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Channel Sounding and Measurements for Pico Cells for LTE and Future Wireless Networks

Sidharth Shukla*, Abhijeet Bishnu, and Vimal Bhatia

Indian Institute of Technology, Indore - 453 552, India
**E-Mail: shukla.sidharth@gmail.com*

ABSTRACT

Wireless networks are the preferred future access networks for both defense and civilian deployments as part of telecommunication networks. The successful implementation of long term evolution (LTE) networks and applications such as the Internet of Things (IoT) in the telecommunication infrastructure has guaranteed rates of up to 100 Mbps while supporting ultra-dense wireless access network. With the incorporation of LTE-Advanced and fifth-generation wireless protocols, the data rates are expected to reach upto 1 Gbps. Hence, there is a pertinent requirement to carry out channel measurements at sub 1 GHz, 2 GHz, and 3 GHz bands to enable the design and implementation of optimum transceivers for pico-cells of LTE and future wireless networks. For the first time measurements and comparison with standard models of channel impulse response models have also been carried out in five different terrains namely Urban, Semi-Urban, Forest, Rural, and Desert terrains in the Indian sub-continent to effectively cover a variety of deployments of future wireless access networks for defense wireless networks.

Keywords: Channel measurements; Channel sounding; CIR; LTE; LTE-advanced; Delay spread; LTE based defence networks

1. INTRODUCTION

Telecommunication networks are ever-evolving and can be categorised into two separate segments namely backbone network and access network[1]. The backbone network comprises of high date rate pure optical highway rings and mesh networks which use state-of-the-art dense wavelength division multiplexing techniques to substantially enhance the data-carrying capability of the existing optical fibers[2]. As a standby media, point-to-point microwave radio links are also used at critical portions of the backbone network segment. The access network segment of the telecommunication networks earlier comprised of copper cable links from the nearest access point to the end-user as the last mile connectivity. Due to the advancements in the wireless technologies and successful implementation of Long-Term Evolution (LTE) protocol[3] and future implementation planning of fifth-generation (5G) cellular technologies, the access network is primarily wireless. LTE as an implemented protocol is already delivering data rates of upto100 Mbps in the access network, whereas LTE Advanced promises download data rates of upto 1 Gbps[4], thereby replacing all copper links in the last mile connectivity.

The present LTE cellular technology is deployed worldwide and it has been observed that it is unable to satisfy the bandwidth (delivered datarate) requirements of end-users. Further, it is incapable to support the mass deployment of future disruptive technology of the Internet of Things (IoT) and supports real-time applications that require very low latency. 5G cellular technology will provide enhanced mobile broadband experience, support the mass deployment of IoT worldwide, and easily support the use of real-time applications in different geographical areas.

Future wireless protocols like 5G and beyond will provide such high data rates at multipath fading environments. Further, these future wireless networks will have small cell sizes to increase capacity in the form of heterogeneous networks (HetNets) comprising of pico-cells which need to be implemented in various terrains which have unique multipath fading characteristics in terms of signal to noise ratio (SNR), received signal strength (RSS) and delay spread (DS).

Hence channel measurements and analysis of CIR response for such small cell architecture is an inescapable requirement for designing and deployment of 5G and beyond trans-receivers of future wireless technologies. Given the above fast-changing access segment of the telecommunication networks, there is an urgent need to carry out channel sounding measurements for pico-cell sizes in multiple bands and in various terrains for doing channel impulse response (CIR) analysis. This CIR analysis can be used in HetNets cellular network[5] having various pico-cells. This will enable the design of efficient transceivers for future wireless technologies which are band-specific and perform optimally in various terrains of deployment.

2. RELATED WORKS

Measurements of channel parameters and analysis of indoor radio channels have been undertaken in[6-10]. Though

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these measurements have been undertaken for MIMO channels in 5.2 GHz, Ultra-Wideband using Software Defined Radios (SDR) and related hardware, but the measurements and channel models are for small distances and purely for indoor setup. Channel measurements on wideband radio and their analysis are discussed in[11] is also for purely indoor environments. Work on channel measurements for ultra-wideband channels has also been done[12-13] for WLAN architecture and specifically using WiFi frequency bands. Channel sounding on Wireless Fidelity (WiFi) 802.11b on the GNU radio platform has been researched[14]. There has been a substantial amount of work in channel sounding for wideband in and around 60 GHz[15-17]. But, these applications will be specifically for 5G cells in the upper 30 GHz bands and picocells only. These bands are not being presently used and may not be implemented for 5G shortly. Further, research on channel models and measurements in virtual drive test methodology and a high-speed train environment for indoor environments for protocols like WiFi and 60 GHz has been undertaken in LTE/LTE-Advance channel models[18-20]. However, channel sounding and measurements for LTE and future wireless protocols for sub-1, 2, and 3 GHz bands for different real terrains in the Indian sub-continent, which could be easily applied to similar terrains worldwide, for pico-cell sizes has not been undertaken to the best of author's knowledge. This research work undertakes channel sounding and measurements at both indoor and field conditions for sub-1, 2, and 3 GHz bands, and for five different terrains namely Urban, Semi-Urban, Forest, Rural, and Desert terrains in India to effectively cover varied deployments of future wireless networks in pico-cell sizes suitable for both commercial and defense requirements.

3. CHANNEL SOUNDING PARAMETERS

Channel sounding for a multipath channel is the process of analysing and understanding the behaviour of a channel for a specific band of frequency for the duration of measurement[21]. An impulse is transmitted through the channel and consequently, the response of the channel to the impulse is measured. This process is repeated multiple times. The above measurements are thereafter ensembled and analysed to ascertain the distortion in amplitude and phase of the transmitted signal by the channel in that duration. Further, the transceivers are designed for a specific band to minimise the effect of channel distortion. These transceivers incorporate equaliser circuits, which will undo the effect of the channel distortion in the amplitude and phase during the channel sounding process.

Various parameters are utilised to analyse the channel measurements during the channel sounding and the same are enumerated below:

(a) *Signal to Noise Ratio (SNR)*

It is defined as the ratio of the transmitted signal power (P_T) to the noise power (P_N) in a multipath channel environment as

$$SNR(dB) = \log\left(\frac{P_T}{P_N}\right) \tag{1}$$

(b) *Received Power* (P_R)

It is the measure of power received at the receiver during the channel sounding process.

(c) *Delay Spread* (σ_τ)

Mean excess delay (τ) and the rms delay spread (σ_τ) are multipath channel parameters that can be determined from a power delay profile (τ). τ is the first moment of the τ, whereas σ_τ is the square root of the second moment of τ and defined as:

$$\sigma_\tau = \sqrt{\tau^2 - \overline{\tau}^2} \tag{2}$$

4. CHANNEL MODELS

There are varieties of channel models available that give the power delay profile of a wireless channel for different frequencies, bandwidth, and environment. The models are specific to the frequency of operation and also to the type of terrain under which the transmitter and receiver are deployed. The following popular models have been considered in this paper for analysis with the real channel measurements:

4.1 Semi-Urban Macrocell Model

This type of model consists of a suburban scenario with some residential buildings and structures. Hills and vegetation are assumed to not be so high. The base station position is ina high position. The pathloss is chosen to be modified COST 231 Hata urban propagation model[22].

4.2 Urban Macrocell Model

This model consists of large cells with moderate height building and significant scattering. The position of the base station is at a high elevation well above the rooftops of any building. The pathloss in this case is also the modified COST 231 Hata urban propagation model[22].

4.3 Urban Microcell Model

This model describes small urban cells and the base station position is located at the rooftops level. The non-line of sight pathloss is chosen to be the COST 231 Walfish–Ikegami[22].

4.4 COST 207 Model

This model is based on 8-10 MHz channel bandwidth in the ultra-high frequency band used for the global system for a mobile communication system. This is also applicable for wideband code division multiple access channel characterisations. This model describes normalised scattering functions as well as amplitude statistics for four classes of the environment: Rural, Urban, Semi-Urban, and Hilly terrains. The values of the delay spread for different terrains are given in[23].

4.5 Stanford University Interim (SUI) Model

This model characterises the channel for WIMAX application in a suburban environment. The model is jointly developed by Stanford University with the IEEE 802.16 working group. The model consists of three categories with frequency ranges around 2 GHz for the forest, hilly and flat terrains. It accounts for a variety of Doppler spreads, delay spread, and LOS/NLOS conditions that are typical of a country like the United States[24].

The above models have been developed for specific frequencies, locations, and terrains, and can give an estimate of the received power levels and delay spreads on the operation of wireless links at specified parameters. The rms delay spread of all the above channel models is considered for comparison with real channel measurements for various terrains in our experiment. The popular COST 207 and SUI channel models have been considered in this paper for comparison with real channel measurements for various terrains. Recent work on performance analysis of wireless protocols on the COST 207 channel model[25-26], and SUI channel model[24-27] are available.

5. CHANNEL SOUNDING AND MEASUREMENT SETUP

To undertake channel sounding and thereafter measurement of the multipath channel conditions the measurement setup as given in Fig. 1 was incorporated. The Lab indoor setup is shown in Fig. 2.

The channel measurements were undertaken by transmitting an impulse from a Signal Generator (Keysight Signal Generator Model No: MXG N5182B) which was coupled to a horn antenna. The signal traverses 100m -150m to realise an average pico-cell size and is received by a horn antenna coupled to a Signal Analyser (Keysight Signal Analyser Model No: PXA N9030B). The procedure to set up the measurement is as enumerated below:

(a) Connect the Horn Antenna, which is a directional antenna, and has been duly calibrated for impedance matching with the output power of the Signal Generator (Keysight Signal Generator Model No: MXG N5182B) and the Signal Analyser (Keysight Signal Analyser Model No: PXA N9030B).

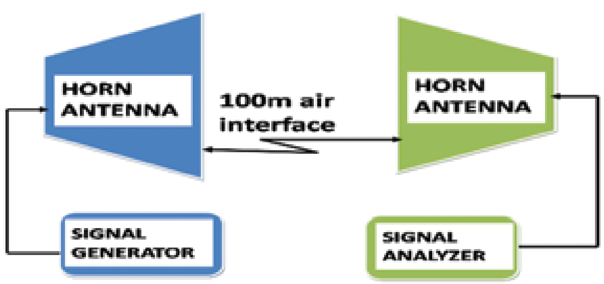

Figure 1. Block diagram of measurement setup for channel sounding and measurement.

(b) Power on both the Signal Generator and setup the frequency output of the Signal Generator to 9 kHz to 6 GHz. Select channel measurements setup with the auto-calibrated impulse response.

(c) Power on the Signal Analyser and setup the frequency input from 10 Hz to 50 GHz. Select the X-Series Software for cellular communications protocol suite for LTE and LTE-Advanced Features.

The annotated screenshot of the output as seen on the Keysight Signal Analyser Model No: PXA N9030B is shown in Fig. 3.

The detailed setup procedure for signal generator and signal analyser is given in user manuals in[28] and[29] respectively.

The measurements are taken after setting the frequency in the Signal Analyser at 700 MHz, 1850 MHz, and 2350 MHz. The received impulse response is analysed in terms of levels of SNR, Received Power, and Delay Spread of the received Impulse response in the window of the Signal Analyser as seen in Fig. 3

The received signal and its relevant parameters from the above measurement setup are tabulated in Section 6 and analysed in great detail in Section 7.

The important parameters from the datasheets for Signal Analyser and Signal Generator are given in Table 1 and Table 2, respectively.

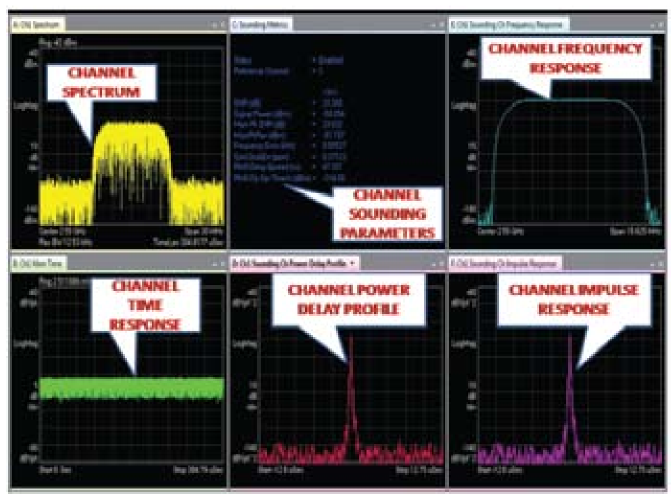

Figure 3. Screenshot of the output as seen on the signal analyzer.

Figure 2. Lab measurement setup for channel sounding and measurement.

Table 1. Data sheet of signal analyser

Parameter	Value
Frequency	2Hz to 50GHz
Frequency options	3.6, 8.4, 13.6, 26.5, 43, 44, 50 GHz, Mixers to 1.1 THz
Maximum analysis bandwidth	510 MHz
Bandwidth options	25 standard, 40, 85, 125, 160, 255, 510 MHz
Maximum real-time bandwidth	510 MHz
Real-time bandwidth options	85, 160, 255, 510 MHz
DANL @1 GHz	-174 dBm
Phase noise @1 GHz (10 kHz offset)	-136 dBc/Hz
Phase noise @1 GHz (30 kHz offset)	-136 dBc/Hz
Phase noise @1 GHz (1 MHz offset)	-146 dBc/Hz
Overall amplitude accuracy	±0.19 dB
TOI @1 GHz (3rd order intercept)	+22 dBm
Maximum dynamic range 3rd order @1 GHz	118 dB

Table 2. Data sheet of signal generator

Parameter	Value
Output power @1 GHz	-144 dBm to +26 dBm
Phase noise @1 GHz (20 kHz offset)	-146 dBc/Hz
Frequency switching	≤ 800 µs
Harmonics @1 GHz	<-35 dBc
IQ modulation BW internal/external	160 MHz to 200 MHz
Non-Harmonics @1 GHz	-96 dBc
Sweep mode	List,step
Baseband generator mode	Waveform playback and real-time
Frequency modulation-maximum Deviation @1 GHz	4 MHz
Frequency modulation-rate @100 kHz deviation	DC to 7 MHz
Phase modulation-maximum deviation in normal mode	0.5 rad to 8 rad

6. CHANNEL MEASUREMENTS

The measurements have been undertaken at five different terrains namely Urban, Semi-Urban, Forest, Rural, and Desert terrains to effectively cover varied deployments of future wireless networks in pico-cell in the Indian sub-continent. The details of the terrains and the locations of measurements undertaken in the Indian sub-continent are enumerated in Fig. 4.

The channel measurements have been undertaken to facilitate design and development of future wireless transceivers operating in various terrains, for pico-cell sizes, and for the following three bands to ensure entire coverage of LTE and other future wireless standards:

(a) Sub 1 GHz - 700 MHz
(b) Sub 2 GHz - 1.850 GHz
(c) Sub 3 GHz - 2.350 GHz

The channel measurements have been done in three phases as given below:

6.1 Phase-1 (Sub-1GHz)

In the first phase, the channel measurements for Sub 1 GHz - 700 MHz bandwidth 20 MHz bandwidth for five different terrains namely Urban, Semi-Urban, Forest, Rural, and Desert terrains are undertaken. The measurement values of SNR, Receive Power, and Delay Spread for 700 MHz with 20 MHz bandwidth, the 100-meter distance between transmitter and receiver at -10 dBm transmitter power are tabulated in Table 3. The calculated values of delay spread from COST-207 models are compared with the measured value of the delay spread in Table 3.

6.2 Phase-2 (Sub-2 GHz)

In this phase, the channel measurements for Sub 2 GHz - 1.850 GHz bandwidth 20 MHz for five different terrains namely Urban, Semi-Urban, Forest, Rural, and Desert terrains are undertaken. The measurement values of SNR, Receive Power, and Delay Spread for 1.850 GHz with 20 MHz bandwidth, the 100-meter distance between the transmitter and receiver

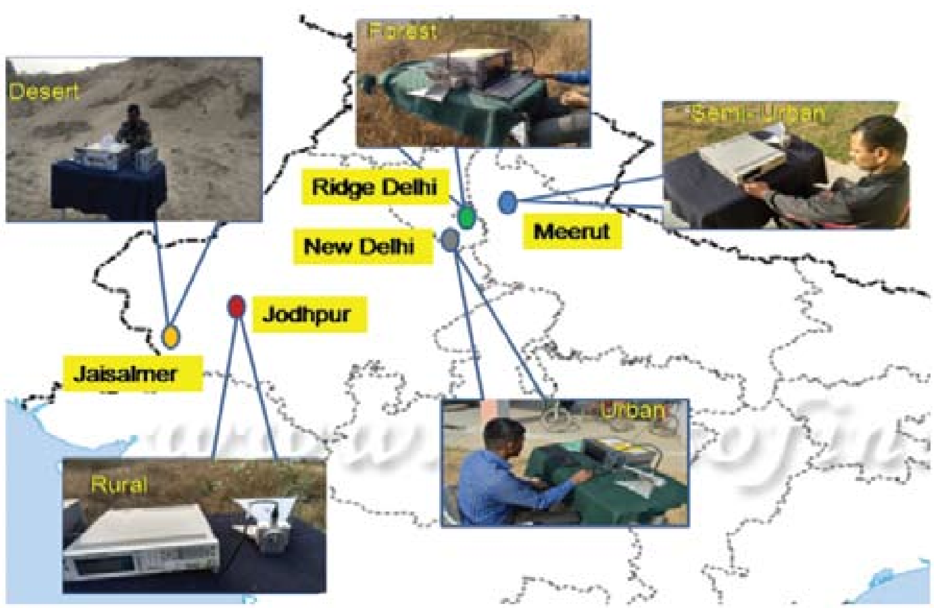

Figure 4. Details of the terrains and the locations of measurements undertaken in India.

Table 3. Parameter measurements for 700 MHZ

Terrain	SNR (dB)	Rx Power (dBm)	Delay spread (ns)	Delay spread (ns) COST-207	Delay spread (ns) microcell	Delay spread (ns) macrocell
Urban	25.81	-66.59	23.32	1250	251	650
Semi-urban	37.67	-52.71	22.56	1650	-	170
Forest	14.27	-77.36	27.96	4300	-	-
Rural	33.93	-47.8	17.21	150	-	-
Desert	35.87	-45.91	15.65	-	-	-

at -10 dBm transmitter power are tabulated in Table 4. The calculated values of delay spread from the COST-207 models are compared with the measured value of the delay spread in Table 4.

6.3 Phase-3 (Sub-3GHz)

In this phase, the channel measurements for Sub 3 GHz -2.350GHz band for five different terrains namely Urban, Semi-Urban, Forest, Rural, and Desert terrains are undertaken. The measurement values of SNR, Receive Power and Delay Spread for 2.350 GHz with 20 MHz bandwidth, the 100-meter distance between transmitter and receiver, and -10 dBm transmitted power are tabulated in Table 4. The calculated values of delay spread from the SUI-1(C) model, are also compared with the measured delay spread in Table 5.

7. CHANNEL MEASUREMENT ANALYSIS

We observe that the calculated values of delay spread from other considered models in Tables 1, 2 and 3 are substantially higher than their respective measured values. The reasons for the same could be that as per these models the BS should be at around 30m or higher, and the distance between BS and MS should be greater than 5 km. Contrary to the above scenarios, in our measurement setup, the height of BS is at 1.5m and the distance between BS and MS is 100m, as we are addressing deployments of pico-cells of LTE and future wireless networks. Further, we used a horn antenna which directs the signal towards a direction and hence leads to a small delay spread as compared to the omni directional antenna. This ensures that the delay spread for the measurement setup is substantially lower than that calculated from the channel models, which are ideally not applicable for pico-cell deployments.

Further, graphical representations of the channel measurements for Sub 1 GHz - 700 MHz bandwidth 20 MHz for five different terrains namely Urban, Semi-Urban, Forest, Rural, and Desert terrains is given in Fig. 5.

The graphical representations of the channel measurements for Sub 2 GHz - 1.850 GHz bandwidth 20 MHz for five different terrains namely Urban, Semi-Urban, Forest, Rural, and Desert terrains is given in Fig. 6.

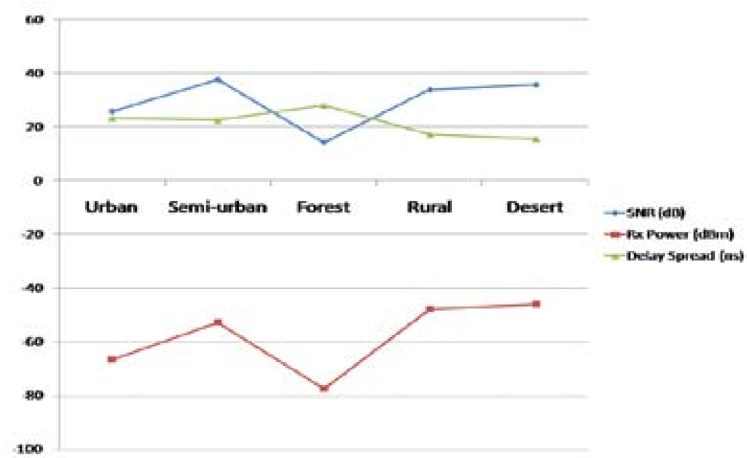

Figure 5. Analysis of measurement results for Sub 1 GHz-700 MHz band with 20 MHz for five different terrains.

Table 4. Parameter measurements for 1.850 GHz

Terrain	SNR (dB)	Rx Power (dBm)	Delay Spread (ns)	Delay Spread (ns) COST-207	Delay Spread (ns) Microcell	Delay Spread (ns) Macrocell
Urban	5.645	-72.954	27.542	1250	251	650
Semi-urban	13.72	-58.717	23.583	1650	-	170
Forest	2.348	-83.074	29.091	4300	-	-
Rural	16.178	-53.253	19.75	150	-	-
Desert	19.997	-52.142	16.146	-	-	-

Table 5. Parameter measurements for 2.350 GHz

Terrain	SNR (dB)	Rx power (dBm)	Delay spread (ns)	Delay spread (ns) SUI-1(C)	Delay spread (ns) microcell	Delay spread (ns) macrocell
Urban	4.213	-75.1	28.575	112.5	251	650
Semi-urban	12.503	-64.37	25.898	112.5	-	170
Forest	-3.331	-86.587	32.015	112.5	-	-
Rural	14.953	-58.782	24.384	112.5	-	-
Desert	18.209	-54.097	22.954	-	-	-

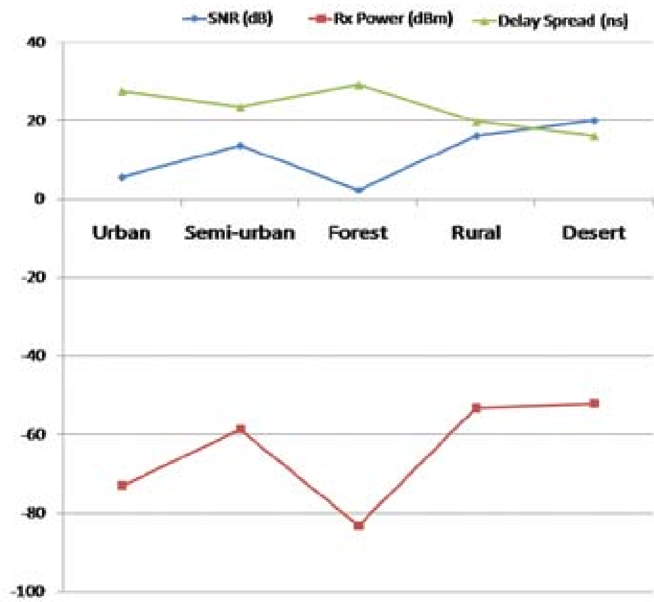

Figure 6. Analysis of measurement results for Sub 2 GHz-1.850 GHz band with 20 MHz for five different terrains.

The graphical representations of the channel measurements for Sub 3 GHz -2.350 GHz bandwidth 20 MHz for five different terrains namely Urban, Semi-Urban, Forest, Rural, and Desert terrains is given in Fig. 7.

It can be inferred from Figs. 5-7 that the SNR (in dB) and the Receive Power (in dBm) increases from Urban terrain to Semi-Urban terrain due to a decrease in building density, however significant drops for Forest terrain due to foliage losses as absorption is observed. The above parameters further increase substantially for Rural Terrain, as the spread of buildings increases. Further, the parameters marginally increase for Desert terrain as it offers obstruction-free propagation. On the other hand, the graph for delay spread (in ns) decreases from Urban terrain to Semi-Urban terrain due to a decrease in building density, however, increases for Forest terrain due to foliage losses and absorption. The graphs further decrease for Rural Terrain, as the spread of structures increases and thereafter marginally decreases for Desert terrain as it offers obstruction-free propagation.

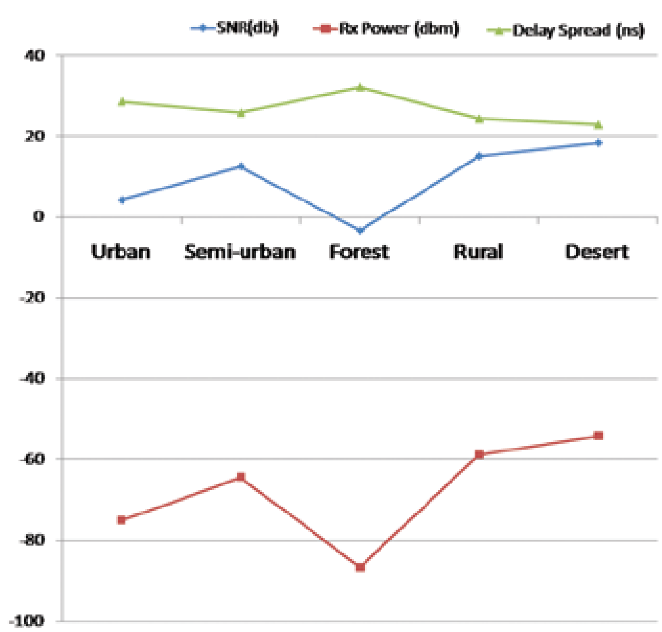

Figure 7. Analysis of measurement results for Sub 3 GHz -2.350 GHz band with 20 MHz for five different terrains.

The Channel Capacity Plots for each frequency band of operation with values for different terrain types have been plotted for better analysis and are shown in Figs. 8 to 10.

On analysing the Channel Capacity Plots of Fig. 8 to 10 brings out the following: -

(a) The value of channel capacity increases from Urban to Semi-Urban terrains for all the three bands, as the density of buildings decreases from Urban to Semi-Urban terrain and hence substantial increase of channel capacity value.

(b) Further, we see the value for channel capacity decreases substantially for Forest terrain, due to heavy foliage losses due to absorption, in all the three bands of measurements.

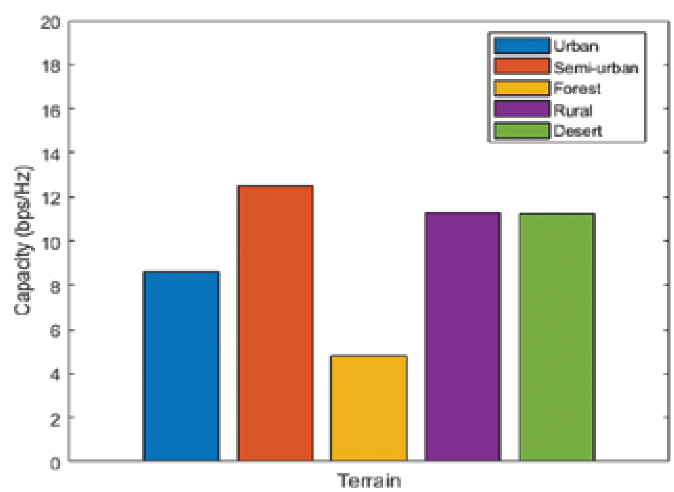

Figure 8. Channel Capacity of different terrain for sub 1 GHz – 700 MHz band.

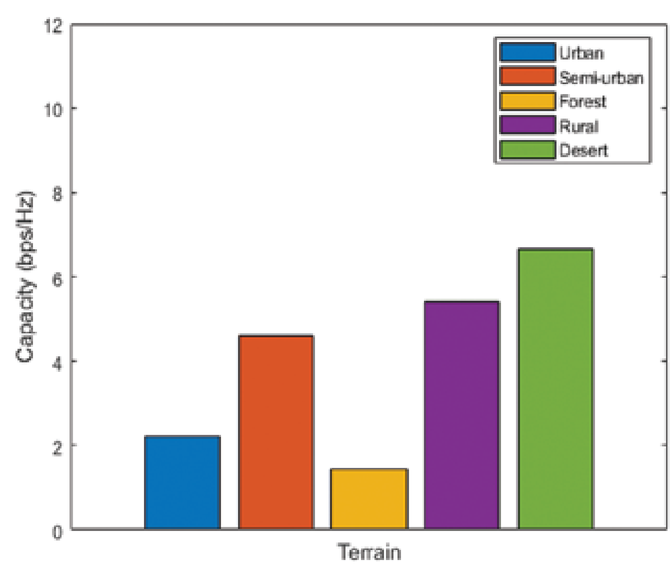

Figure 9. Channel Capacity of different terrain for sub 2 GHz – 1.850 GHz band.

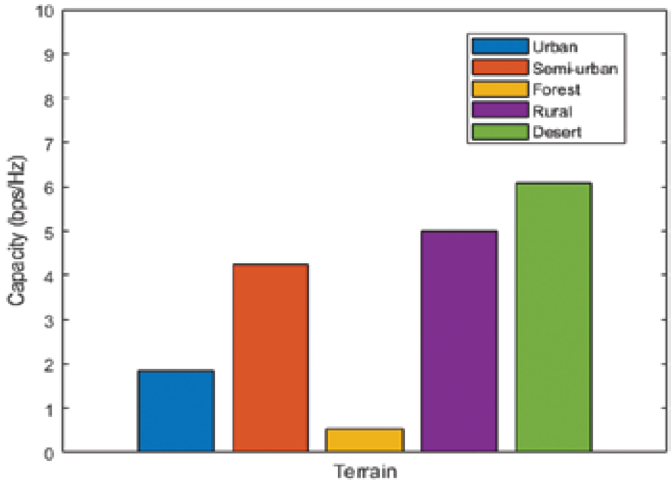

Figure 10. Channel Capacity of different terrain for sub 3 GHz – 2.350 GHz band.

(c) Finally, we notice that the value of channel capacity for Rural and Desert Terrains increases substantially, for all the three sub-bands of measurements. This is because Rural and Desert terrains offer obstruction-free propagation for the cellular signals, and thus provide higher values of channel capacity.

These findings are also suitable for connecting the unconnected in the rural and remote areas of the Indian subcontinent. Further, LTE-based or future wireless technologies like 5G and beyond[30] based defense networks, which are incorporating pico-cells for deployment and are dynamic which require flexibility for success in real operations, are a need of the hour. To ensure proper designing of transmitters and receivers and optimum implementation of such present and future wireless technologies in defense networks, the above channel measurements, and their analysis are a pre-requisite.

The above research work has been extensively carried out in various sub-bands and for various terrains. The limitations of the research work are that the work qualifies only for pico-cells at the moment, due to the limitation of the output power of the transmitting hardware of the measurement setup. As a future scope, the same measurements can be undertaken for micro-cells which have a cell coverage of 200m to 2 Km by incorporating powerful transmitter hardware in the measurement setup. Both pico and micro-cells would be incorporated for the deployment of 5G technology which will support IoT and artificial intelligence (AI) applications soon.

8. CONCLUSION

The telecommunication access network is fast migrating to high data rate wireless networks which incorporate LTE/LTE-Advanced standards and in near future will augment 5G wireless standards. Pico-cell deployments will be favored to increase the capacity of these future wireless networks. Such networks are ideally suited for civilian and defense deployments. These networks are prone to multipath fading conditions due to higher bands of operation and the use of high data rates. For the first time, channel sounding measurements and analysis which have been undertaken in multiple bands and various terrains in the Indian sub-continent in this research work characterises the above channels for the deployment of present and future wireless civilian and defense networks in pico-cells. This measurement and analysis will enable optimum design and deployment of future wireless transceiver technologies in varied terrains for future deployments in civil and defense establishments.

As a future direction to this research work, the channel measurements can further be conducted for microcells which can cover upto 2 Km range in cellular architecture. The above measurements of pico and micro-cells in various terrains of the Indian sub-continent, which can be used for similar terrains worldwide, will be suitable for future deployment of 5G technology which will support IoT and AI applications soon.

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CONTRIBUTORS

Dr Sidharth Shukla has done his MTech in Communication Systems from IIT Roorkee, and PhD from IIT, Indore. He is a Lieutenant Colonel in the Corps of Signals in the Indian Army and has worked in the telecommunication networks for the last 18 years. He has been involved in optical networks, ATM and MPLS switching technologies, 3G cellular networks, WiMax networks and designing and implementation of LTE network for the Indian Army.
Contribution in the current study - Primary work in terms of physical channel measurements, and their detailed interpretations and analysis.

Dr Abhijeet Bishnu received his BE in Electronics and Communication Engineering from Technocrat Institute of Technology, Bhopal, India in 2010. He also received his ME in Electronics and Telecommunication Engineering from S.G.S.I.T.S. Indore, India in 2013. He did his PhD from Indian Institute of Technology Indore, India, in 2019. He is currently a postdoctoral research associate in The University of Edinburgh, UK. His research interests include signal processing for wireless communications, cognitive radio, and full-duplex communication.
Contribution in the current study - Involved in comparison of measured channel model parameters with the existing channel models

Dr Vimal Bhatia received PhD from Institute for Digital Communications at The University of Edinburgh (UoE), UK in 2005. He is currently a Professor with IIT Indore. He has over 120 publications in international journals and conferences and has filled 11 patents. He is a recipient of DeitY's Young Faculty Research Fellowship and Senior Member IEEE. His research interests are in the algorithms and solutions for future communication and optical systems.
Contribution in the current study - Overall supervision and guidance of the research work.