In-Building Small Cell Networks: Achieving High Capacity Indoors

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Short Description - In this tutorial, we discuss the potential of small cells in achieving the high capacity demands of in-building users in cellular mobile networks. In typical cellular mobile networks, a major portion of the data is generated by indoor users at high data rates to support rich multimedia services on mobile phones, particularly in urban high-rise buildings, many of which encompassing several hundreds of apartments. Due to the presence of high external wall penetration loss of a building, the scarcity of available system bandwidth below 3 GHz, and a limit to the maximum transmission power to avoid excessive interference, serving this large amount of indoor data at a high rate with an outdoor Macrocell Base Station (MBS) is difficult. Hence, it now becomes inevitable how to address indoor high data rates and enormous capacity demands.

The received signal capacity at a receiver is a function of the distance from the transmitter and available spectrum bandwidth. The lower the distance and higher the spectrum bandwidth, the better the received signal capacity. The distance can be lowered by reducing the cell size so that the transmitter and receiver are as close in distance as possible. Moreover, reduction in cell coverage allows reusing the same spectrum spatially (an indirect impact toward the spectrum extension), resulting in achieving more capacity over a certain area. In this regard, because of a small coverage and low transmission power, deploying Small Cell Base Stations (BSs) within buildings is considered an effective approach to serve such a large amount of indoor data at a high data rate. From Shannon's capacity formula, it can be observed that the network capacity can be improved mainly by addressing three directions, including spectrum accessibility, spectral efficiency improvement, and network densification.

Regarding *spectrum accessibility*, because spectrum bands below 3 GHz are almost occupied, the high-frequency Millimeter-Wave (mmWave) spectrum bands have already been considered to address the high capacity demand of Fifth-Generation (5G) and beyond mobile systems, particularly, indoors within multistory buildings. In this regard, to address the massive deployments of small cells to provide high data rates at a short distance, the short-range and the availability of a large amount of mmWave spectrum are promising, particularly in urban indoor environments. Further, the spectrum can be extended by increasing the number of available spectra such that each small cell can operate in more than one spectrum.

Besides, usually, each Mobile Network Operator (MNO) of a country is allocated with a dedicated licensed spectrum to serve its users' traffic. Such static allocations of radio spectra were once sufficient to ensure user demands. To reuse the same dedicated spectrum for an MNO, recently, the dynamic sharing of radio spectrum allocated statically already to MNOs using small cells indoors has been found to be more effective. In Dynamic Spectrum Sharing (DSS), the spectrum allocated statically to a system (primary) can be shared dynamically or opportunistically by another system (secondary) subject to satisfying the condition that the primary system is not affected due to sharing. Indoor small cells, by exploiting their architectures, can play a crucial role in realizing numerous DSS techniques. In this regard, to avoid Co-Channel Interference (CCI), when sharing the licensed spectrum of one MNO to another, Almost Blank Subframe (ABS) based Enhanced Intercell Interference Coordination (eICIC) can be employed to small cells to allow time orthogonality while serving traffic of the respective MNO.

Regarding *spectral efficiency improvement*, MNOs in a country facing challenges from enabling efficient utilization of its available licensed spectrum. This is because the user traffic demand of different MNOs in a country varies abruptly over time and space such that the demand for the required amount of spectra for different MNOs varies accordingly. This causes a great portion of the available spectrum allocated to each MNO in a country to be left unused or underutilized either in time or space. In recent times, Cognitive Radio (CR) has appeared as an enabling technology to address this spectrum under-utilization issue. In CR, spectrum access is a major function, which prevents collisions between primary User Equipments (UEs) and Secondary UEs (SUs) to allows sharing the licensed spectrum of one MNO with another to increase its effective spectrum bandwidth, resulting in improving its spectral efficiency to serve high capacity.

Finally, about *network densification*, Small Cell BSs (SBSs) can be deployed both in the intra-floor, as well as the inter-floor, level of a building, resulting in an ultra-dense deployment of SBSs over a certain area of 2-Dimensional (2D) physical space within the coverage of a macrocell. Moreover, due to the high penetration losses of mmWave

bands through external and internal walls and floors in any multi-story building compared to low-frequency microwave bands, the reuse of mmWave bands can be explored in the third dimension (i.e., the height of a multistory building), which results in reusing the same mmWave band more than once at the inter-floor level. In addition, the conventional spectrum reuse techniques at the intra-floor level in a multistory building can be used to facilitate extensive reuse of mmWave spectra in ultra-dense deployed small cells within the building.

Hence, 3-Dimensional (3D) spatial reuse of mmWave spectra by capturing 3D effects on indoor signal propagations with in-building multiband-enabled *ultra-dense* small cells to *avail additional spectrum* using DSS, along with exploiting CR technology to improve *spectrum utilization*, can achieve enormous high capacity demand of mobile networks. In this *tutorial*, we learn about exploiting in-building small cells along these aforementioned three directions to achieve the high capacity demand of existing and upcoming mobile networks.

Acknowledgment: This tutorial is mainly based on the presenter's research works mentioned in the reference section below. Consequently, contents in the presentation slides, as well as in this document, in terms of texts, figures, tables, equations, and other forms, can be found merged partly or fully with those works. This tutorial presentation in any form should not be considered a new or novel one. It is prepared with the purpose of disseminating existing information (toward addressing a specific issue highlighted by the title of the tutorial) in the form of research works provided by the presenter as mentioned in the reference. For interested readers, please refer to the relevant works for any sort of further information. References other than these are cited in the presentation slides in the appropriate places, wherever used.

REFERENCES

[1] 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, no. 7, 1748, 2020. doi: 10.3390/EN13071748.

[2] 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, no. 11, pp. 95-118, July 2017, doi: 10.1002/DAC.3240.

[3] R. K. Saha, "A Tactic for Architectural Exploitation of Indoor Small Cells for Dynamic Spectrum Sharing in 5G," IEEE Access, vol. 8, pp. 15056-15071, January 2020, doi: 10.1109/ACCESS.2020.2966230.

[4] R. K. Saha, "Interweave Shared-Use Model for Dynamic Spectrum Access in Millimeter-Wave Mobile Systems for 6G," Proc. 2020 IEEE 92nd Vehicular Technology Conference (VTC2020- Fall), Victoria, BC, Canada, 18-Nov.-16 Dec., 2020, pp. 1-6, doi: 10.1109/VTC2020- Fall49728.2020.9348671.

[5] R. K. Saha, "Underlay Cognitive Radio Millimeter-Wave Spectrum Access for In-Building Dense Small Cells in Multi-Operator Environments Toward 6G," Proc. IEEE 23rd International Symposium on Wireless Personal Multimedia Communications (WPMC), Okayama, Japan, 19-26 Oct. 2020, pp. 1-6, doi: 10.1109/WPMC50192.2020.9309471.

[6] R. K. Saha, "Hybrid Interweave-Underlay Millimeter-Wave Spectrum Access in Multi-Operator Cognitive Radio Networks Toward 6G," Proc. Fifteenth International Conference on Systems and Networks Communications (ICSNC), Porto, Portugal, 18-22 Oct. 2020, pp. 42-48.