A Massive Millimeter-Wave Spectrum Allocation and Exploitation Technique Toward 6G Mobile Networks

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

KDDI Research

IARIA

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
  - System Architecture, Proposed Technique, and Interference Management
  - Mathematical Analysis
    - Performance Results and Analysis
    - Conclusion
      - References

Problem Statement

The high capacity and data rates requirements result in the scarcity of the radio spectrum.

Spectrum allocation and spectrum exploitation can play a vital role in addressing the spectrum scarcity.

- By **carefully allocating the spectrum** among its MNOs, the available **amount of spectrum** for an MNO can be extended considerably.
- Furthermore, **by exploiting the available spectrum** for an MNO in space, the **utilization of the spectrum** can be increased.
  - Accordingly, **the spatial reuse of the spectrum to small cells**, particularly in a 3-Dimensional (3D) space, e.g., **a multistory building**, is considered as an effective approach.

Problem Statement

Numerous research works have already addressed the issues of spectrum allocation [1]-[3], as well as spectrum exploitation [4]-[6].

However, unlike the traditional **static licensed spectrum allocation** that considers allocating a certain portion of the countrywide spectrum to an MNO

→

The **whole countrywide Millimeter-Wave (mmWave) spectrum can be allocated to each MNO** to increase its spectrum.

Besides, due to **high floor penetration loss**, the same countrywide mmWave spectrum for each MNO can be **exploited spatially to reuse it more than once to small cells within a building**.

Hence, **a technique** that can

- employ both the **spectrum allocation and spectrum exploitation** means to the mmWave spectrum
- using **in-building small cells** to allocate the countrywide mmWave spectrum to each MNO,
- which is **exploited further to reuse spatially** to small cells in a building

is considered promising to **achieve high Spectral Efficiency (SE) and Energy Efficiency (EE) requirements** for the next generation mobile networks.

Scope

We propose A **Countrywide MmWave Spectrum Allocation and Reuse (CoMSAR) technique** that considers allocating and then reusing the massive 28 GHz mmWave spectrum specified countrywide to each MNO of a country to achieve the expected SE and EE requirements for 6G mobile networks.

- We first present the **system architecture** and the **proposed technique**,
- develop a **frequency-domain Co-Channel Interference** (CCI) avoidance scheme,
- derive average **capacity, SE, EE,** and **CE** metrics for the proposed technique,
- carry out extensive **numerical and simulation results** and analyses for an example scenario of a country consisting of four MNOs under **two extreme CCI** scenarios for an MNO,
  - no CCI and
  - the maximum CCI,
- show that the proposed technique can **achieve SE and EE requirements for 6G** systems.

System Architecture, Proposed Technique, and Interference Management

(a) System Architecture

- Four MNOs (i.e., MNO 1, MNO 2, MNO 3, and MNO 4) are operating in a country.
- SBSs within each building are considered operating at the 28 GHz mmWave spectrum, whereas MBSs and PBSs are operating at the 2 GHz spectrum (Figure 1(a)).

- Each MNO is given access to the countrywide 28 GHz mmWave spectrum by enforcing the frequency-domain CCI management (Figure 1(d)).
- Figure 1(d) shows two extreme CCI scenarios for SBSs of MNO 1 on a floor based on the presence of UEs of $\boldsymbol{O}\backslash o$.
- By exploiting high floor penetration loss of 28 GHz (about 55 dB), spectrum exploitation is considered by reusing the countrywide spectrum to SBSs of each MNO on each floor to increase spectral utilization (Figures 1(b) and 1(d)).

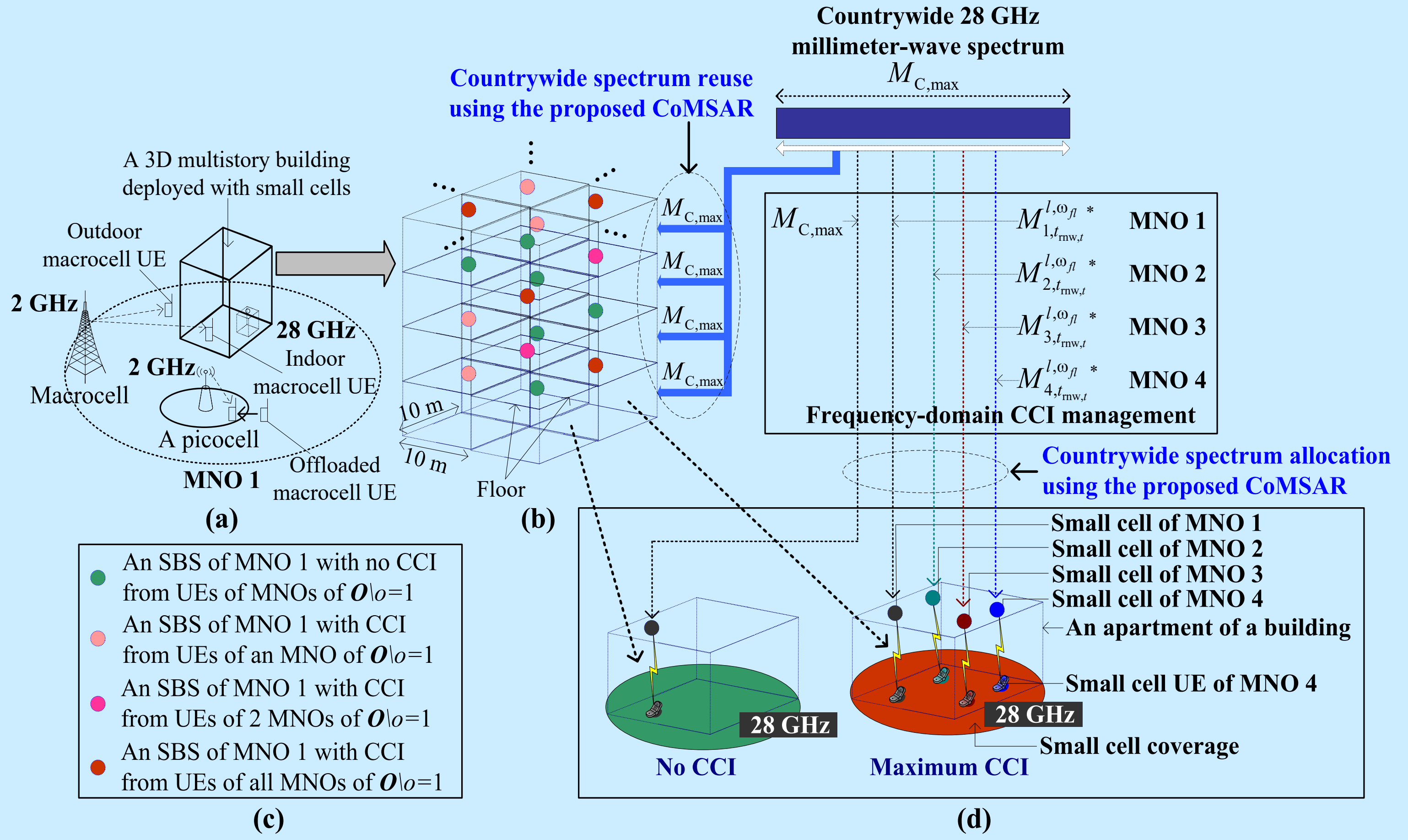

Figure 1. A system architecture for the proposed technique

System Architecture, Proposed Technique, and Interference Management

(b) Proposed Technique

We propose a countrywide mmWave spectrum allocation and reuse (CoMSAR) technique to extend the available spectrum for an MNO and to increase its utilization as follows.

Each MNO** of a country is **assigned with** the massive **28 GHz mmWave** spectrum specified countrywide, which is **reused further**, to operate its small cells deployed **on each floor** in a building at the cost of paying the spectrum licensing fee **subject to avoiding CCI**. The amount of the spectrum licensing fee for an MNO is updated corresponding to the change in its **number of subscribers** at each license **renew term t_{rnw}

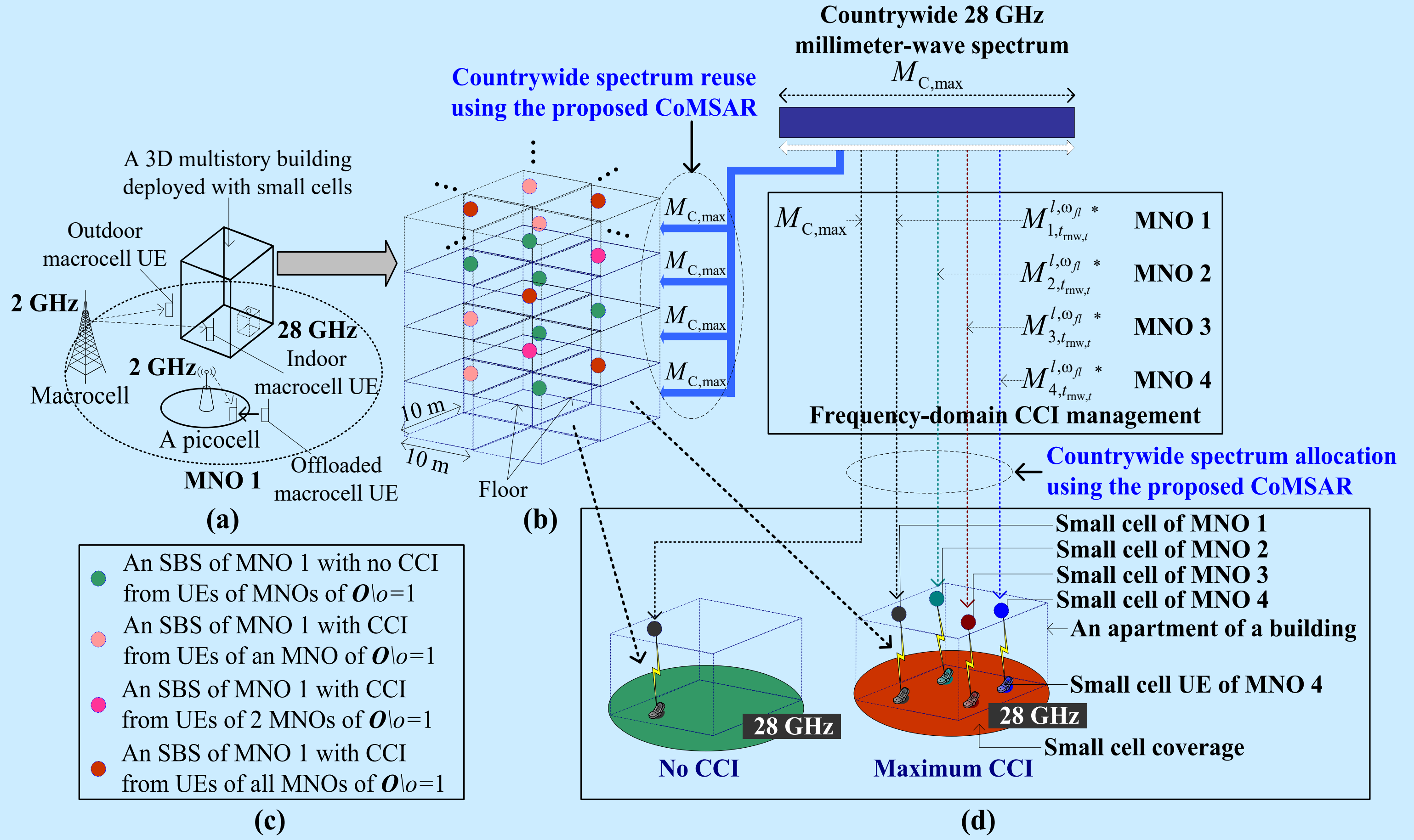

Figure 1. A system architecture for the proposed technique

- Proposed technique can overcome the **lack of a sufficient amount of spectrum** of an MNO, and address the **issue of the under-utilized or unused spectrum** of other MNOs, improving the overall countrywide spectrum utilization.
- Moreover, an MNO **pays the licensing fee** only for the amount of spectrum that **it uses** in accordance with its number of users.

System Architecture, Proposed Technique, and Interference Management

(c) Interference Management

CCI occurs when small cell UEs of more than one MNO on the same floor in a building are scheduled to the same frequency simultaneously.

Such CCI can be avoided by allocating UEs **orthogonally in the frequency-domain**:
UEs of MNOs located **on the same floor in a building are allocated orthogonally to different parts** of the countrywide 28 GHz mmWave spectrum.

The **optimal amount of licensed spectrum** can be found by solving the following problem.

$$\min_{o \in \boldsymbol{O}} \quad M^{l,\omega_{fl}}_{o,t_{\text{rnw}},t}$$

$$\text{subject to} \quad \text{(a)}\ N^{l,\omega_{fl}}_{o,t_{\text{rnw}}} \Big/ N^{l,\omega_{fl}}_{t_{\text{rnw}},t} = M^{l,\omega_{fl}}_{o,t_{\text{rnw}},t} \Big/ M_{\text{C,max}}$$

$$\text{(b)}\ \forall o \forall t_{\text{rnw}} \forall l \forall \omega_{fl} \sum_{o}^{O} N^{l,\omega_{fl}}_{o,t_{\text{rnw}}} N_{o,t_{\text{rnw}}} \le N^{l,\omega_{fl}}_{\text{C,max},t_{\text{rnw}}}$$

The **solution** to the above optimization problem:

$$M^{l,\omega_{fl}\,*}_{o,t_{\text{rnw}},t} = \left\lceil \left(\left(N^{l,\omega_{fl}}_{o,t_{\text{rnw}}} \Big/ \sum_{o=1}^{O} \left(1_{\nu_o} \left(N^{l,\omega_{fl}}_{o,t_{\text{rnw}}} \right) \times N^{l,\omega_{fl}}_{o,t_{\text{rnw}}} \right) \right) \times M_{\text{C,max}} \right) \right\rceil$$

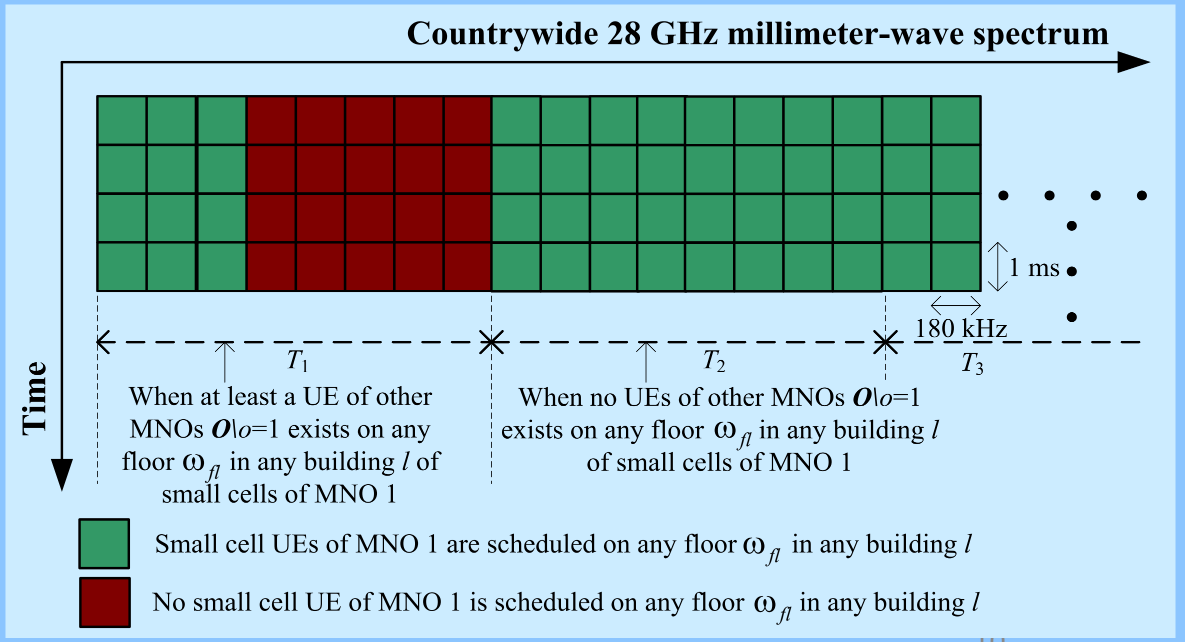

Figure 2. The frequency-domain CCI avoidance for UEs of MNO 1 on any floor

Mathematical Analysis

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

Capacity of all macrocell UEs

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

Proposed Technique

Aggregate capacity served by an SBS, all SBSs per floor as well as all SBSs in a building

$$\sigma_{\mathrm{FD},o,l,s_{x,o}}^{t_{\mathrm{rnw}},\omega_{fl}}=\sum_{t\in\boldsymbol{T}}\sum_{i=1}^{M_{o,t_{\mathrm{rnw}},t}^{l,\omega_{fl}\,*}}\sigma_{t,i,o}^{t_{\mathrm{rnw}}}\left(\rho_{t,i,o}^{t_{\mathrm{rnw}}}\right)$$

$$\sigma_{\mathrm{FD},o,l,s_{\omega_{fl},o}}^{t_{\mathrm{rnw}},\omega_{fl}}=\sum_{s_{x,o}=1}^{S_{\omega_{fl},o}}\sigma_{\mathrm{FD},o,l,s_{x,o}}^{t_{\mathrm{rnw}},\omega_{fl}}$$

$$\sigma_{\mathrm{FD},o,l,s_{\omega_{fl},o}}^{t_{\mathrm{rnw}},\omega_{\mathrm{FL}}}=\sum_{\omega_{fl}=1}^{\omega_{\mathrm{FL}}}\sigma_{\mathrm{FD},o,l,s_{\omega_{fl},o}}^{t_{\mathrm{rnw}},\omega_{fl}}$$

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

$$\sigma_{\mathrm{FD,cap},O}^{\mathrm{sys},t_{\mathrm{rnw}}}(L)=\sum_{o=1}^{O}\left(\sigma_{\mathrm{MBS},o}^{t_{\mathrm{rnw}}}+\left(L\times\sigma_{\mathrm{FD},o,l,s_{\omega_{fl},o}}^{t_{\mathrm{rnw}},\omega_{\mathrm{FL}}}\right)\right)$$

$$\sigma_{\mathrm{FD,SE},O}^{\mathrm{sys},t_{\mathrm{rnw}}}(L)=\sigma_{\mathrm{FD,cap},O}^{\mathrm{sys},t_{\mathrm{rnw}}}(L)\Big/\left(\left(M_{\mathrm{C,max}}+\sum_{o=1}^{O}M_{\mathrm{MBS},o}\right)\times Q\right)$$

$$\sigma_{\mathrm{FD,EE},O}^{\mathrm{sys},t_{\mathrm{rnw}}}(L)=\left(\sum_{o=1}^{O}\left(\begin{array}{l}\left(L\times S_{\mathrm{F},o}\times P_{\mathrm{SC}}\right)\\+\left(S_{\mathrm{P},o}\times P_{\mathrm{PC}}\right)+\left(S_{\mathrm{M},o}\times P_{\mathrm{MC}}\right)\end{array}\right)\right)\Big/\left(\sigma_{\mathrm{FD,cap},O}^{\mathrm{sys},t_{\mathrm{rnw}}}(L)/Q\right)$$

Static Licensed Spectrum Allocation (SLSA) technique

$$\sigma_{\mathrm{SLSA,cap},O}^{\mathrm{sys},t_{\mathrm{rnw}}}(L)=\sum_{o=1}^{O}\left(\sigma_{\mathrm{MBS},o}^{t_{\mathrm{rnw}}}+\left(L\times\sum_{\omega_{fl}=1}^{\omega_{\mathrm{FL}}}\sum_{s_{x,o}=1}^{S_{\omega_{fl},o}}\sum_{t\in\boldsymbol{T}}\sum_{i=1}^{M}\sigma_{s_{x,o},t,i,o}^{t_{\mathrm{rnw}},\omega_{fl}}\left(\rho_{s_{x,o},t,i,o}^{t_{\mathrm{rnw}},\omega_{fl}}\right)\right)\right)$$

$$\sigma_{\mathrm{SLSA,SE},O}^{\mathrm{sys},t_{\mathrm{rnw}}}(L)=\sigma_{\mathrm{SLSA,cap},O}^{\mathrm{sys},t_{\mathrm{rnw}}}(L)\Big/\left(\left(M_{\mathrm{C,max}}+\sum_{o=1}^{O}M_{\mathrm{MBS},o}\right)\times Q\right)$$

$$\sigma_{\mathrm{SLSA,EE},O}^{\mathrm{sys},t_{\mathrm{rnw}}}(L)=\left(\sum_{o=1}^{O}\left(\begin{array}{l}\left(L\times S_{\mathrm{F},o}\times P_{\mathrm{SC}}\right)+\\\left(S_{\mathrm{P},o}\times P_{\mathrm{PC}}\right)+\left(S_{\mathrm{M},o}\times P_{\mathrm{MC}}\right)\end{array}\right)\right)\Big/\left(\sigma_{\mathrm{SLSA,cap},O}^{\mathrm{sys},t_{\mathrm{rnw}}}(L)/Q\right)$$

Cost Efficiency: Cost required per unit capacity (i.e., per bps)

$$\varsigma_{\mathrm{FD,CE},O}^{\mathrm{sys},t_{\mathrm{rnw}}}=\varepsilon_{\mathrm{C}}\Big/\sigma_{\mathrm{FD,cap},O}^{\mathrm{sys},t_{\mathrm{rnw}}}(L)$$

$$\varsigma_{\mathrm{SLSA,CE},O}^{\mathrm{sys},t_{\mathrm{rnw}}}=\varepsilon_{\mathrm{C}}\Big/\sigma_{\mathrm{SLSA,cap},O}^{\mathrm{sys},t_{\mathrm{rnw}}}(L)$$

Improvement Factors

$$\varsigma_{\mathrm{cap},O,\mathrm{IF}}^{\mathrm{sys},t_{\mathrm{rnw}}}=\sigma_{\mathrm{FD,cap},O}^{\mathrm{sys},t_{\mathrm{rnw}}}(L)\Big/\sigma_{\mathrm{SLSA,cap},O}^{\mathrm{sys},t_{\mathrm{rnw}}}(L)$$

$$\varsigma_{\mathrm{SE},O,\mathrm{IF}}^{\mathrm{sys},t_{\mathrm{rnw}}}=\sigma_{\mathrm{FD,SE},O}^{\mathrm{sys},t_{\mathrm{rnw}}}(L)\Big/\sigma_{\mathrm{SLSA,SE},O}^{\mathrm{sys},t_{\mathrm{rnw}}}(L)$$

$$\varsigma_{\mathrm{EE},O,\mathrm{IF}}^{\mathrm{sys},t_{\mathrm{rnw}}}=\sigma_{\mathrm{FD,EE},O}^{\mathrm{sys},t_{\mathrm{rnw}}}(L)\Big/\sigma_{\mathrm{SLSA,EE},O}^{\mathrm{sys},t_{\mathrm{rnw}}}(L)$$

$$\varsigma_{\mathrm{CE},O,\mathrm{IF}}^{\mathrm{sys},t_{\mathrm{rnw}}}=\varsigma_{\mathrm{FD,CE},O}^{\mathrm{sys},t_{\mathrm{rnw}}}\Big/\varsigma_{\mathrm{SLSA,CE},O}^{\mathrm{sys},t_{\mathrm{rnw}}}$$

Performance Results and Analysis

Table III. Default Parameters and Assumptions

Parameters and Assumptions	Value
28 GHz spectrum countrywide	200 MHz
Number of MNOs and subscribers	4 and $N_{C,max}$
Number of subscribers for MNOs 1, 2, 3, and 4, respectively	40%, 30%, 20%, and 10% of $N_{C,max}$
For each MNO	
E-UTRA simulation case[1]	3GPP case 3
Cellular layout[2], Inter-Site Distance (ISD)[1,2], transmit direction	Hexagonal grid, dense urban, 3 sectors per macrocell site, 1732 m, downlink
Carrier frequency[2,5]	2 GHz Non-line-of-Sight (NLOS) for macrocells and picocells, 28 GHz Line-Of-Sight (LOS) for all small cells
Number of cells	1 macrocell, 2 picocells, 280 small cells per building
Total BS transmit power[1] (dBm)	46 for macrocell[1,4], 37 for picocells[1], 19 for small cells[1,3,4]
Co-channel small-scale fading model[1,3,5]	Frequency selective Rayleigh for 2 GHz, none for 28 GHz
Path loss: MBS and a UE[1], Outdoor macrocell UE	$PL(\text{dB})=15.3+37.6\log_{10}R$, R is in m
Path loss: MBS and a UE[1], Indoor macrocell UE	$PL(\text{dB})=15.3+37.6\log_{10}R+L_{ow}$, R is in m
Path loss: PBS and a UE[1]	$PL(\text{dB})=140.7+36.7\log_{10}R$, R is in km
Path loss: SBS and a UE[1,2,5]	$PL(\text{dB})=61.38+17.97\log_{10}(d)$, d is in m
Lognormal shadowing standard deviation (dB)	8 for MBS[2], 10 for PBS[1], and 9.9 for SBS[2,5]
Antenna configuration	Single-input single-output for all BSs and UEs
Antenna pattern (horizontal)	Directional (120^0) for MBS[1], omnidirectional for PBS[1] and SBS[1]
Antenna gain plus connector loss (dBi)	14 for MBS[2], 5 for PBS[1], 5 for SBS[1,3]
UE antenna gain[2,3]	0 dBi (for 2 GHz), 5 dBi (for 28 GHz, Biconical horn)
UE noise figure[2,3] and UE speed[1]	9 dB (for 2 GHz) and 10 dB (for 28 GHz), 3 km/hr
Picocell coverage, number of macrocell UEs, and macrocell UEs offloaded to all picocells[1]	40 m (radius), 30, 2/15
Indoor macrocell UEs[1]	35%
3D multistory building and SBS models (square-grid apartments): number of buildings, number of floors per building, number of apartments per floor, number of SBSs per apartment, number of SBSs per building, area of an apartment, materials used	L, 35, 8, 1, 280, 10×10 m^2, reinforced concrete
Scheduler and traffic model[2]	Proportional Fair and full buffer
Type of SBSs	Closed Subscriber Group femtocell BSs
Channel State Information	Ideal
TTI[1] and scheduler time constant (t_c)	1 ms and 100 ms
Total simulation run time	8 ms

taken [1]from [15], [2]from [16], [3]from [17], [4]from [18], from [5][19].

We generate performance results by simulating all assumptions and parameters given in Table III by a **simulator** that is built by using the default instruction sets of the computational tool **MATLAB R2012b** version running on a personal computer.

The **performance** of the proposed technique is evaluated with regard to the **traditional SLSA** technique

Performance Results and Analysis

With regard to SLSA, the proposed technique improves the average **capacity, SE, EE, and CE** by **300%, 165%, 75%, and 60%,** respectively with **no CCI**, whereas only **60%, 6%, 37%, and 0.4**%, respectively with **the maximum CCI**.

From Figure 4, with an **increase in the number of floors**, SE increases linearly, whereas EE increases negative exponentially, irrespective of the degree of CCI.

Further, since SE is affected additionally by the optimal amount of countrywide spectrum, the **proposed technique with the maximum CCI provides insignificant** SE while noticeable EE improvement over the traditional SLSA technique because of its higher average capacity performance as shown in Figure 3(b).

6G mobile systems: Required SE of **370** bps/Hz and EE of **0.3** µJ/bit

By reusing the countrywide 28 GHz spectrum to small cells of MNO 1 of about 60% less number of floors (ω_{F} =12 with no CCI, whereas 3.3% less number of floors (ω_{F} =29) with the maximum CCI, than that required by the traditional SLSA technique (ω_{FL} =30).

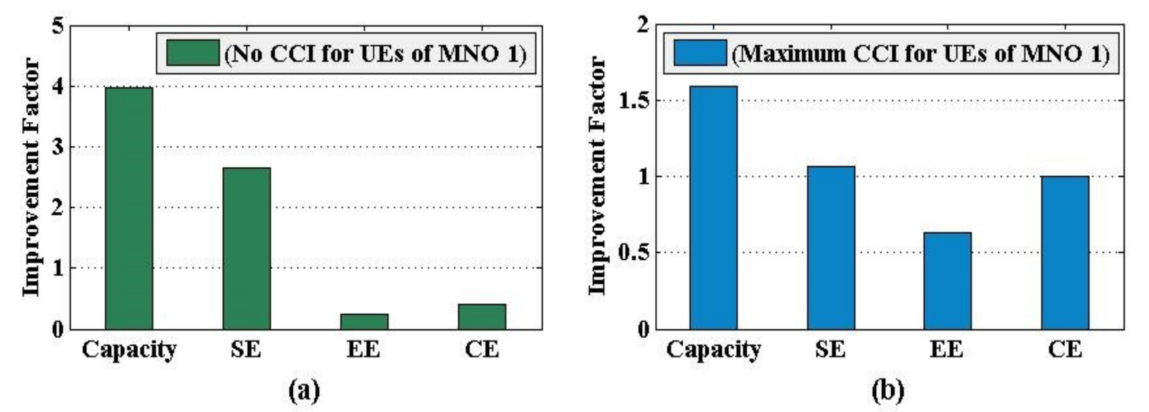

Figure 3. Performance improvement of the proposed CoMSAR technique for MNO 1 in terms of average capacity, SE, EE, and CE (a) with no CCI and (b) with the maximum CCI for UEs of MNO 1 on a single floor in a building.

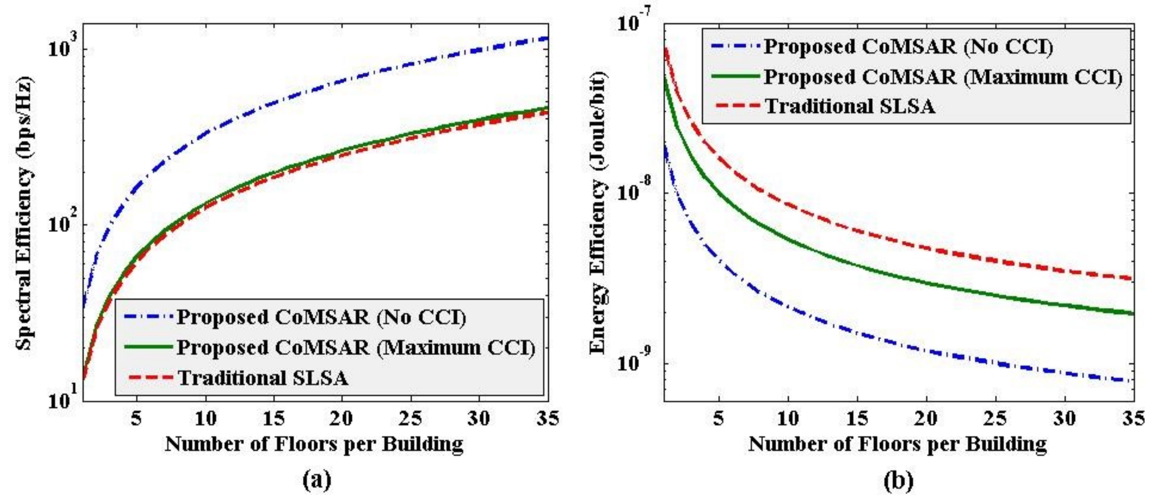

Figure 4. (a) SE and (b) EE performances of CoMSAR with respect to SLSA for a multistory building with ω_{FL} = 35

Conclusion

Addresses

- In this paper, we have proposed a **countrywide millimeter-wave (mmWave) spectrum allocation and reuse (CoMSAR) technique** that considers assigning each MNO with the massive 28 GHz mmWave spectrum countrywide subject to avoiding co-channel interference (CCI).
- The assigned spectrum to each MNO is **reused** further to operate its small cells deployed on each floor.
- CCI has been avoided by developing a **frequency-domain CCI avoidance scheme** that allocates UEs of different MNOs on any floor of a building orthogonally to the countrywide 28 GHz mmWave spectrum.
- We have **derived average capacity, Spectral Efficiency** (SE), **Energy Efficiency** (EE), and **Cost Efficiency** (CE) metrics for the proposed technique. Extensive **numerical and simulation results and analyses** have been carried out for an example scenario of a country consisting of four MNOs.

Findings

- For MNO 1, for a single building, the proposed technique can improve the average capacity, SE, EE, and CE performances by **300%, 165%, 75%, and 60%**, respectively **with no CCI**, whereas **60%, 6%, 37%, and 0.4%,** respectively with the **maximum CCI**, as compared to that of SLSA technique.
- We also have shown that the proposed CoMSAR technique can satisfy the SE and EE requirements for 6G by reusing the countrywide 28 GHz mmWave spectrum to small cells of MNO 1 of about **60% less number of floors with no CCI**, whereas **3.3% less number of floors with the maximum CCI**, than that required by the traditional SLSA technique in a multistory building.

Conclusion

Further Studies

- In this paper, we have **restricted inv**estigating to SBSs deployed **indo**ors, i.e., buildings.
- However, the **propagation characteristics** of mmWave signals in **outdoor environments differ greatly f**rom that in indoor one, particularly,
  - rain and atmospheric absorption effect,
  - cell coverage,
  - shadowing effect from large buildings,
  - outage probability,
  - user density, and
  - speed and mobility and handover management.

Above aspects have a significant impact on the allocation and reuse of the mmWave outdoors.

- Hence, how to allocate the countrywide mmWave spectrum to each MNO outdoors without causing CCI to each other and reuse the same mmWave spectrum for an MNO spatially need considerable research works.
- We aim to address these issues, **i.e., mmWave spectrum allocation and reuse, in outdoor environments** in our future research studies.

References

1. X. Yan, S. Qijun, Z. Hongshun, and S. Lulu, “Dynamic Spectrum Allocation Based on Cognitive Radio,” Proc. *the 2009 5th Asia-Pacific Conference on Environmental Electromagnetics*, Sept. 2009, pp. 254-257.
2. H. Kim, Y. Lee, and S. Yun, “A Dynamic Spectrum Allocation Between Network Operators with Priority-Based Sharing and Negotiation,” Proc. *The 2005 IEEE 16th International Symposium on Personal, Indoor and Mobile Radio Communications*, Sept. 2005, pp. 1004-1008.
3. 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*, Sept. 2009, pp. 106-109.
4. R. K. Saha and C. Aswakul, “A Tractable Analytical Model for Interference Characterization and Minimum Distance Enforcement to Reuse Resources in Three-Dimensional In-Building Dense Small Cell Networks,” International Journal of Communication Systems, vol. 30, Art. No. e3240, Jul. 2017, doi.org/10.1002/dac.3240
5. N. Saquib, E. Hossain, and D. Kim, “Fractional Frequency Reuse for Interference Management in LTE-Advanced Hetnets,” IEEE Wireless Communications, vol. 20, pp. 113-122, Apr. 2013, doi: 10.1109/MWC.2013.6507402.
6. 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)*, Sept. 2019, pp. 1-7.
7. R. K. Saha, “A Hybrid Interweave-Underlay Countrywide Millimeter-Wave Spectrum Access and Reuse Technique for CR Indoor Small Cells in 5G/6G Era,” Sensors, vol. 20, Art. No. 3979, 2020, doi.org/10.3390/s20143979.
8. 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.
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, doi.org/10.3390/en13071748.
10. R. Allan, “Application of FSS Structures to Selectively Control the Propagation of Signals into and Out of Buildings – Executive Summary,” ERA Technology Ltd, Cleeve Road, Leatherhead Surrey, KT22 7SA UK. Available online: https://www.ofcom.org.uk/__data/assets/pdf_file/0020/ 36155/exec_summary.pdf [retrieved: February, 2020)
11. Propagation Data and Prediction Methods for The Planning of Indoor Radiocommunication Systems and Radio Local Area Networks in The Frequency Range 300 MHz to 450 GHz. Recommendation ITU-R P.1238-10, 08/2019. Available online: https://www.itu.int/rec/R-REC-P.1238 [retrieved: February, 2020)
12. D. Lu and D. Rutledge, “Investigation of Indoor Radio Channels from 2.4 GHz to 24 GHz,” Proc. *IEEE Antennas and Propagation Society International Symposium. Digest. Held in conjunction with: USNC/CNC/URSI North American Radio Sci. Meeting (Cat. No.03CH37450),* June 2003, pp. 134-137.
13. R. K. Saha, “A Hybrid System and Technique for Sharing Multiple Spectrums of Satellite Plus Mobile Systems with Indoor Small Cells in 5G and Beyond Era,” IEEE Access, vol. 7, pp. 77569-77596, 2019, doi: 10.1109/ACCESS.2019.2921723.
14. R. K. Saha and C. Aswakul, “A Novel Frequency Reuse Technique for In-Building Small Cells in Dense Heterogeneous Networks,” IEEJ Transactions on Electrical and Electronic Engineering, vol. 13, pp. 98-111, Jan. 2018, doi.org/10.1002/tee.22503.
15. Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Frequency (RF) System Scenarios. document 3GPP TR 36.942, V.1.2.0, 3rd Generation Partnership Project, Jul. 2007. Available online: https://portal.3gpp.org/ desktopmodules /Specifications/Specification Details.aspx?specificationId=2592 [retrieved: February, 2020]
16. Simulation Assumptions and Parameters for FDD HeNB RF Requirements. document TSG RAN WG4 (Radio) Meeting #51, R4-092042, 3GPP, May 2009. Available online: https://www.3gpp.org/ftp/tsg_ran /WG4_Radio/TSGR4_51/Documents/ [retrieved: February, 2020].
17. Guidelines for Evaluation of Radio Interface Technologies for IMT-2020. Report ITU-R M.2412-0 (10/2017), Geneva, 2017. Available online: https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2412-2017-PDF-E.pdf [retrieved: February, 2020]
18. R. K. Saha, P. Saengudomlert, and C. Aswakul, “Evolution Toward 5G Mobile Networks-A Survey On Enabling Technologies,” Engineering Journal, vol. 20, pp. 87-119, Jan. 2016, doi.org/10.4186/ej.2016.20.1.87.
19. G. R. Maccartney, T. S. Rappaport, S. Sun, and S. Deng, “Indoor Office Wideband Millimeter-Wave Propagation Measurements and Channel Models at 28 and 73 GHz for Ultra-Dense 5G Wireless Networks,” IEEE Access, vol. 3, pp. 2388-2424, 2015, doi: 10.1109/ACCESS.2015.2486778.
20. Z. Zhang et al., “6G Wireless Networks: Vision, Requirements, Architecture, and Key Technologies,” IEEE Vehicular Technology Magazine, vol. 14, pp. 28-41, Sept. 2019, doi: 10.1109/MVT.2019.2921208.
21. S. Chen et al., “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, Apr. 2020, doi: 10.1109/MWC.001.1900333.
22. C.-X. Wang et al., “Cellular Architecture and Key Technologies for 5G Wireless Communication Networks,” IEEE Communications Magazine, vol. 52, pp. 122-130, Feb. 2014, doi: 10.1109/MCOM.2014.6736752.
23. G. Auer et al., “How Much Energy is Needed to Run a Wireless Network?” IEEE Wireless Communications, vol. 18, pp. 40-49, Oct. 2011, doi: 10.1109/MWC.2011.6056691.

End of the Presentation

Thank You …