Dynamic Spectrum Sharing in Multi-Operator Millimeter-Wave Indoor 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 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
- Contribution
  - System Architecture
  - Proposed DSS Technique
    - Problem Formulation
    - Performance Evaluation and Comparison
      - Conclusion
      - References

Background and Problem Statement (1)

PROBLEM → Serving **high capacity and data rates with limited spectrum bandwidth** allocated to a Mobile Network Operator (MNO) has become a major issue for the Fifth-Generation (5G) and beyond mobile systems.

OVERCOME → An effective approach to overcome these issues is to allow each MNO to access the **Countrywide Full-Spectrum** (**CFS**).

EFFECT → Each MNO causes **Co-Channel Interference** (CCI), which can be managed in the Power-Domain (PD).

RELATED WORK →

- The concept of **CFS** allocation and sharing is not obvious
- Saha [1] proposed a hybrid interweave-underlay CFS allocation in the 28 GHz band by managing CCI in the **PD**.
- CFS allocation in the 28 GHz has been investigated later in Saha [2] by managing CCI in the **time-and frequency-domain**.

Background and Problem Statement (2)

LIMITATION ➔ In both studies, the analyses were **limited to a specific number of MNOs** in a country.

CONTRIBUTION ➔ In this paper, we **relax the assumptions** in Saha [1] and Saha [2] and present a Dynamic Spectrum Sharing (DSS) technique for **an arbitrary number of MNOs** in a country.

NOVELTY/ DIFFERENCE ➔

- Unlike the traditional DSS techniques where **each MNO is allocated to a portion of the countrywide full spectra** and shares its spectrum dynamically with other MNOs countrywide,
- The proposed DSS technique allows access to the **countrywide full 28 GHz spectrum** to each MNO dynamically to **serve its in-building Small Cells (SCs)** by controlling the transmission power of SCs within each building using **the Equal Likelihood Criterion and the properties of left-justified Pascal's triangle.**

Contribution

- We **present** a **Dynamic Spectrum Sharing (DSS)** technique, which allows dynamic access to the countrywide full 28 GHz mmWave spectrum to **an arbitrary number of MNOs** to serve their respective in-building Small Cells (SCs).
- **Co-Channel Interference (CCI)** is managed by controlling the transmission power of in-building SCs of each MNO.
- Using **the Equal Likelihood Criterion** and the **properties of left-justified Pascal's triangle**, we **derive** the system-level average capacity, Spectral Efficiency (SE), and Energy Efficiency (EE) performance metrics.
- It is shown that the **proposed DSS can improve SE and** EE over that of the Static Equal Spectrum Allocation (SESA).
- Moreover, we show that the **proposed DSS requires** the **reuse of the countrywide mmWave spectrum to 71.87%** fewer buildings of SCs than that required by the SESA to satisfy the expected SE and EE requirements **for the Sixth-Generation (6G) mobile systems**.

System Architecture

- The system architecture consists of an arbitrary number of O MNOs in a country, which is shown in **Figure 1(a)** for O=4.
- Considering a similar architectural feature for each MNO, only one MNO (e.g., MNO 1) is shown in detail in **Figure 1(c).**
- Small Cells (SCs) operate at the 28 GHz indoors
- **Figure 1(b)** shows the transmission power levels of an SC to manage CCI for O=4.

Let P_{m} and P_{r} denote, respectively, the maximum and the reduced transmission powers of an SC of MNO o.

Let $\alpha_1, \alpha_2, \ldots \alpha_{(|O|-1)}$ denote scaling factors such that $\alpha_1 > \alpha_2 > \cdots > \alpha_{(|O|-1)}$

To satisfy the condition that the **aggregate interference power does not exceed the interference threshold to share simultaneously by SCs of all MNOs** in an apartment, **the following must hold.**

$$\sum_{x=1}^{(|O|-1)} (\alpha_x \times P_{\mathrm{m}}) \leq I_{\mathrm{m}}$$

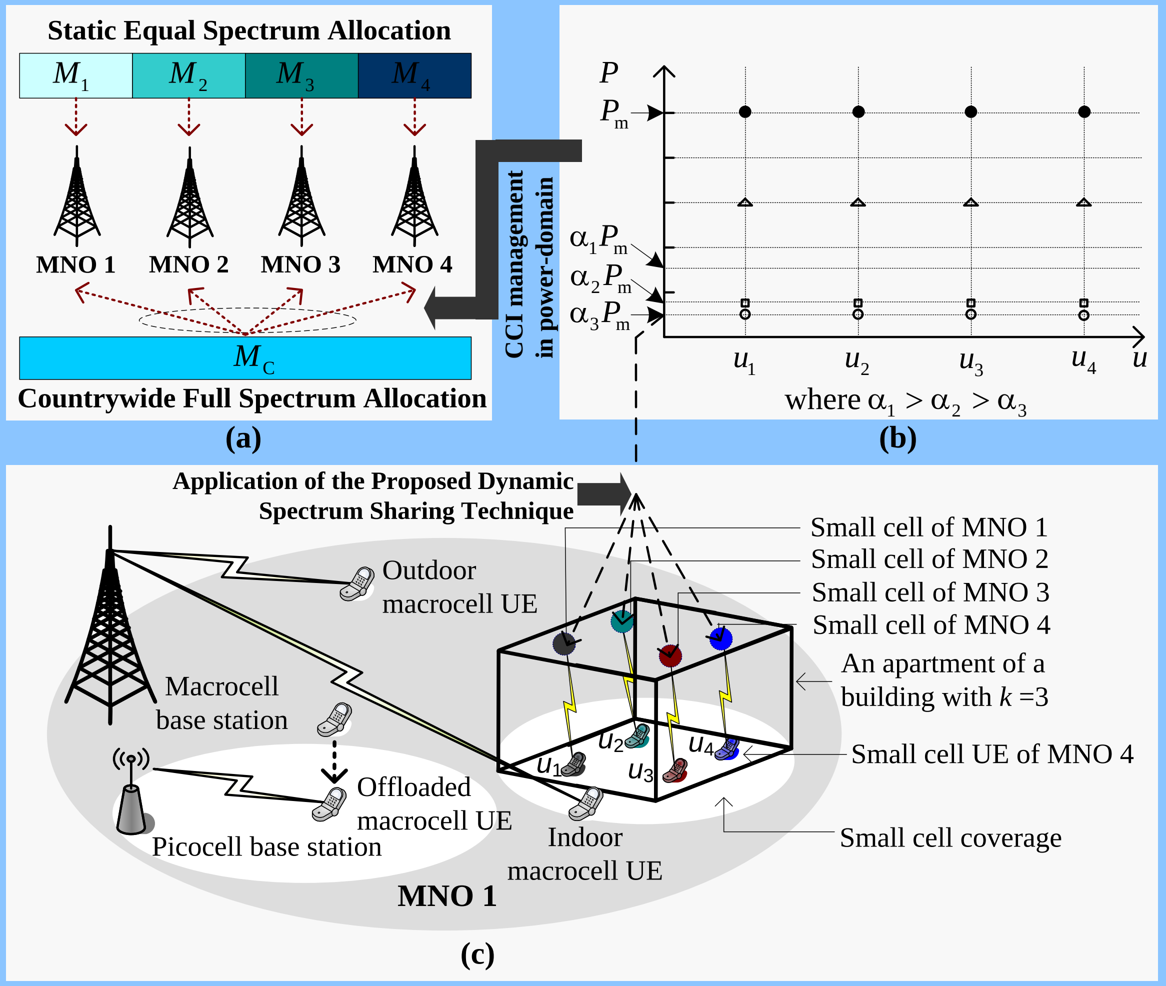

Figure 1. (a) Static Equal Spectrum Allocation (SESA) and CFS allocation. (b) Transmission power levels of an SC to manage CCI. (c) System architecture with 4 MNOs in a country.

Proposed DSS Technique

The proposed **Dynamic Spectrum Sharing (DSS)** technique is stated as follows:

An MNO *o* can be allocated to the CFS dynamically to operate its in-building SCs, subjected to managing CCI with SCs of other MNOs ***O****o* over a certain license renewal term

CCI is managed in the PD by controlling the transmission power of each SC using the following principle.

An **SC of MNO *o* operates**:

- at the maximum transmission power if no SC User Equipment (UE) of MNOs ***O****o* is present,
- while at reduced power if an SUE of MNO ***O****o* is present,

within the corresponding SC coverage of MNO *o* in a building.

The reduced power is subjected to satisfying the **maximum allowable CCI** at the SC of MNO *o*.

$$\sum_{x=1}^{(|\boldsymbol{O}|-1)} (\alpha_x \times P_{\mathrm{m}}) \leq I_{\mathrm{m}}$$

Problem Formulation (1)

Consider that each SC can serve one SUE at a time, and each combination of the coexistence of SUEs of MNOs $\boldsymbol{O}\backslash o$ (one UE from each MNO) with a UE of MNO o in an apartment is equally likely over any observation time $|\boldsymbol{T}| = Q$ and hence occurs with a probability of $\left(Q/2^{O-1}\right)$

Let k be a set of positive integers (representing the number of iSUEs of MNOs $\boldsymbol{O}\backslash o$ in an apartment) such that $0 \le k \le \left(|\boldsymbol{O}|-1\right)$

The duration of an SC of MNO o corresponding to k can be defined using Pascal's triangle as follows

$$t_{o,k} = \mathbf{C}\left(O-1, k\right)\left(Q/2^{O-1}\right)$$

Let $\boldsymbol{U}_o$ denote a set of iSUEs of MNOs $\boldsymbol{O}\backslash o$ for an SC of o

P_{r} can be adjusted as follows.

$$P_{\mathrm{r}} = \begin{cases} \alpha_1 P_{\mathrm{m}}, & \text{for } |\boldsymbol{U}_o| = 1 \\ \vdots & \vdots \\ \alpha_{(|\boldsymbol{O}|-1)} P_{\mathrm{m}}, & \text{for } |\boldsymbol{U}_o| = \left(|\boldsymbol{O}|-1\right) \end{cases}$$

Using Shannon's capacity formula, a link throughput at RB=i in TTI=t for an MNO o in bps per Hz is given by

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

The average capacity of an MC of MNO o can be given as

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

Problem Formulation (2)

Consider that each building has similar indoor signal propagation characteristics. Then, by linear approximation, the average capacity, Spectral Efficiency (SE), and Energy Efficiency (EE) of all MNOs for the proposed DSS, as well as SESA techniques can be given as follows where for SESA, each MNO is allocated to an equal amount of spectrum of *M* RBs.

For the proposed DSS

$$\sigma_{\mathrm{DSS}}^{\mathrm{CA}} = \sum_{o=1}^{O}\left(\sigma_{o}^{\mathrm{MC}} + \left(\sum_{l=1}^{L}\sum_{s=1}^{S_{\mathrm{F}}}\sum_{k=0}^{O-1}\left(\sum_{t=1}^{\mathbf{C}(O-1,k)\left(\frac{Q}{2^{O-1}}\right)}\sum_{i=1}^{M_{\mathrm{C}}}\sigma_{o,k,t,i}\left(\rho_{o,k,t,i}\right)\right)\right)\right)$$

$$\sigma_{\mathrm{DSS}}^{\mathrm{SE}} = \sigma_{\mathrm{DSS}}^{\mathrm{CA}} \Big/ \left(\left(M_{\mathrm{C}} + \sum_{o=1}^{O} M_{o}^{\mathrm{MC}}\right)\times Q\right)$$

$$\sigma_{\mathrm{DSS}}^{\mathrm{EE}} = \frac{\sum_{o=1}^{O}\left(\sum_{l=1}^{L}\left(\left(P_{\mathrm{m}}/2^{O-1}\right) + \sum_{k=1}^{(|\mathbf{O}|-1)}\left(\mathbf{C}(O-1,k)\left(\left(\alpha_{k}P_{\mathrm{m}}\right)/2^{O-1}\right)\right)\right) + \left(S_{\mathrm{P},o}P_{\mathrm{PC}} + S_{\mathrm{M},o}P_{\mathrm{MC}}\right)\right)}{\left(\sigma_{\mathrm{DSS}}^{\mathrm{CA}}/Q\right)}$$

For the SESA

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

$$\sigma_{\mathrm{SESA}}^{\mathrm{SE}} = \sigma_{\mathrm{SESA}}^{\mathrm{CA}} \Big/ \left(\left(M_{\mathrm{C}} + \sum_{o=1}^{O} M_{o}^{\mathrm{MC}}\right)\times Q\right)$$

$$\sigma_{\mathrm{SESA}}^{\mathrm{EE}} = \sum_{o=1}^{O}\left(\sum_{l=1}^{L}\sum_{s=1}^{S_{\mathrm{F}}}P_{\mathrm{m}} + \left(S_{\mathrm{P},o}P_{\mathrm{PC}}\right) + \left(S_{\mathrm{M},o}P_{\mathrm{MC}}\right)\right) \Big/ \left(\sigma_{\mathrm{SESA}}^{\mathrm{CA}}/Q\right)$$

Performance Evaluation and Comparison

From Figure 2(a), it can be found that proposed DSS improves SE by about 2.64 times and EE by about 74.28%, respectively over that of the traditional SESA. The similar outperformance in SE and EE can be found in Figures 2(b)-2(c) over that of SESA with the variation of *L*.

The Sixth-Generation (6G) mobile system is expected to offer SE of 370 bps/Hz and EE of 0.3 uJ/bit [5]. Using Figure 2(b), the minimum values of *L* required by DSS and SESA are 9 and 32, respectively, to satisfy the above SE and EE requirements for 6G.

Hence, DSS requires the reuse of the countrywide 28 GHz spectrum to 71.87% fewer buildings than that of SESA.

Table I. Default parameters and assumptions*

Parameters and Assumptions	Value
Spectrum bandwidth	200 MHz (28 GHz) and 40 MHz (2 GHz)
Number of MNOs, Transmission direction	4, downlink
P_m,CCI threshold, SCs per building	19 dBm, $0.3P_m$,48

*the detailed simulation parameters and assumptions can be found in [2]

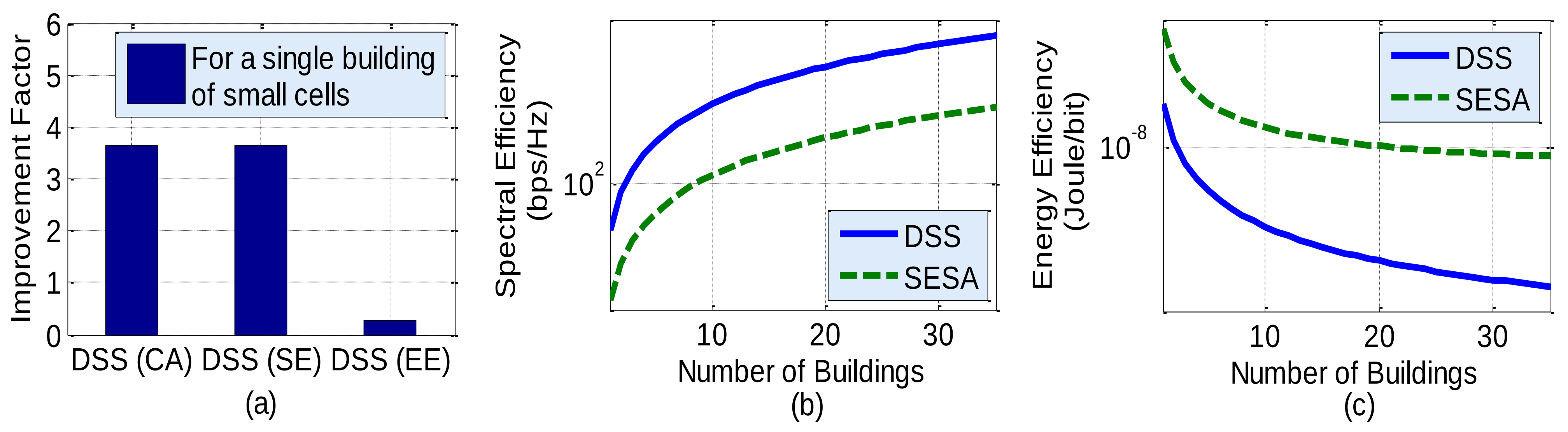

Figure 2. (a) Average capacity, SE, and EE improvement factors of DSS over that of SESA for *L*=1. (b) SE and (c) EE of DSS and SESA techniques for *L*>1.

Conclusion

- In this paper, we have presented a Dynamic Spectrum Sharing (DSS) technique to share the countrywide full 28 GHz spectrum with in-building SCs of each MNO by controlling the transmission power of SCs.

- The proposed DSS has been detailed, and its outperformance over the traditional SESA in terms of average capacity, SE and, EE has been shown.

References

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End of the Presentation

Thank You …