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## Analysis of Indoor Solutions for Provision of Indoor Coverage at 3.5 GHz and 28 GHz for 5G System

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Abstract—The 5th Generation (5G) wireless networks are envisioned to support emerging bandwidth-hungry applications. Millimeter wave (mmWave) communications have been considered as a promising solution for future capacity crunch due to large available bandwidth. However, an outdoor macrocellular layer lacks the capability of providing an adequate coverage to indoor users, especially at higher frequencies i.e. 28 GHz. Therefore, the provision of high data rates and high system capacity in an indoor environment requires a separate indoor solution. The main target of this paper is to analyze the performance of Ultra Dense Network (UDN) and Distributed Antenna System (DAS) deployment in an indoor (university office) environment at 1.8 GHz, 2.6 GHz, 3.5 GHz and 28 GHz frequency. This research work is conducted by performing a ray tracing simulation using a three dimensional floor plan. The obtained results show that an existing indoor solutions which are in operation at 2.6 GHz can be re-used at 3.5 GHz frequency with minor power adjustment, or by using antennas with little higher gain. However, the operation at 28 GHz requires a new plan for providing good indoor coverage. Acquired results show that DAS improves the cell capacity by reducing the interference. However, the UDN provides a higher system capacity due to more number of cells. The real gain of operation at 28 GHz can only be achieved by using larger system bandwidth e.g. 200 MHz band. Index Terms-Indoor coverage; Millimeter wave; 3D Ray

launching; 5G; System performance; 3.5 GHz; 28 GHz.

### I. INTRODUCTION

Applications with gigantic data rate requirement is projected to increase significantly in Fifth Generation (5G) cellular system. Emerging applications such as health care, high definition video streaming, high definition gaming, real time virtual reality, and augmented reality are few to name here which require high capacity. In order to address this challenging capacity demand, different solutions have been proposed in literature, and Millimeter Wave (mmWave) communication is one of them [1]- [2]. Millimeter wave communications have received considerable attention from both academia and industry due to large available bandwidth. Wide bandwidth in the mmWave communications can be utilized in the 5G cellular radio access networks in order to provide mammoth capacity [3]- [4]. However, mmWave communications has several drawbacks. Pathloss is the direct function of the frequency. Therefore, mmWave frequencies experience higher attenuation as compared with sub-6 GHz frequency band. Millimeter mmWave frequencies also encounter severe atmospheric absorption and rain attenuation. In addition, mmWave

features poor diffraction while encountering an obstacle [5]. Fortunately, the 28 GHz band has a small rain attenuation of 1.4 dB, and has a negligible atmospheric absorption of 0.012 dB over 200 m distance [2]. The 28 GHz band has an available bandwidth of over 1 GHz. These factors makes a 28 GHz band a favourite choice for mobile operators to start their 5G deployment with large frequency band. Providing ubiquitous coverage and delivering high Quality of Service (QoS) to the users in an indoor environment remains as a major challenge for radio network planners. As there is a strict requirement of maximum allowed transmission power in an indoor environment, therefore high power cannot be used to compensate higher pathloss at higher frequencies, likely to be used for 5G system. Moreover, wall penetration losses in an indoor environment are more prominent at higher frequencies [6]- [7].

An intuitive way of increasing the system capacity is to reuse the radio resources in the same geographical area as frequently as possible. The spectrum resources can be reused by decreasing the size of the cells, or in simple words by deploying small cells. The dense deployment of small cells is also termed as Ultra Dense Network (UDN) deployment. Especially in an indoor environment, UDN ensures un-interrupted coverage with high capacity. Another advantage of indoor UDN deployment is that it offloads the traffic from the macro layer, and spares the macro layer capacity for outdoor users [8]. In case of Distributed Antenna System (DAS), a single cell has spatially scattered multiple antennas. Power is being shared between the antennas using tappers and splitters. The deployment cost of DAS is less than small cell deployment, as in case of DAS each antenna does not require own RF module. However, the power sharing between the antennas makes the planning of DAS challenging compared with UDN [9].

Ray launching is a deterministic model used for radio propagation prediction. Rays are shoot from the transmitter with discrete intervals, which are then reflected, diffracted, and transmitted through the walls and obstacles. The target of this research work is to study radio propagation and system performance in an indoor environment using UDN and DAS system at current cellular frequencies and at future system frequencies i.e. 3.5 GHz and 28 GHz. This research work is carried out by performing ray tracing simulations using a ray launching tool and 3D floor plan data.

### II. BACKGROUND THEORY

### A. 5G

Three key drivers in 5G are identified as Enhanced Mobile Broadband (eMBB) services, support of Ultra Reliable and Low Latency Communications (URLLC), and Massive Machine Type Communications (mMTC). Due to power constrains/limitation in sensors associated with MTC/IoT devices, the energy efficiency in 5G systems has got vital attention. The 5G system is expected to provide multi-Gbps of data rates, and should support extensive future data growth. The 5G system is foreseen as highly reliable and security proof, and should support services such as mobile health care and autonomous vehicles with ultra low latency. Billions of sensor devices are expected to be operational in coming years, and 5G system should have the ability to support the massive number of Internet of Things (IoTs) sensors over the wide coverage area. In order to meet these requirements, a scalable Orthogonal Frequency Division Multiplexing (OFDM) numerology with extensible subcarrier spacing is recommended to be used for 5G radio access. The spectrum being considered by the operators for 5G lies in 3.4-3.8 GHz and 24.25-29.5 GHz range [10]. Therefore, for the study purpose of this paper the frequency band of 3.5 GHz and 28 GHz is selected.

### B. Potential of 28 GHz Band

Millimeter wave (mmWave) communications have been considered as a potential solution for eMBB services in 5G due to spectrum scarcity at sub-6 GHz band. The untapped spectrum available at mmWave band can be directly translated into large data rates and huge system capacity. On the other hand, mmWave communications has several inherent disadvantages such as higher penetration and propagation loss. Hence, it is challenging to provide indoor coverage at mmWave frequencies. The 28 GHz band has caught special attention due to small rain attenuation of 1.4 dB, and has a negligible atmospheric absorption of just 0.012 dB over 200 m distance [2]. Therefore, at 28 GHz the indoor small cells with cell radius of few tens of meters will not experience any extra attenuation due to atmospheric absorption or water vapours. It is essential to understand the propagation at mmWave frequencies for better planning and optimization of the network.

On the other hand, small wavelengths of mmWave frequency provide the possibility of incorporating large number of small size antennas in small space. Higher antenna gains can be achieved at mmWave frequency, and that directive antenna gain can compensate higher propagation losses upto some extend.

### C. Ray Launching

Propagation characteristics play a fundamental role in the planning and implementation of cellular system. Hence, it is desirable to perform accurate coverage prediction. Ray tracing methods are widely used for studying the channel models, as it is a deterministic model and it considers the physical phenomenon of propagation such as reflections, diffractions, transmissions through wall and scattering. Ray launching (RL)

technique based on Shoot and Bouncing (SBR) method is a promising approach to model the wireless channel using physical radio propagation characteristics. In SBR method, ray are emitted from the tramsmitter with discrete interval in angular domain. Ray continues to propagate until in interacts with some obstacle or wall. The received power at the receiver is the superposition of multiple rays reaching the receiver point from different directions [11]. Ray launching can be used for complex indoor environment, given an accurate indoor environment data is available. Ray launching tool based on SBR method developed by the authors of this paper can find the propagation paths between the transmitter and the receiver with high accuracy and computational efficiency. The computational load of the ray launching tool increase with the increase in number of emitted rays, and it also depends upon the complexity of the simulation environment.

### III. SIMULATION ENVIRONMENT, TOOL. CASES AND PARAMETERS

This section provides details about the simulation environment considered in this paper. It also gives detail about the tool used to carry out this research work. This section briefly explains the simulation methodology adopted, and describes different simulation cases considered in this paper.

### A. Simulation Environment and Tool

The target of this paper is to study about the indoor coverage. The floor plan of Information Technology building from Tampere University of Technology is used for the simulation and analysis. The two dimensional floor plan is shown in Fig. 1. The considered building has four wings, and the offices are made up of partition walls. A three dimensional floor plan is used for ray tracing simulations. The propagation paths between the transmitter and receiver are found by using a ray launching tool based on Shoot and Bouncing Ray (SBR) method. A ray launching tool is developed by the the authors using a MATLAB platform. Rays were launched from the transmitter with  $0.5^{\circ}$  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 considers Line of Sight (LOS) path, penetrated paths through walls, and paths with multiple reflections and diffraction. The test locations are homogeneously distributed in an indoor environment with 0.5 m separation. All the indoor test locations are assumed to have 1.5 m antenna height with zero dBi antenna gain. The total received power is computed as the sum of all the paths reaching at the receiver point.

### B. Simulation Cases and Parameters

This campaign of simulation targets four different frequencies. The two frequencies are selected from the existing cellular bands i.e. 1.8 GHz and 2.6 GHz, and the other two considered frequencies are the candidate frequency bands for the 5G system i.e. 3.5 GHz and 28 GHz. In this paper three network layouts are targeted. The details about each network layout is given as follows:



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

1) Reference layout with two cells: In this layout, there are only two transmitter points as shown in Fig. 1(a), and each transmitter point represents one cell. This is used as a reference layout for comparing the results with other network layouts.

2) Seven cells layout: In this layout, there are seven transmitter 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) DAS layout with three cells: In this layout, a single cell has multiple antennas located geographically far apart. In DAS layout, there are seven transmitters, however the transmit antennas TX1, TX3 and TX4 belong to Cell1, and the transmit antennas TX2, TX5 and TX6 belong to Cell2, and the Cell3 has only one transmit antenna as shown in Fig. 1(c).

All the transmit antennas are placed at the height of 3 m on the ceiling, and assumed to have omni directional antenna with unity gain in all directions. The transmit power for each transmit point is 250 mW (24 dBm). All the transmitters are assumed to be transmitted at their full power, with no power control and thus depicts the worst case scenario in terms of interference. In literature different values of wall penetration loss is reported for different frequencies and for different kind of materials. Therefore, in simulations the office partition walls are assumed to have the wall penetration loss of 4 dB, 4.3 dB, and 6.8 dB at 1.8 GHz, 3.5 GHz, and 28 GHz, respectively [6], [7], [12]. There is large system bandwidth available at 28 GHz, therefore results are also provided with 200 MHz of system bandwidth at 28 GHz frequency of operation. General simulation parameters are shown in Table I.

TABLE I GENERAL SIMULATION PARAMETERS

Parameters	Unit	Value
Frequency	GHz	1.8/2.6/3.5/28
System bandwidth	MHz	20/200
TX power per antenna	dBm	24
TX antenna height	m	3
RX antenna height	m	1.5
Wall penetration loss	dB	4/4/4.3/6.8
UE noise figure	dB	8

### **IV. SIMULATION RESULTS AND DISCUSSION**

The first metric considered for the analysis is the received signal strength. Fig. 2 shows the heat map of received signal strength in dBm value. However, due to limited space the heap map of received power level for only few cases are shown. The Fig. 2(a) shows that with the reference layout, an adequate coverage is not provided even at 1.8 GHz. The received signal strength is low i.e. around -80 dBm in the rooms located at the end of the four wings. Pathloss is the function of the frequency, and therefore it can be directly deduced that the signal coverage will be even more bad at other higher frequencies. Whereas, Fig. 2(b) shows the heat map of signal strength achieved with seven transmission points at 1.8 GHz. The coverage in the information technology building has significantly improved with more number of transmission points. All those coverage holes which were left in case of reference layout are well covered with 7 antennas. Similarly, Fig. 2(c) and Fig. 2(d) shows the signal strength map for seven cell layout at 3.5 GHz and 28 GHz, respectively. The different between the radio propagation at different frequencies are clearly evident, and Fig. 2(d) shows that it is challenging to provide indoor coverage at 28 GHz frequency even with far more number of antennas compared with the current cellular frequency.

Fig. 3 shows the CDF plots of received signal strength for reference network layout along with seven cell network layout. It is interesting to see that the mean RX level of -47.44 dBm acquired with reference layout i.e. with two antennas at 1.8 GHz is better than the mean RX level of -52.92 dBm obtained with seven transmit antennas at 28 GHz. It is learned from the CDF plots shown in Fig. 3 that quite a large number of RX points are clearly noise limited with reference layout at 28 GHz frequency of operation, therefore ultra dense cells or distributed antenna solution is must required for providing proper indoor coverage comparable to current cellular frequencies. The mean RX levels with reference layout are -50.64 dBm and -54.01 dBm at 2.6 GHz and 3.5 GHz, respectively, which is then further improved by 19-20 dB with more number of transmission points. The signal strength



Fig. 2. Heat map of received signal strength with, (a) Reference layout with two cells at 1.8 GHz, (b) Seven transmit point layout at 1.8 GHz, (c) Seven transmit point layout at 3.5 GHz, and (d) Seven transmit point layout at 28 GHz.



Fig. 3. CDF plots of received power for reference layout along with seven cell configuration.

results shown in Fig. 3 also highlight that existing indoor solution for current cellular frequency bands can be re-used for operation at 3.5 GHz frequency with minor power adjustment or by using antennas with little higher gain. However, the operation at 28 GHz requires a new plan for providing good

indoor coverage. There is a slight improvement i.e. less than 0.2 dB in signal strength with DAS configuration, therefore the received power results with DAS are not separately provided in this paper.

Fig. 4(a) shows the CDF plots of SINR for reference network layout along with seven cell network layout. For 28 GHz frequency, the SINR results are provided with 20 MHz and 200 MHz system bandwidth. As stated earlier that the system is noise limited at 28 GHz with reference layout for both 20 MHz and 200 MHz system bandwidth. Therefore, the SINR at 28 GHz is bad and pretty low compared with all other considered frequencies. Whereas, the received signal level was improved with seven cell deployment which in turn improves the SINR by huge margin for 28 GHz frequency of operation. The mean SINR of 24.23 dB and 21.97 dB is achieved at 28 GHz with 20 MHz and 200 MHz bandwidth, respectively. It also highlights the fact that once the received signal strength is improved with more number of cells, then the SINR is not much degraded even with 200 MHz bandwidth compared with 20 MHz bandwidth. Except 28 GHz case, the SINR is degraded while transiting from the reference layout to seven cell layout, due to the presence of more number of cells (interferers). The mean SINR at 1.8 GHz, 2.6 GHz, and



![](_page_5_Figure_1.jpeg)

Fig. 4. CDF plots of SINR for reference layout along with, (a) Seven cell configuration, (b) Three cell configuration with DAS.

Fig. 5. CDF plots of SINR upto 20 percentile, (a) Seven cell configuration, (b) Three cell configuration with DAS.

3.5 GHz is 20.35 dB, 20.35 dB, and 20.91 dB, respectively.

Fig. 4(b) shows the CDF plots of SINR for reference network layout along with DAS layout. It is interesting to see now that due to better radio propagation characteristics at 1.8 GHz, 2.6 GHz and 3.5 GHz, the DAS layout does not provide any gain in terms of improving the SINR compared with reference layout. Rather, the SINR is further degraded with DAS 1.8 GHz, 2.6 GHz, and almost same mean SINR of 23.9 dB is achieved at 3.5 GHz with reference and DAS layout. However, the DAS solution is found suitable for 28 GHz of operation and the mean SINR is improved from 9.79 dB to 27.14 dB by DAS at 28 GHz. It is important to mention here that with reference layout there are only cells in the network, and whereas with DAS and multicell layout there are three and seven cells in the system, respectively. In this case, two way advantages are acquired by DAS at 28 GHz, first it improves the SINR and secondly there are more cells in the system, which means more capacity.

It is hard to distinguish different cases upto  $20^{th}$  percentile data. Therefore, the  $20^{th}$  percentile data for SINR is sepa-

rately analyzed in Fig.5. Generally, the  $10^{th}$  percentile users represent the cell edge users, and those are considered as the most problematic users from the performance point of view. The mean SINR is -13.23 dB and -23.23 dB for  $10^{th}$  percentile users with reference layout at 28 GHz with 20 MHz and 200 MHz bandwidth, respectively, and therefore these cases are not shown in Fig.5(a) and Fig.5(b). The trend of curves is same for  $20^{th}$  percentile data as with whole data.

Summary of signal strength, SINR, cell capacity, and system capacity results is provided in Table II. We have already seen that how the SINR changes with different network layout at different frequencies. Now, it would be interesting to see the overall impact of different network layouts on system capacity, as there are different number of cells in different layouts. The focus of this paper is 3.5 GHz and 28 GHz, therefore they are more discussed here. At 3.5 GHz the mean system capacity with reference layout i.e. with two cells is around 0.32 Gbps, and then the system capacity is improved to 0.48 Gbps with DAS layout i.e. with three cells. The improvement in the system capacity is linear with the

TABLE II Summary of results.

	10 <sup>th</sup> prctile RX	Mean RX level	10 <sup>th</sup> prctile	Mean SINR	$10^{th}$ prctile cell	Mean cell	Mean system
	level $[dBm]$	[dBm]	SINR $[dB]$	[dB]	capacity [Mbps]	capacity [Mbps]	capacity [Gbps]
1.8 GHz Ref	-68.07	-47.04	5.56	25.64	44.02	172.13	0.34
1.8 GHz	-37.66	-26.82	3.95	20.35	36.02	137.87	0.97
1.8 GHz DAS	-37.55	-26.75	4.63	23.17	39.32	154.28	0.46
2.6 GHz Ref	-71.28	-50.65	5.48	24.78	43.59	166.49	0.33
2.6 GHz	-40.86	-30.62	3.95	20.35	36.03	137.87	0.97
2.6 GHz DAS	-40.76	-29.95	4.63	23.17	39.32	154.28	0.46
3.5 GHz Ref	-75.45	-54.02	5.14	23.87	41.44	160.62	0.32
3.5 GHz	-43.90	-32.85	4.01	20.91	36.29	141.53	0.99
3.5 GHz DAS	-43.74	-32.77	4.76	23.90	39.96	160.38	0.48
28 GHz Ref - 20MHz	-106.15	-78.19	-13.23	9.79	1.34	90.61	0.18
28 GHz Ref - 200MHz	-106.15	-78.19	-23.23	2.38	1.37	652.89	1.31
28 GHz - 20MHz	-65.79	-52.93	4.24	24.23	37.42	163.20	1.14
28 GHz - 200MHz	-65.79	-52.93	4.10	21.97	367.41	1484.30	10.39
28 GHz DAS - 20 MHz	-65.63	-52.86	5.17	27.14	42.01	182.12	0.55
28 GHz DAS - 200 MHz	-65.63	-52.86	4.87	23.77	404.89	1595.60	4.79

increase in number of cells with DAS layout. The system capacity is almost identical at 1.8 GHz, 2.6 GHz, and 3.5 GHz, as the signal propagation properties at these frequencies are similar. On the other hand, the mean system capacity is very low i.e. 0.18 Gbps and 1.31 Gbps with reference layout at 28 GHz 20 MHz and 200 MHz bandwidth. Reference layout is clearly not a suitable layout for 28 GHz. Whereas, DAS deployment improves the cell capacity as well as the system capacity. However, the maximum cell capacity of 10.39 Gbps is achieved with ultra dense network deployment at 28 GHz using 200 MHz bandwidth. This large available bandwidth at 28 GHz band makes it a suitable choice for the mobile operators for enhancing the system capacity by significant margin.

### V. CONCLUSION

This paper has examined the performance of UDN and DAS deployment in an indoor building environment at 1.8 GHz, 2.6 GHz, 3.5 GHz, and 28 GHz. Ray launching tool was used as a radio propagation tool for the simulations. The system performance is analytically quantified in terms of received signal strength, SINR, and system capacity. The acquired results indicate that the system is clearly noise limited at 28 GHz when the indoor coverage is provided with basic indoor solution. However, basic indoor antenna solution provides adequate coverage at lower frequencies. The 28 GHz deployment needs a UDN deployment or DAS solution for providing adequate indoor coverage. Secondly, it is learned that existing indoor solutions for 2.6 GHz can be re-used at 3.5 GHz frequency with minor power adjustment, or by using antennas with little higher gain. As the difference in mean received power levels between 2.6 GHz and 3.5 GHz is less than 3 dB. It is learned that the DAS deployment shows minor improvement in signal strength compared with UDN, however DAS improves the SINR by a healthy margin. It is also found that UDN still provides better system capacity compared with DAS due to more number of cells, despite of lower SINR compared with DAS.

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