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DAS and UDN Solutions for Indoor Coverage at Millimeter Wave (mmWave) Frequencies

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***Abstract*—The future 5th Generation (5G) wireless networks are expected to support a variety of bandwidth hungry applications. Millimeter wave (mmWave) communications, and Ultra Dense Network (UDN) deployment along with smart Distributed Antenna System (DAS) can be considered as a tempting solution for cellular networks. The aim of this paper is to analyze the performance of different UDN and DAS configurations in an indoor environment i.e. real university office building at 3.5 GHz, 28 GHz, and 60 GHz frequency. System performance is analyzed by performing ray launching simulations using a three dimensional floor plan. The obtained results show the incapability of basic indoor solution in providing the ubiquitous Quality of Service (QoS) in an indoor environment at higher frequencies. Simulation results shows that it is inevitable to have a dedicated indoor network with UDN or DAS configuration to provide homogeneous coverage in an indoor condition. It is found that despite of more interference the UDN deployment provides a higher system capacity compared with DAS due to more number of cells. However, the gain of cell densification saturates with the increasing number of cells.**

***Index Terms*—Ultra dense network; Millimeter wave; Distributed antenna system; 5G; System performance; 3.5 GHz.**

I. INTRODUCTION

The massive amount of data traffic is expected to be generated by future applications with gigantic data rate requirement. The leading solutions for providing huge and homogeneous capacity includes the Millimeter wave (mmWave) communications [1], Ultra Dense Network (UDN) deployments [2] and smart antenna solutions i.e. Distributed Antenna System (DAS) [3]. Network planning requires a paradigm shift as the traditional outdoor macrocellular base stations are not able to provide uniform quality of services to indoor users at mmWave frequencies. There is a strict requirement of maximum allowed transmission power in an indoor environment. Therefore, in this case a small cell with low transmission power in an indoor environment can serve the purpose of fulfilling the coverage and capacity requirement. Considering the scarcity of the spectrum at sub-6 GHz band, one possible way to increase the system capacity is to increase the re-usability of radio resources per unit area, and that can be done by cell densification. The cellular systems are susceptible to co-channel interference. Therefore, the interference mitigation/avoidance is crucial in dense network deployment. The DAS configuration is famous for interference management while providing better coverage [3]. In case of DAS, a distributed Remote Antenna Units (RAUs) are connected to a Central Unit (CU). The multiple RAUs belong to same cell, therefore does not cause interference to each other. Another option of improving the system capacity is to migrate to mmWave band, as an abundant amount of free spectrum is available for cellular usage at mmWave frequencies [4]. However, several drawbacks are associated with mmWave communications, and that includes the higher path loss, severe atmospheric absorption and rain attenuation especially at 60 GHz, and higher wall penetration loss Fortunately, the 28 GHz band has a negligible atmospheric absorption [1].

II. SIMULATION ENVIRONMENT, TOOL, CASES AND PARAMETERS

A. Simulation Environment and Tool

The focus of this paper is to study about the indoor coverage at speculated 5G frequencies using an indoor antennas. Therefore, an indoor office environment from Information Technology building of Tampere University of Technology is considered for the simulation and analysis. The three dimensional floor plan was created using a MATLAB tool, without considering any furniture or windows. The two dimensional dimensional floor plan is shown in Fig. 1. The considered floos plan has four wings, and the offices are made up of thin partition walls. A three dimensional floor plan is used for ray tracing simulations. For radio propagation simulations, a three dimensional ray launching tool is developed by the the authors using a MATLAB platform. The propagation paths between the transmitter and receiver are found by ray launching tool based on Shoot and Bouncing Ray (SBR) method. Rays were launched from the transmitter point with fixed 0.5° angular separation between the rays. Each ray continues propagating, until it reaches the maximum number of allowed interaction. The maximum number of supported interaction is 10 in our simulations. A ray launching tool not only considers the Line of Sight (LOS) path, rather it also finds the penetrated paths through wall or multiple wall, and considers paths with multiple reflections. The users are are homogeneously distributed in an indoor environment with 0.5 m separation between them. All the indoor test locations are assumed to have antenna at 1.5 m height with zero dBi antenna gain.

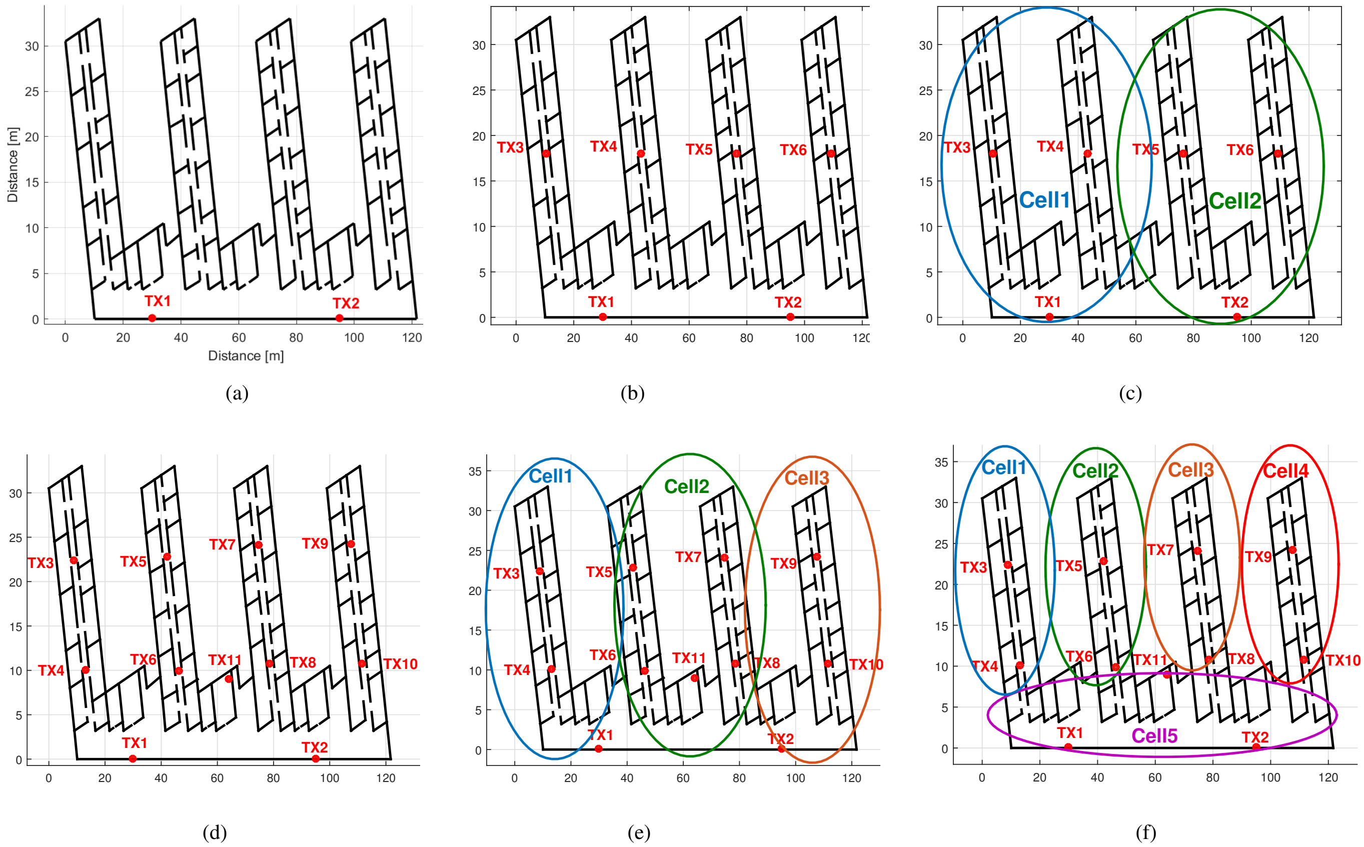


Fig. 1. Floor plan of information building, (a) Reference layout with two cells, (b) Seven cells layout, (c) Distributed antenna layout with three cells.

B. Simulation Cases and Parameters

Already, certain bands have been proposed for 5G system. However, we have only targeted 3.5 GHz, 28 GHz and 60 GHz bands in this paper. The later two bands are from mmWave frequency band, whereas 3.5 GHz band is from sub-6 GHz band which is currently in use by most mobile operators for mobile communications. In this paper six different indoor network layouts are studied. The details about each network layout is given as follows:

1) Reference layout with two transmission points: In this layout, there are only two transmitter points as shown in Fig. 1(a), and each transmitter point represents one cell. This is the basic configuration and is used as a reference layout for comparing the results with other network layouts. The position of the transmission points are marked with red circles.

2) UDN with six transmission points: In this layout, there are six transmission points as shown in Fig. 1(b), and each transmitter point represents an independent cell. This layout represents the case of ultra dense network in an indoor environment.

3) Two cells DAS layout with six transmission points: In this layout, a single cell comprises of multiple antennas located geographically far apart from each other. There are two cells, and each cell has three antennas. The transmission points TX1, TX3 and TX4 belong to Cell1, and the transmission points TX2, TX5 and TX6 belong to Cell2 as shown in Fig. 1(c).

4) Higher order UDN with eleven transmission points: It represents a UDN case with higher order of cell densification. In this layout, a same building is covered with eleven transmitters, as shown in Fig. 1(d), and each transmitter point represents a single cell.

5) Three cells DAS layout with eleven transmission points: In this layout there are three cells. Cell1 and Cell3 have four antennas each, whereas, Cell2 have five antennas as shown in Fig. 1(e). It shows that in a DAS network it is possible to have different number of antennas for different cells, and depending upon the need the number of antennas in each cell can be adjusted.

6) Five cells DAS layout with eleven transmission points: This is the last configuration and represents a DAS layout having five cells using eleven transmission points as shows in Fig. 1(f). The antennas belong to each cell are enclosed in ellipse, and each cell is marked with different color. Only Cell5 has three antennas, rest all other cells consist of two antennas each.

Average floor height is 3 m, and the all the transmit antennas are placed at the height of 3 m on the ceiling. Omni directional antenna with unity gain in all directions are assumed at the transmitter point. There is strict requirement of using a low

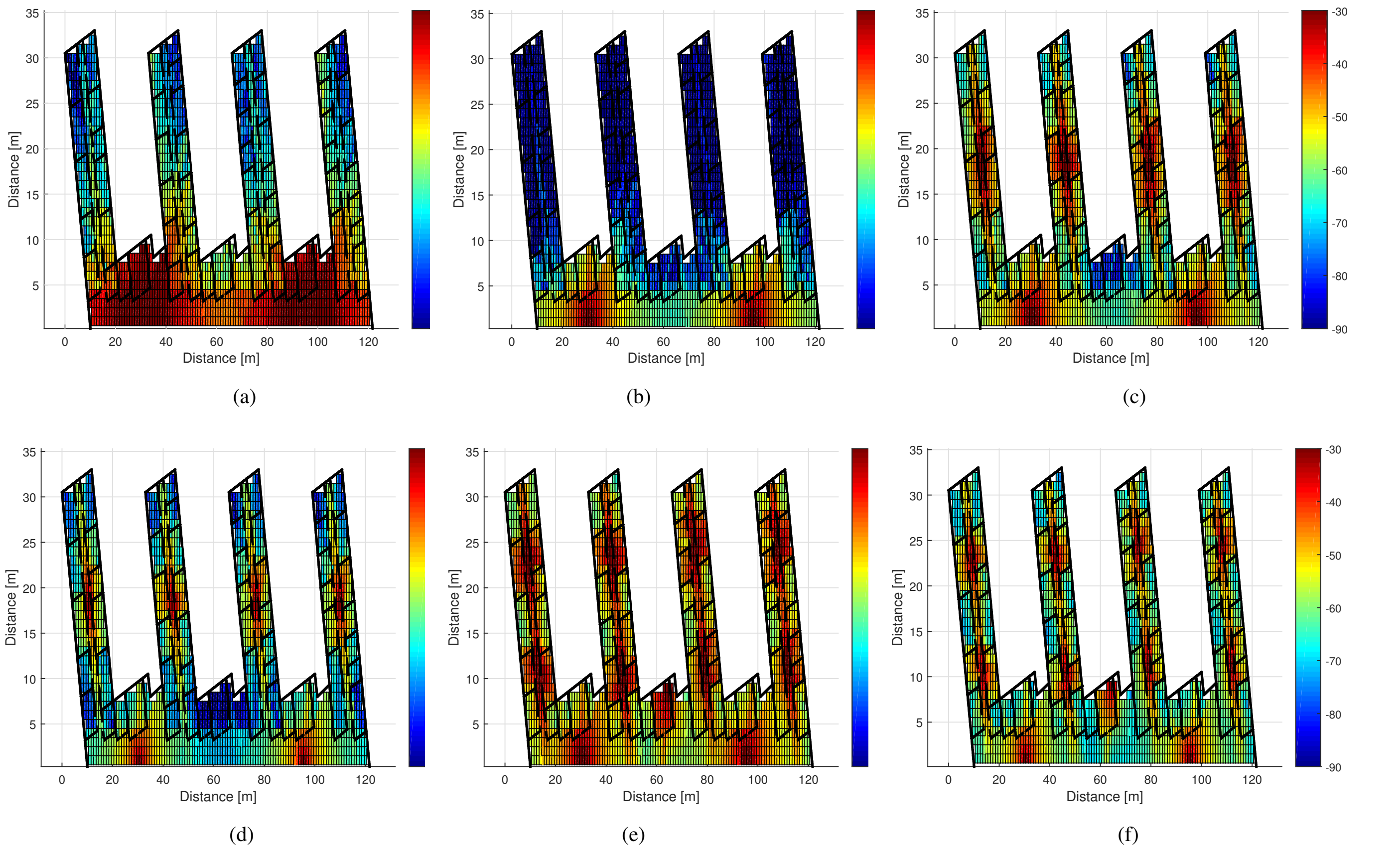


Fig. 2. Heat map of received signal strength with, (a) Reference layout with two transmission points at 3.5 GHz, (b) Two transmission points at 28 GHz, (c) Six transmission points layout at 28 GHz, (d) Six transmission points layout at 60 GHz, (e) Eleven transmission points at 28 GHz, and (f) Eleven transmission points at 60 GHz

power for indoor base stations, therefore the The transmit power for each transmit point is set to 250 mW (24 dBm). In terms of interference, a worst case scenario is considered where all the transmitters are assumed to be transmitted at their full power, with no power control. In literature different values of wall penetration loss is reported for different frequencies and for different kind of materials, and it is important to include wall penetration loss for accurate modeling. Therefore, in simulations the office partition walls are assumed to have the wall penetration loss of 4.3 dB, 6.8 dB, and 9 dB at 3.5 GHz, 28 GHz, and 60 GHz, respectively [5], [6]. There is huge amount of bandwidth available at 28 GHz and 60 GHz, therefore it is interesting to analyze the results with large bandwidths i.e. 200 MHz bandwidth at 28 GHz and 60 GHz.

III. Simulation Results and Discussion

There are several Key Performance Indicators (KPIs) used in mobile industry for analyzing the system performance, and the general parameter used for coverage and service prediction is received signal power. Fig. 2 shows the heat map of received signal strength in dBm value for few of the considered cases. Due to limited space only few cases are shown. The Fig. 2(a) shows the coverage map at 3.5 GHz with only two transmitters using a reference layout. It can be seen that the reference layout is not able to provide sufficient coverage even at 3.5 GHz. The received signal strength is low i.e. around -85 dBm in the rooms located at the end of the building wings. Propagation pathloss increases with the increase in frequency, therefore it can be envisioned that the coverage will get poor at mmWave frequencies. Fig. 2(b) shows the coverage heat map at 28 GHz with two transmission points. It is clearly visible that the system is certainly coverage limited, and undoubtedly the coverage will get worst at 60 GHz with two transmitters only. Whereas, the Fig. 2(c) shows the heat map of signal strength achieved with six transmitters 28 GHz. The signal coverage at 28 GHz is significantly improved with more number of transmission points, except a coverage hole in the middle part of the building. However, the coverage issue still prevails at 60 GHz as shown in the Fig. 2(d). Similarly, Fig. 2(e) and Fig. 2(f) shows the signal strength map with eleven transmission points at 28 GHz and 60 GHz, respectively. All those coverage holes are well accommodated with eleven transmission points. The received power results show that it is challenging to provide indoor coverage at 28 GHz and 60 GHz frequency even with far more number of antennas compared with 3.5 GHz frequency. Careful planning is needed to meet the service requirement at mmWave frequencies.

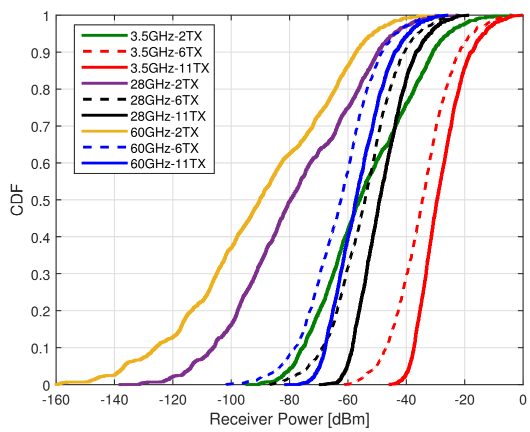


Fig. 3. CDF plots of received power for different configurations.

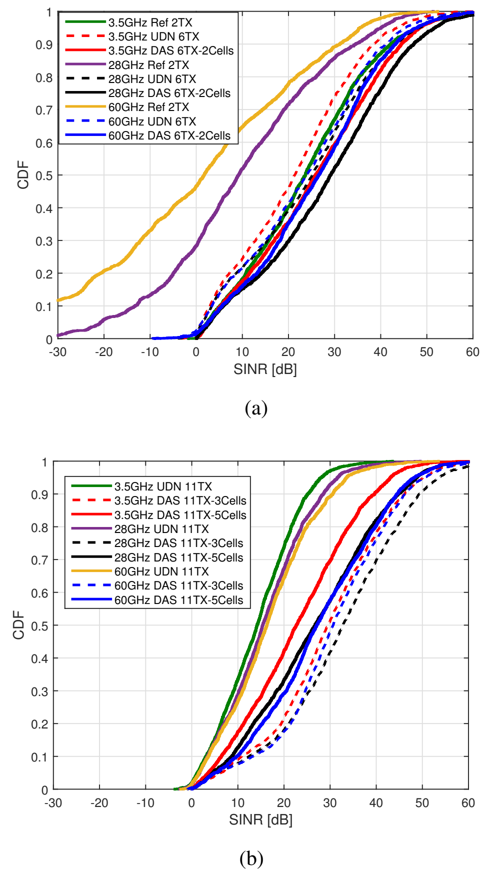


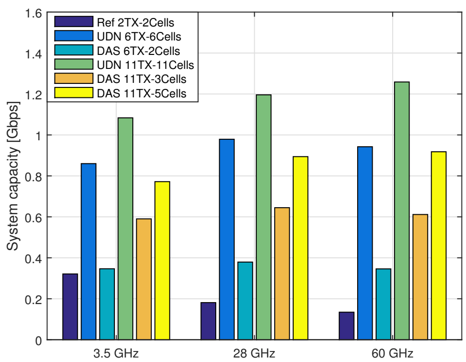
Fig. 4. CDF plots of SINR for reference layout along with, (a) Six transmission points configurations (b) Eleven transmission points configurations.

The Fig. 3 shows CDF plots of received power for reference network layout and UDN configurations. It is learned from the results shown in Fig. 3 that fairly a large number of RX points are certainly noise limited with reference layout at 28 GHz and 60 GHz frequency. Therefore ultra dense cell deployment or distributed antenna solution is required for providing proper indoor coverage. Almost 30 percentile and 50 percentile of the samples are below -90 dBm at 28 GHz and 60 GHz, respectively with two transmit antennas. The mean RX level of -54.02 dBm, -78.18 dBm, and -90.23 dBm were acquired with two TX antennas at 3.5 GHz, 28 GHz and 60 GHz respectively. The mean RX levels were improved by 19.62 dB, 23.62 dB, and 27.22 dB with six transmit antennas at 3.5 GHz, 28 GHz and 60 GHz, respectively, compared with reference layout. Similarly, the improvement of 25.69 dB, 30.03 dB, and 33.82 dB is witnessed in the mean RX levels at 3.5 GHz, 28 GHz and 60 GHz, respectively, with eleven transmission points compared with reference layout. There is a strict requirement of maximum allowed transmission power in an indoor environment, therefore high power cannot be used at the transmitters to compensate the higher pathloss at higher frequencies. This power limitation factor highlights the need of using a separate indoor solution for providing ubiquitous services to indoor users as outdoor users. It was found that the DAS layouts improved the signal strength by 0.15 dB-0.4 dB compared with UDN. Therefore, here the DAS results are not shown separately.

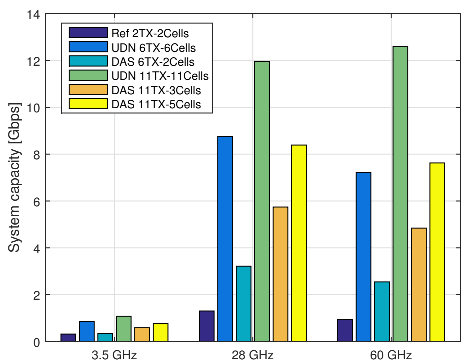
Another vital KPI considered in radio network planning is Signal to Interference plus Noise Ratio (SINR). The Fig. 4(a) shows the CDF plots of SINR for reference network layout and UDN layout with six transmission points, and two cells DAS configuration with six antenna locations. The received signal results presented in Fig. 3 has shown that the system is noise limited at 28 GHz and 60 GHz with reference layout as there were many samples with low received signal power. Similarly, in Fig. 4(a), it can be seen that fairly a large number of samples are with below 0 dB SINR at 28 GHz and 60 GHz with reference layout. Whereas, on the other hand the received signal level was improved with six transmission points and that in turn improves the SINR by vast margin for both 28 GHz and 60 GHz frequency of operation. The DAS configuration provides better SINR results compared with UDN configuration. The mean SINR of 28.3 dB and 25.74 dB is achieved at 28 GHz and 60 GHz, respectively, with DAS configuration. Whereas, the UDN offers a mean SINR of 24.16 dB and 23.22 dB at 28 GHz and 60 GHz, respectively, considering 20 MHz system bandwidth. Due to limited space the results with 200 MHz bandwidth are not included in Fig. 4(a). However, a separate analysis revealed that the SINR is degraded with 200 MHz bandwidth due to larger noise rise. It also highlights the fact that the received power is improved with more number of cells, however the SINR is still affected with 200 MHz bandwidth compared with 20 MHz bandwidth.

Fig. 4(b) shows the CDF plots of SINR for different configurations with eleven transmission points. With eleven transmission points the system is not noise limited at any of the considered frequencies. In case of UDN layout, the best mean SINR is acquired at 60 GHz and then comes 28 GHz and 3.5 GHz. It can be derived from this result that in case of ultra dense deployment of network the SINR becomes the direct function of frequency. It means higher the frequency of operation the higher will be the SINR of the system.However, in DAS operation the highest mean SINR of 31.21 dB is achieved with 3 cells DAS configuration at 28 GHz, and that is then followed by 30.54 dB of SINR at 60 GHz. Again, increasing the number of DAS cells deteriorate the SINR as can be seen by comparing the 3-cells and 5-cells DAS configuration.

Ultimately, the principal goal of mobile operator is to achieve



(a)



(b)

Fig. 5. System capacity, (a) 20 MHz bandwidth, and (b) 200 MHz bandwidth at 28 GHz and 60 GHz band.

a maximum system capacity while utilizing a fair fraction of financial resources. Therefore, it is critical to analyze the system capacity provided by different solutions presented in this paper. The Fig. 5(a) shows the bar graph of system capacity for different solutions at three different frequencies utilizing 20 MHz bandwidth. Although, the UDN solution has degraded the SINR compared with the DAS solution, however, due to more number of cells the maximum system capacity was achieved with eleven cells UDN configuration, and is then followed by six cells UDN configuration. It is important to mention here that the increase in system capacity is not linear with the increase in the number of cells in UDN configuration. Rather a considerable portion of capacity is lost due to excessive interference coming from the closely located cells in the ultra dense network. Whereas, the DAS configuration improves the cell capacity relatively by bigger margin while moving from 2-cell to 3-cell DAS layout. The Fig. 5(a) shows the comparison of capacities at 3.5 GHz, 28 GHz, and 60 GHz while utilizing a same bandwidth of 20 MHz. Whereas, Fig. 5(b) shows the gain in system capacity by using a large bandwidth i.e. 200 MHz at 28 GHz and 60 GHz frequencies. Interestingly, 5-cell DAS layout is able to provide better system capacity compared with 6 Cells UDN configuration due to better interference management at 60 GHz.

IV. Conclusion

In this paper the performance of different UDN and DAS configurations are analyzed in an indoor environment, and the system performance is analytically quantified in terms of received signal strength, SINR, and system capacity. The obtained results revealed that a dedicated indoor solution is necessarily required to meet the QoS requirement for indoor users at 28 GHz and 60 GHz. It was found that the basic indoor solution may provide essential level of coverage at 3.5 GHz. However, the system is clearly noise limited with basic indoor solution at 28 GHz and 60 GHz. Moreover, it is learned that the DAS deployment shows minor improvement in signal strength compared with UDN. Whereas,the DAS improves the SINR i.e. quality of the network by a healthy margin. However, the UDN deployment still provides more capacity than DAS layout due to more number of cells in the network. The gain in system capacity does not increase linearly with cell densification. Initially, a significant improvement in system capacity is witnessed while migrating from two transmitter layout to six transmitter layout at all considered frequencies. However, the relative capacity gain was limited to only 22%-33.5% while shifting from six cell dense deployment to eleven cells ultra dense deployment.

Acknowledgement

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