) Workshops, IEEE Press, Oct. 2020, pp. 1-7.

End of the Presentation

Thank You …