5G Technology Proposals Evaluation

A Project Report

Submitted by

PREETHI P
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THESIS CERTIFICATE

This is to certify that the thesis entitled **“5G Technology Proposals Evaluation”** submitted by **PREETHI P** to the Indian Institute of Technology, Madras for the award of the degree of BACHELOR OF TECHNOLOGY in ELECTRICAL ENGINEERING & MASTER OF TECHNOLOGY in ELECTRICAL ENGINEERING is a bona fide record of research work carried out by her under my supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

Prof. David Koilpillai
Professor & Head
Department of Electrical Engineering
Indian Institute of Technology Madras
Chennai – 600 036.

TABLE OF CONTENTS

LIST OF FIGURES

All figures are used from the **Report ITU-R M.2412-0 [1] .** The mathematical equations and expressions in Chapter 2 are taken as reference from the same document from the literature survey.

Chapter 1

Introduction

Evolution of cellular standards

There has been a continuous evolution of digital cellular technologies, right from the first time cellular technology trasitioned from analog to digital in 1990. It has evolved through different generations or standards ranging from 1G to 4G and 5G has already been deployed in a handful of areas and its widespread deployment is expected soon. 1G (deployed in 1980) was an analog system which used FM and FDMA techniques where providing voice services was the predominant application of the technology.

The first digital cellular technology, was deployed as 2G in 1990, with voice transmission still being the main use case and an additional option to send text messages and data with speeds of upto 64 kbps over the network. It uses GSM as its key technology and 2G is still the most widespread cellular technology used in India and many other developing countries for voice transmission. There were improvements such as CDMA, GPRS, EDGE done to 2G, which improved the data rates upto 144 kbps and enabled services like email and web-browsing.

3G which used WCDMA as a key technology, came into the picture in 2000 and there was a significant improvement in data speeds, which increased upto 2Mbps when initially deployed and upto 20Mbps later. Global roaming was enabled for the first time and data based applications like video streaming also came into picture with it.

With higher demands for data based applications, the data speeds provided by 3G were not enough and this paved way for 4G in 2010, where even voice was sent over as packets(VOIP) and LTE was the key technology used. It used OFDM and MIMO as the key technologies and supports data rates in the range 20-1000 Mbps and thus enabled high quality video streaming and other such applications.

Motivating factors for deploying 5G

Through the evolution of these standards, new countries have joined the making process of these cellular standards and India has also become a small part in bringing up the 5G ecosystem along with countries like South Korea, USA, China and Europe.

Today cellular technology has become a common man’s technology and the market for it has grown manifolds. While 4G managed to provide good enough data rates, they were not designed to support extremely high data rates, low latency to support real time applications like automated vehicles or to support a large number of IOT devices, which clearly are the order of the day. These are the key motivating factors to bring in 5G, designed to support upto speeds of 10 Gbps.

Technologies that provide 5G with significant advantages over 4G

There are several key technologies used in 5G which enables it to serve the ever growing demand for data. OFDM which is already the main technology used in 4G, has been ramped up in 5G, to optimize the signals sent and pack users in a better way during the implementation of frequency division multiplexing , by the means to support multiple frequency allocation granularities.

The other key technology being Massive MIMO, which includes directional beams targetting specific users, unlike the some of the previous cellular standards where the signals were transmitted all around. This makes energy utilization optimal and enables the ability to serve the users more efficiently. Massive MIMO essentially transmits from several small antenna elements instead of a single antenna that transmit multiple narrow beams, which thus enables beam-forming and also subsequently increases the data capacity that can provided to users in a downlink scenario.

The key factor enabling drastic differences in data speeds in 5G, is the use of mmWave spectrum bands, frequencies above 20GHz. Though there is a flipside of the issue of transmitting signals efficiently at these frequencies, which have been tackled with the help of technologies like phased arrays, they provide much larger bandwidths compared to the lower frequencies used in earlier standards like 700 Mhz or 4GHz, thus increasing the data capacity manifolds.

Definition of cellular standards and bringing about the technology

The International Telecom Union (ITU) is the body that defines each generation of these cellular/ wireless standards and makes sure the spectrum needed for these standards are allocated accordingly. It is an UN agency that legally binds all of its member countries. 3G/CDMA was defined by IMT-2000 , 4G/LTE by IMT-Advanced and 5G by IMT-2020. The ITU essentially defines the targets of KPIs like user experienced data rate, peak and average spectral efficiency, to list a few examples, that are to be met by each cellular standard/ generation developed.

The Third Generation Partnership Project(3GPP) initially set up to bring about the 3G standard, is the body that makes the cellular technology to meet the ITU and consumer requirements. It is made up of key technology companies and research labs and has been the significant contributor in developing 3G, 4G and 5G standards and all the existing standards are complaint with those made by 3GPP. It submits the proposed technology to ITU for ratification. The ITU has independent bodies which verify if they meet the set standards.

The 5G Testbed in India

The IITM 5G testbed, as a part of the 5G testbed comprising a lot of institutes and industrial contributors with funding from the Department of Telecommunicatons (DOT), has been developing the 5G standard specifically for Indian markets. The major goal has been to bring up the deployment of 5G standard in India and to increase India's participation in global forums like 3GPP and ITU and present the test/ evaluation results for Indian use cases.

Simulations and Evaluation procedure of the proposed candidate technologies

As a part of India's telecom standards organization TSDSI's submission of candidate RITs and SRITs to the IMT-2020 evaluation, the 5G IITM testbed has been developing standards too and consequently been simulating the same for evaluations.

The 5G candidate RadioInterface Technology(RIT) or Set of RITs (SRIT) evaluations, to be submitted by to ITU for ratification, is done by a simulation group. As a part of this, the project involved running simulations on servers to verify if the proposed 5G technology developed in the 5G testbed in IITM, meets the required KPIs.

The simulations are done through an executable and a set of configuration files from CEWiT, another technology company part of the 5G testbed, with the simulator built by them for evaluation purposes, called the BWSimulator. The configurations are modified to ensure that the RITs work properly in all the test environments.

The configurarions used for each simulation and the results of KPIs from the respective simulation are maintained in Excel sheets in a given template. The results are then used to create the Self Evaluation report in the submission template defined in the ITU-R documents.

The later part of the project involved developing the 5G Stochastic Channel Model(SCM) 3GPP channel model in Matlab as a part of the own simulator being built in the IITM 5G testbed for carrying out the evaluation procedures. This simulator is built as an alternative for the open-source BWSimulator and provides more flexibility in the simulation procedures as we have full control over setting the configuration parameters unlike the former.

The channel model mentioned earlier is built as defined in the ITU document M.2412 defining the evaluation procedures.The document explains in detail about the small scale and large scale parameters generation procedure for each test environment and usage scenarios, explained in detail in the later part of this report, which are then used to generate the channel coefficients between transmit and recieve antennas.

Chapter 2

2.1 Problem Statement

Perform simulation procedures to evaluate the proposed RITs/SRITs on the BWSimulator for various test environments, usage scenarios and configuration parameters to verify if the required KPIs are met. These simulation results are used for creating the Self-Evaluation Report to be submitted.

Create the 5G SCM channel model in Matlab to create channel coefficients between individual channels for a set of multiple gNBs and UEs per sector. These coefficients are to be used for getting a received signal when a 5G signal is transmitted and subsequently use it to measure the SINR and other KPIs required for self-evaluation. This channel model will be used as a part of the own simulator created in the IITM 5G tested as an alternative to BWSimulator.

Key concepts from Literature Survey

2.2 Introduction to IMT-2020

International Mobile Telecommunications-2020 (IMT-2020) systems are mobile systems that include new radio interface(s) which support the new capabilities of systems beyond IMT-2000 and IMT-Advanced. The ITU-R M.2083 recommendation explains the capabilities of IMT-2020 .

The recommendation aims to make IMT-2020 more flexible, reliable and secure than previous IMT when services are provided in the intended three usage scenarios, namely enhanced mobile broadband (eMBB), ultra-reliable and low-latency communications (URLLC), and massive machine type communications (mMTC).

Evaluation procedures

The evaluation procedures, following the evaluation configurations for simulations, are done as explained in the ITU document M.2412 across a number of test environments, which are chosen to simulate environments that are as close as possible to the more real stringent radio operating environments.

Evaluation of proposals can be done through simulation, analytical and inspection procedures. Each proposal is evaluated to verify if the key minimum technical performance requirements are met as defined in the ITU-R M.2410 document.

The self-evaluation report is then done following the guidelines in ITU-R M.2412 and submitted for assessment of the proposed RITs/SRITs.

2.2.1 Evaluation procedure

The evaluation procedures can be carried out in either of the following 3 ways.

- **Simulation**: A detailed description of the evaluation method for each minimum technical performance requirements that uses simulation is given in the documents.
- **Analytical**: A straight forward calculation or mathematical analysis based on the definitions of the technical performance requirements given in ITU-R M.2410- can be used to evaluate them analytically.
- **Inspection**: It is done by reviewing the functionality and parameterization of a proposal say, by looking at its energy efficiency, bandwidth support and hence if the proposal can support a of wide range of services and usage scenarios etc,.

2.2.2 Minimum Key Requirements

The key minimum technical performance requirements are defined for the purpose of consistent definition and evaluation of the candidate IMT-2020 RITs/SRITs.

There are 13 of them listed in the ITU-R M.2410 document. They are as listed below:

1. Peak data rate
2. Peak spectral efficiency
3. User experienced data rate
4. 5th percentile user spectral efficiency
5. Average spectral efficiency
6. Area traffic capacity
7. Latency
8. Connection density
9. Energy efficiency
10. Reliability
11. Mobility
12. Mobility interruption time
13. Bandwidth

The high-level assessment method (simulation/ analytical/ inspection) to be used for evaluating each one of the above KPIs along with the corresponding evaluation procedure is given in ITU-R M.2412 and the same is followed while carrying out the self-evaluation procedure.

2.2.3 Usage Scenarios

The proposed RIT/SRIT shall support a wide range of services across different usage scenarios like:

- ***eMBB*** - Enhanced Mobile Broadband
- ***mMTC*** - Massive machine type communications
- ***URLLC*** - Ultra-reliable and low latency communications

Test environments

A test environment reflects a combination of geographic environment and any one of the usage scenarios listed above. The five environments used for the evaluation procedure are:

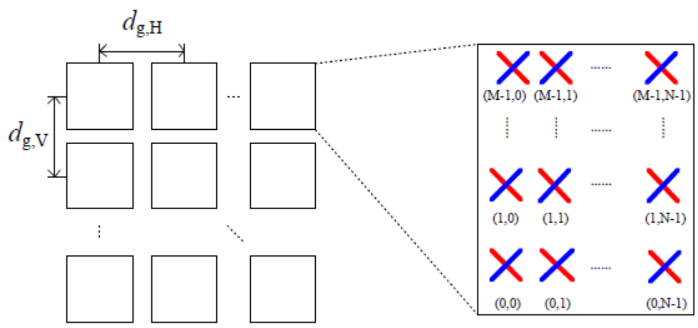
- Indoor Hotspot-eMBB
- Dense Urban-eMBB
- Rural-eMBB
- Urban Macro–mMTC
- Urban Macro–URLLC

2.2.4 Evaluation configurations

Evaluation configurations are defined for the selected test environments. The configuration parameters are applied in analytical and simulation assessments of candidate RITs/SRITs. The technical performance requirement corresponding to that test environment is fulfilled if this requirement is met for one of the evaluation configurations under that specific test environment.

2.2.5 Base station Antenna Characteristics

BS antenna model



BS antennas are modelled as one or multiple antenna panels, where an antenna panel has one or multiple antenna elements placed in a two-dimensional array within each panel. Each antenna panel has M×N antenna elements(single or dual polarized), where N is the number of columns and M is the number of antenna elements with the same polarization in each column. The antenna elements are spaced uniformly with a centre-to-centre distance of dH horizontally and dV vertically.

In case of multiple antenna panels, a uniform rectangular panel array is modeled, comprising *MgNg* antenna panels where *Mg* and *Ng* are number of panels in a column and row respectively. Antenna panels are uniformly spaced with a center-to-center spacing of *dg,H* and *dg,V* in the horizontal and vertical direction respectively.

The antenna polarization and the values *M*, *N*, *Mg*, *Ng*, *dH, dV, dg,H* and *dg,V* used during the evaluation is reported in the submission report.

2.2.6 Antenna radiation pattern

The field radiation pattern from an antenna element in the azimuthal and zenith directions as a function of the arrival and departure angles in both directions for transmitter and receiver respectively, to be used for channel coefficients generation are given in the ITU-R M.2412 document.

3 Channel Model Appraoch

5G Stochastic Channel Modelling

Channel modelling is required for realistically modelling the propogation conditions for radio transmission for all required test environments and usage scenarios. There are three IMT-2020 channel modules described in ITU-R M.2412 namely, the primary, extension and map-based hybrid modules. The project involved modelling the channel based on Primary module, which is a geometry-based stochastic channel model.

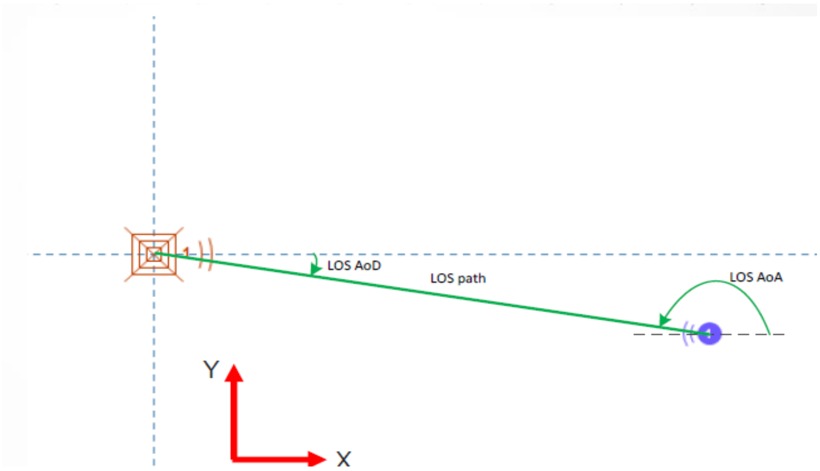
A Single Input Single Output (SISO) channel is characterized by two domains, time and frequency and the multipath propagation is defined by attenuation, time delay and path phase.

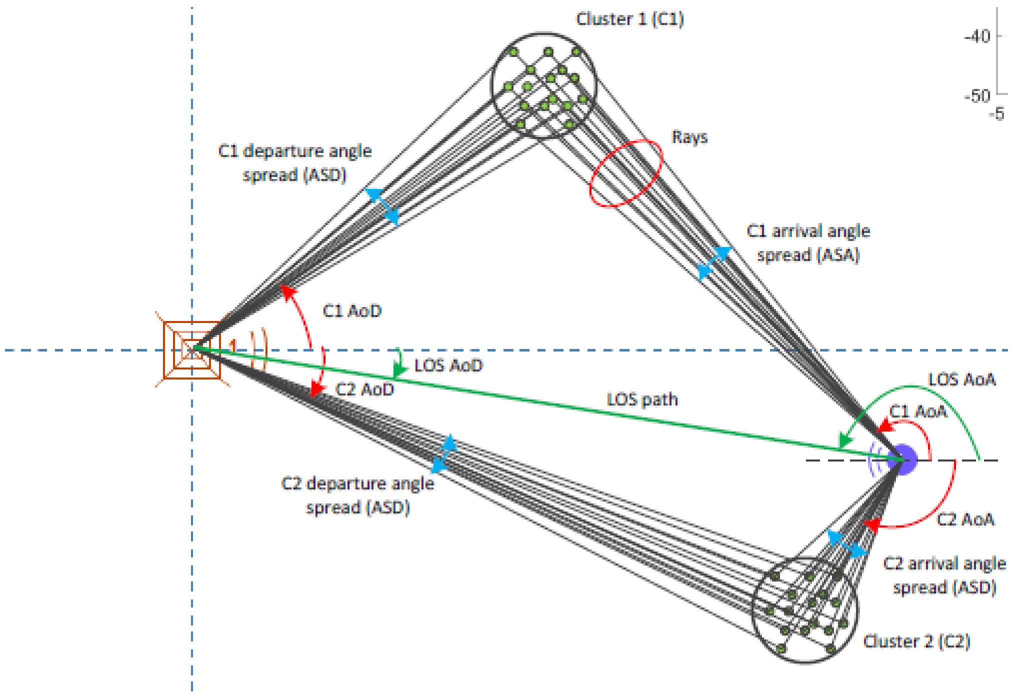
The Multiple Input Multiple Output (MIMO) channel however is characterized by four domains: Time, Frequency, Space, Polarization. The channel coefficients depend on the transmit and receive antenna characteristics and the propagation characteristics.

The MIMO channel models can either be physical or analytical. Physical models are based on physical theory (often geometrical optics) or on physical measurements. Analytical models are based on mathematical assumptions about the channel behaviour. A physical model further can be either deterministic, where the output of the model is fully determined by the parameter values or stochastic models which possess inherent randomness and the same set of parameter values can lead to an ensemble of output values.

In the Primary Module used for designing the channel model, instead of specifying the location of the scatterers explicitly, the direction of rays are used. This geometry based modelling enables separation of propagation parameters and antennas.

In the absence of environmental scatterers, we get a single pure LOS path.





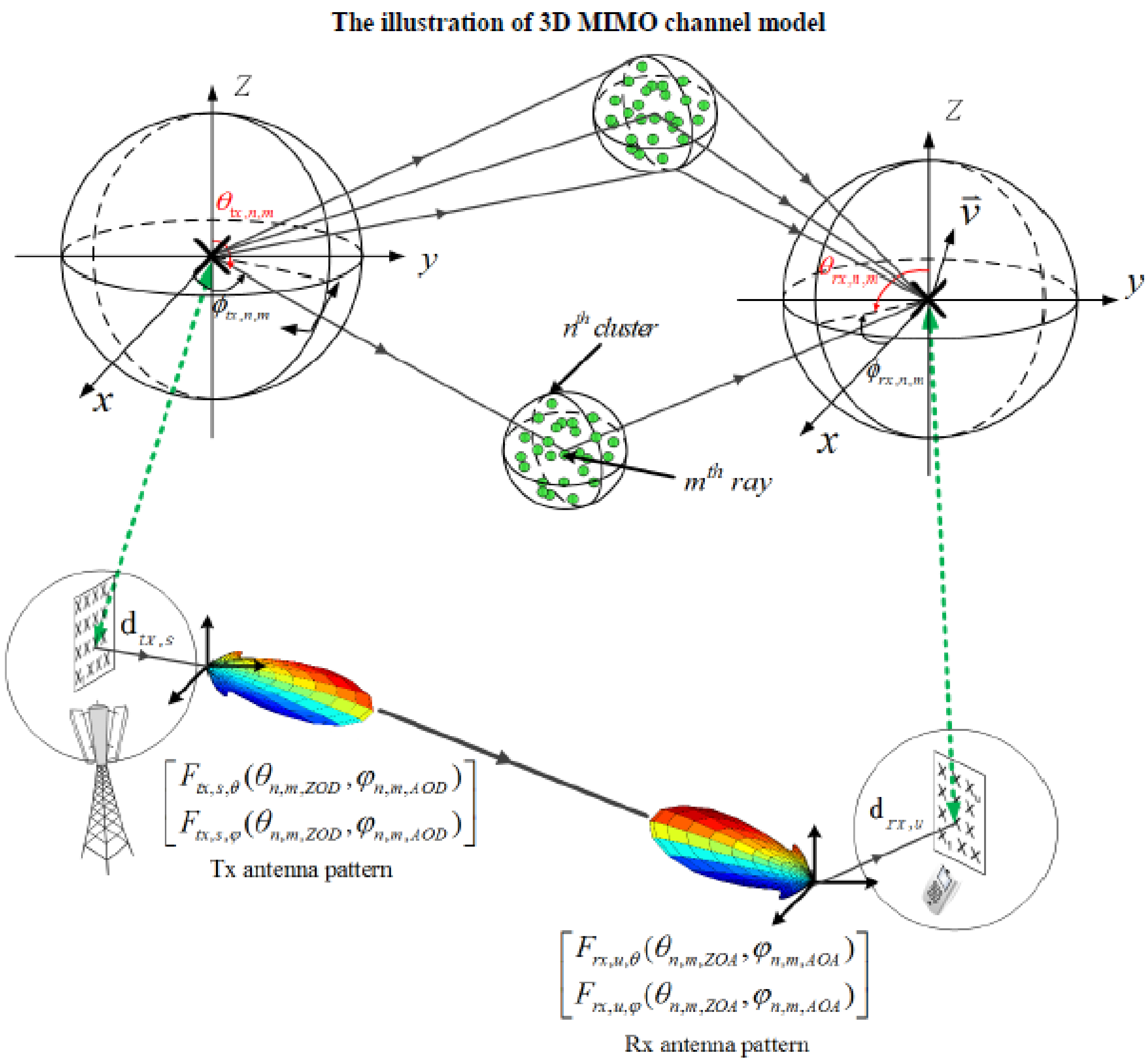
But in the presence of environmental scatterers, multiple propagation paths or (rays) are scattered from buildings etc rather than a LOS path. Scattering from such rough surfaces results as groups of rays close to each dominant propagation path, resulting in the concept of Clusters, as depicted below.

Clusters are defined by angular characteristics like Angular Spread of Departure (ASD), Angular Spread of Arrival (ASA), Angle of Departure (AOD) and Angle of Arrival (AOA) in stochastic models.

The channel parameters are determined stochastically based on statistical distributions from channel measurements. The channel is then realized through the application of the geometrical principle by summing the contributions of rays with specific small-scale parameters like delay, power, azimuth angles of arrival and departure and elevation angles of arrival and departure, which results in correlation of antenna elements and fading due to Doppler as well.

In the absence of a detailed environment database, the precise physical propagation parameters like Direction of Departure (DOD), Direction Of Arrival (DOA), number of paths, path delay, path power are unpredictable, but they have well defined statistical behaviours. Probability models can therefore be constructed for these propagation parameters.

The 3D MIMO channel model



The above illustration is for a single link channel model. Each circle with several dots represents a scattering region causing one cluster. Each cluster is constituted by *M* rays, and we assume N clusters and *S* antenna elements for transmitter (Tx) and *U* antenna elements for receiver (Rx), respectively. The small-scale parameters like delay $\tau_{n,m}$, azimuth angle of arrival $\varphi_{rx,n,m}$, elevation angle of arrival $\theta_{rx,n,m}$, azimuth angle of departure $\varphi_{tx,n,m}$ and elevation angle of departure $\theta_{tx,n,m}$ are assumed to be different for each ray, where *n* , *m, u, s* are the indices of the cluster, ray, receiver element and transmitter element respectively. $d_{rx,u}$ and $d_{tx,s}$ are the location vectors of the receive antenna element *u* and transmit antenna element s.

Test environments in IMT-2020 primary module

IMT-2020 covers the usage scenarios eMBB, URLLC and mMTC across the Indoor Hotspot, Urban and Rural test environments. IMT primary module defines Channel A and B for each of the test environment based on field measurements and are both valid for IMT-2020 candidate evaluations. The mapping of the channel models with the test environments is as shown below.

Test environment	**Indoor Hotspot-eMBB**	**Rural- eMBB**	**Dense Urban - eMBB**	**Urban Macro-URLLC**	**Urban Macro-mMTC**
Channel model	InH_A,InH_B	RMa_A,RMa_B	Macro layer: UMa_A, UMa_B Micro layer: UMi_A, UMi_B	UMa_A,Uma_B	UMa_A,Uma_B

Advances in channel modelling

3D modelling

This considers channel propagation both in azimuth and elevation dimensions at both Tx and Rx unlike 2D modelling where only azimuth dimension is considered and hence is more accurate. Multi-antenna techniques capable of exploiting the elevation dimension are expected to be important in IMT-2020, so 3D channel model is required. This includes elevation angles of departure and arrival and their correlation with other parameters.

Spatial consistency and clusters

The channel evolves smoothly without discontinuities when the Tx and/or Rx moves. The channel characteristics are highly correlated in closely located links.

Large bandwidth and large antenna arrays

To support the large size of the antenna array and the large number of antenna elements of antenna array, the key features of massive MIMO, the channel model should be specified with sufficiently high resolution in the delay and angular domain. This will help in more accurate modelling of AOA/AOD and higher number of multi-paths.

Blockage modelling

Stationary or moving objects between the transmitter and receiver changes the channel characteristics when the signal is blocked. High frequency bands/ mm-waves especially do not effectively penetrate or diffract around human bodies and other objects (such as cars, trucks, etc.). Shadowing by these objects is an important factor in the link budget and the time variation of the channel. This Dynamic blocking may be important to capture in evaluations of technologies that include beam-finding and beam-tracking capabilities.

Gaseous absorption

Effect of gaseous absorption may not be neglected in the high frequency band, as it causes additional loss to the radio wave propagation. For frequencies around 60 GHz, additional loss of gaseous absorption is applied to the cluster responses for different centre frequency and bandwidth correspondingly.

Ground Reflection

Ground reflection in mm wave has a significant effect which can produce a strong propagation path that superimposes with the direct LOS path and induce severe fading effects. So ground reflection has been added as an optional feature for IMT-2020 channel modelling.

Vegetation effects

Radio waves are affected by foliage and this effect increases with frequency, which is the case with the higher frequency bands used for 5G. The radiation is attenuated through foliage, diffraction above or below and sideways around canopy, and diffuse scattering by leaves. The vegetation effects are captured implicitly in the path loss equations.

Cluster Number

The number of clusters are fixed and are frequency independent. The number of clusters reported in the literature is often small, random and can be modeled as a Poisson distribution.

Path loss, Shadow fading and LOS Probability models

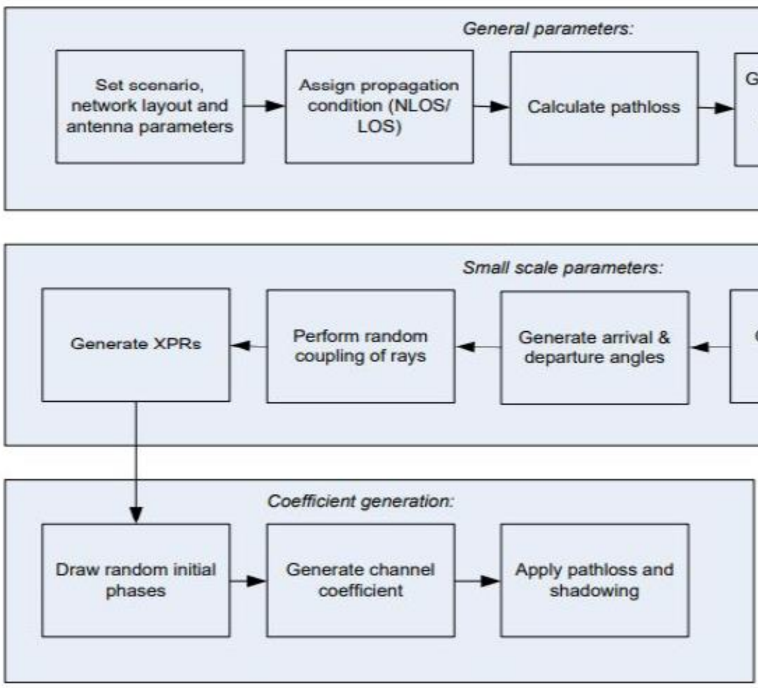
The path loss models and their applicability, including frequency ranges and the LOS probability, for the 4 cases of test environments are given in ITU-R M.2412. Shadow fading is modelled as log-normal and the corresponding standard deviation are mentioned along as well.

Procedure to generate the channel co-efficients

The channel is realised through a detailed step-step procedure consisting of 12 steps as shown below. Apart from this, the advanced channel modelling options described in ITU-R M.2412 can be used for simulating certain cases during the evaluation procedure as well.

The geometric description is such that the arrival angle is from the last scattered bounce and the departure angle is to the first scatterer from the transmitting side. Thus the propagation between the first and last interaction is not defined and this allows for modelling multiple interactions in the scattering media. Therefore parameters like delay can't be deduced from geometry and the procedure for generating such parameters is described in the document.

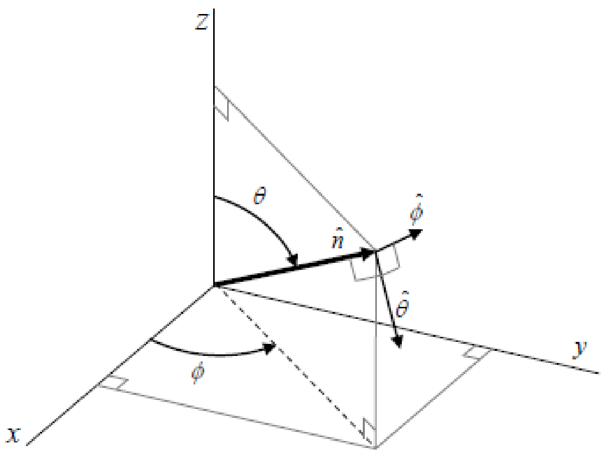
The following steps are defined for the downlink scenario. For the uplink scenario, the departure and arrival parameters are swapped.



Coordinate System

The coordinate system to be followed is defined by the x,y, z axes, spherical angles and vectors as shown in the figure below. The zenith angle(θ) and azimuth angle(φ) are defined in the Cartesian system as shown below. The spherical basis vectors $\hat{\theta}$ and $\hat{\varphi}$ are defined based on the propogation direction $\hat{n}$. The field component in the direction of $\hat{\theta}$ is given by F_θ and the field component in the direction of $\hat{\varphi}$ is given by F_φ.

Definition of a global coordinate system showing the zenith angle θ and the azimuth angle ϕ



Step-by-step procedure

Generation of General parameters

Step 1: Setting environment, network layout, and antenna array parameters

- Choose one of the test environments and corresponding network layouts
- Choose a global coordinate system and define the zenith and azimuth angles and spherical unit vectors as discussed earlier.
- Give the number of Base Station(BS) and User terminals(UT).
- Give 3D location of BS and UT and determine LOS AOD,LOS ZOD,LOS AOA,LOS ZOA.
- Give BS and and UT antenna field patterns F_{rx} and F_{tx} in the global coordinate system and array geometries.
- Give BS and UT array orientations with respect to the global coordinate system
- Array orientation is defined by three angles: Bearing angle,downtilt angle, slant angle
- Give speed and direction of motion of UT in the global coordinate system.
- Give system centre frequency f_c and bandwidth B.

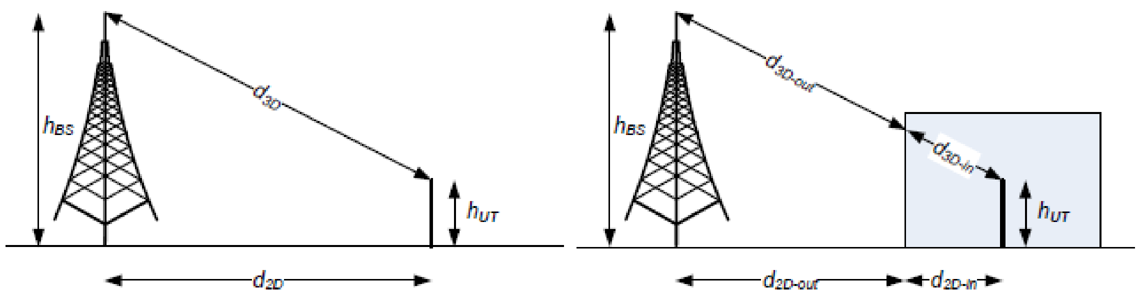
Generation of large scale parameters (LSPs)

Step 2: Propagation condition LOS/NLOS

- Assign propagation condition (LOS/NLOS).
- The propagation conditions for different BS-UT links are uncorrelated.
- LOS is a probability distribution which depends on distance from BS and height of UT. This distribution is different for indoor and outdoor state.
- Assign an indoor/outdoor state for each UT.
- All the links from a single UT have the same indoor/outdoor state.

Step 3: Modelling and calculation of pathloss

Definition of d_{2D} and d_{3D} for outdoor UTs (left), definition of $d_{2D\text{-}out}$, $d_{2D\text{-}in}$, $d_{3D\text{-}out}$, and $d_{3D\text{-}in}$ for indoor UTs (right)



- h_{UT} and h_{BS} are the antenna height at BS and UT, respectively.
- Pathloss depends on LOS/NLOS condition, the distance between BS and UT and frequency of carrier f_C.
- Different pathloss models has been specified for different test environments in the ITU document for 2 frequency ranges: one in the range 0.5 GHz - 6 GHz and the other, those above 6 GHz.
- In addition to this, outdoor to indoor (O-I) building penetration and car penetration losses should also be taken into account.

Step 4: Generation of other LSPs

Large scale parameters listed below are generated in this step :

- Root-mean-square delay spread (DS)

  The maximum delay time spread is the total time interval during which reflections with significant energy arrive. The r.m.s. delay spread is the standard deviation (or root-mean-square) value of the delay of reflections, weighted proportional to the energy in the reflected waves.

- Root-mean-square angular spreads: Azimuth Angle Spread of Arrival (ASA), Azimuth Angle Spread of Departure (ASD), Zenith Angle Spread of Arrival (ZSA) and Zenith Angle Spread of Departure (ZSD)

- Ricean K-factor (K)

  The ratio of signal power in dominant component over the (local-mean) scattered power.

- Shadow fading (SF)

All these LSPs are correlated and the correlated LSPs are generated taking into account the cross-correlation parameters given in the ITU document using the procedure described in § 3.3.1 of WINNER II Channel Models [4].

Generation of Small scale parameters

Step 5: Generation of delays

Delays are drawn randomly from an exponential delay distribution and are calculated as:

$$\tau_n' = - r_\tau \, DS \, ln\,(X_n)$$

where r_τ is the delay distribution proportionality factor, X_n ~ uniform (0,1), and n is the cluster index n = 1,. . . ,N.

The delays are then normalised by subtracting the minimum delay and are then sorted in the ascending order.

$$\tau_n = sort\,(\tau_n' - min(\tau_n'))$$

In the case of LOS condition, additional scaling of delays is required to compensate for the effect of LOS peak addition to the delay spread. The Ricean K-factor dependent scaling constant is:

$$C_K = 0.7705 - 0.0433\,K + 0.002\,K^2 + 0.000017\,K^3$$

where K [dB] is the Ricean K-factor as generated in Step 4.

The scaled delays $\tau_n^{LOS} = \tau_n / C_K$ are not to be used in cluster power generation.

Step 6: Generation of cluster powers

Cluster powers are calculated, assuming a single slope exponential power delay profile. Power assignment depends on the exponential delay distribution. The cluster

$$P_n' = exp\left(-\tau_n \frac{r_\tau - 1}{r_\tau \mathrm{DS}}\right) \cdot 10^{\frac{-Z_n}{10}}$$

powers are determined by:

where $Z_n \sim N(0, \zeta^2)$ is the per cluster shadowing term in [dB]

The cluster powers are then normalised so that the sum power of all cluster powers is equal to one.

$$P_n = \frac{P_n'}{\sum_{n=1}^{N} P_n'}$$

In the case of LOS condition, an additional specular component is added to the first cluster. The power of the single LOS ray is given by:

$$P_{1,LOS} = \frac{K_R}{K_R + 1}$$

And the cluster powers are given by:

$$P_n = \frac{1}{K_R + 1} \frac{P'_n}{\sum_{n=1}^{N} P'_n} + \delta(n-1) P_{1,LOS}$$

The power of each ray within a cluster is assigned as *Pn/M*, where *M* is the number of rays per cluster. The clusters with less than −25 dB power compared to the maximum cluster power are then removed.

Step 7: Generation of arrival and departure angles in both dimensions

Angle generation in azimuth direction

The composite Power Azimuth Spectrum(PAS) in azimuth of all clusters can be modelled as wrapped Gaussian or Laplacian. The AOAs are determined by applying the inverse Gaussian function equation or the inverse Laplacian function equation with input parameters P_n and RMS angle spread ASA, respectively.

$$\text{Gaussian: } \varphi_{n,AOA}' = \frac{2(\text{ASA}/1.4)\sqrt{-\ln\left(P_n/\max\left(P_n\right)\right)}}{C_\varphi}$$

$$\text{Laplacian: } \phi_{n,AOA}' = -\frac{\text{ASA}\ln\left(P_n/\max\left(P_n\right)\right)}{C_\phi}$$

with C_ϕ defined as:

$$\text{Guassian: } C_\phi = \begin{cases} C_\phi^{\text{NLOS}} \cdot \left(1.1035 - 0.028K - 0.002K^2 + 0.0001K^3\right) & \text{,for LOS} \\ C_\phi^{\text{NLOS}} & \text{,for NLOS} \end{cases},$$

$$\text{Laplacian: } C_\phi = \begin{cases} C_\phi^{\text{NLOS}} \cdot \left(0.9275 + 0.0439K - 0.0071K^2 + 0.0002K^3\right) & \text{,for LOS} \\ C_\phi^{\text{NLOS}} & \text{,for NLOS} \end{cases},$$

where C_φ^{NLOS} is defined as a scaling factor related to the total number of clusters and the values for each cluster for both Laplacian and Gaussian distributions are given in the document.

A positive or negative sign is assigned to the angles by multiplying with a random variable X_n with uniform distribution to the discrete set of {1,–1}, and add a component $Y_n \sim N(0, (ASA/7)^2)$ to introduce a random variation.

$$\phi_{n,AOA} = X_n \phi'_{n,AOA} + Y_n + \phi_{LOS,AOA}$$

where $\varphi_{LOS,AOA}$ is the LOS direction defined in the network layout description as mentioned in Step 1.

In the LOS case, the constant C_φ also depends on the Ricean K-factor in [dB], as generated in Step 4. Additional scaling of the angles is required to compensate for the effect of LOS peak addition to the angle spread.

In the LOS case, instead of the above equation, the below equation is used so that the first cluster is forced to the LOS direction $\varphi_{LOS, AOA}$:

$$\phi_{n,AOA} = \left(X_n \phi'_{n,AOA} + Y_n\right) - \left(X_1 \phi'_{1,AOA} + Y_1 - \phi_{LOS,AOA}\right)$$

Ray offset angles α_m for each of the rays within a cluster, are given for rms angle spread normalized to 1, in the document. These are added to the cluster angles as shown below:

$$\phi_{n,m,AOA} = \phi_{n,AOA} + c_{ASA}\alpha_m$$

where c_{ASA} is the cluster-wise rms azimuth spread of arrival angles (cluster ASA), which are also given in the document. The generation of AOD ($\varphi_{n,m,AOD}$) follows a procedure similar to AOA as described above.

Angle generation in zenith direction

The composite Power Azimuth Spectrum(PAS) in zenith of all clusters are modelled as Laplacian. The ZOAs are determined by applying the inverse Laplacian function equation with input parameters P_n and RMS angle spread ZSA, respectively.

$$\theta'_{n,ZOA} = -\frac{\mathrm{ZSA}\, ln\left(P_n / max(P_n)\right)}{C_\theta}$$

For channel model A, C_θ is defined as:

$$C_\theta = \begin{cases} C_\theta^{\mathrm{NLOS}} \cdot \left(1.35 + 0.0202K - 0.0077K^2 + 0.0002K^3\right) & \text{, for LOS} \\ C_\theta^{\mathrm{NLOS}} & \text{, for NLOS} \end{cases}$$

For channel model B, C_θ is defined as:

$$C_\theta = \begin{cases} C_\theta^{\mathrm{NLOS}} \cdot \left(1.3086 + 0.0339K - 0.0077K^2 + 0.0002K^3\right) & \text{, for LOS} \\ C_\theta^{\mathrm{NLOS}} & \text{, for NLOS} \end{cases}$$

Where C_θ^{NLOS} is defined as a scaling factor related to the total number of clusters and the values for each cluster for the Laplacian distribution are given in the document.

A positive or negative sign is assigned to the angles by multiplying with a random variable X_n with uniform distribution to the discrete set of {1,–1}, and add a component Y_n ~ N (0, $(ASA/7)^2$) to introduce a random variation.

$$\theta_{n,ZOA} = X_n \theta'_{n,ZOA} + Y_n + \bar{\theta}_{ZOA},$$

where $\bar{\theta}_{ZOA}$ = 90° if the BS-UT link is O2I and $\bar{\theta}_{ZOA} = \theta_{LOS,ZOA}$ which is the LOS direction defined in the network layout description as mentioned in Step 1.

In the LOS case, instead of the above equation, the below equation is used so that the first cluster is forced to the LOS direction $\theta_{LOS,ZOA}$:

$$\theta_{n,ZOA} = \left(X_n \theta'_{n,ZOA} + Y_n\right) - \left(X_1 \theta'_{1,ZOA} + Y_1 - \theta_{LOS,ZOA}\right).$$

Ray offset angles α_m for each of the rays within a cluster, are given for rms angle spread normalized to 1, in the document. These are added to the cluster angles as shown below:

$$\theta_{n,m,ZOA} = \theta_{n,ZOA} + c_{ZSA} \alpha_m$$

where c_{zSA} is the cluster-wise rms azimuth spread of arrival angles (cluster ZSA), which are also given in the document.

The generation of ZOD ($\theta_{n,m,ZOD}$) follows a similar procedure.

$$\theta_{n,ZOD} = X_n \theta'_{n,ZOD} + Y_n + \theta_{LOS,ZOD} + \mu_{offset,ZOD}$$

where X_n is a variable with uniform distribution to the discrete set of {1,–1}, Y_n ~ N (0, $(ASA/7)^2$) and the values for $\mu_{offset,ZOD}$ are mentioned in the document.

Ray offset angles α_m for each of the rays within a cluster, are given for rms angle spread normalized to 1, in the document. These are added to the cluster angles as shown below:

$$\theta_{n,m,ZOD} = \theta_{n,ZOD} + (3/8)(10^{\mu_{1gZSD}})\alpha_m$$

where μ_{1gZSD} is the mean of the ZSD log-normal distribution.

In the LOS case, the generation of ZOD follows the same procedure as ZOA described above using equation.

Step 8: Coupling of rays within a cluster for both dimensions

- Couple randomly AOD angles $\varphi_{n,m,AOD}$ to AOA angles $\varphi_{n,m,AOA}$ within a cluster n, or within a subcluster in the case of two strongest clusters (described in Step 11).

- Couple randomly ZOD angles $\theta_{n,m,ZOD}$ with ZOA angles $\theta_{n,m,ZOA}$ using the same procedure.
- Also, Couple randomly AOD angles $\varphi_{n,m,AOD}$ with ZOD angles $\theta_{n,m,ZOD}$ using the same procedure.

Step 9: Generation of cross polarization power ratios

The cross polarization power ratios K (XPR) are generated for each ray ***m*** of each cluster ***n***. XPR is log-normal distributed. The XPR values are drawn as shown below:

$$K_{n,m} = 10^{X/10}$$

where $X \sim N(\mu_{XPR}, \sigma^2_{XPR})$ is Gaussian distributed with $\mu_{XPR}, \sigma^2_{XPR}$ values given in the document.

Generation of channel coefficients

Step 10: Drawing of initial phases

The initial phase $\{\Phi_{n,m}^{\theta\theta}, \Phi_{n,m}^{\theta\varphi}, \Phi_{n,m}^{\varphi\theta}, \Phi_{n,m}^{\varphi\varphi}\}$ is drawn randomly for each ray *m* of each cluster *n* and for four different polarisation combinations (θθ, θφ, φθ and φφ). The distribution for initial phases is uniform within (-π, +π). It is added to ensure a random starting point for fast fading.

In the LOS case, if Φ_{LOS} is chosen as a random variable, then a random initial phase for both θθ and φφ polarisations are drawn.

Step 11: Generation of channel coefficients

Channel impulse response generation for a single link(Single antenna panel at both tx and rx)

The channel coefficients are generated for each cluster *n* and each receiver and transmitter element pair *u, s*.

For the *N – 2* weakest clusters, say n = 3, 4,…, *N*, the channel coefficients are given by:

$$H_{u,s,n}^{\mathrm{NLOS}}(t)=\sqrt{\frac{P_n}{M}}\sum_{m=1}^{M}\begin{bmatrix}F_{rx,u,\theta}\left(\theta_{n,m,ZOA},\varphi_{n,m,AOA}\right)\\ F_{rx,u,\varphi}\left(\theta_{n,m,ZOA},\varphi_{n,m,AOA}\right)\end{bmatrix}^T\begin{bmatrix}\exp\left(j\Phi_{n,m}^{\theta\theta}\right) & \sqrt{\kappa_{n,m}}^{-1}\exp\left(j\Phi_{n,m}^{\theta\varphi}\right)\\ \sqrt{\kappa_{n,m}}^{-1}\exp\left(j\Phi_{n,m}^{\varphi\theta}\right) & \exp\left(j\Phi_{n,m}^{\varphi\varphi}\right)\end{bmatrix}$$

$$\begin{bmatrix}F_{tx,s,\theta}\left(\theta_{n,m,ZOD},\varphi_{n,m,AOD}\right)\\ F_{tx,s,\varphi}\left(\theta_{n,m,ZOD},\varphi_{n,m,AOD}\right)\end{bmatrix}\exp\left(j2\pi\frac{\hat{r}_{rx,n,m}^T.\bar{d}_{rx,u}}{\lambda_0}\right)\exp\left(j2\pi\frac{\hat{r}_{tx,n,m}^T.\bar{d}_{tx,s}}{\lambda_0}\right)\exp\left(j2\pi\frac{\hat{r}_{rx,n,m}^T.\bar{v}}{\lambda_0}t\right)$$

where $F_{rx,u,\theta}$ and $F_{rx,u,\varphi}$ are the field patterns of receive antenna element u in the direction of the spherical basis vectors, $\hat{\theta}$ and $\hat{\varphi}$ respectively, $F_{tx,s,\theta}$ and $F_{tx,s,\varphi}$ are the field patterns of transmit antenna element s in the direction of the spherical basis vectors, $\hat{\theta}$ and $\hat{\varphi}$ respectively.

$\hat{r}_{rx,n,m}$ is the spherical unit vector with azimuth arrival angle $\varphi_{n,m,AOA}$ and elevation arrival angle $\theta_{n,m,ZOA}$, given by:

$$\hat{r}_{rx,n,m}=\begin{bmatrix}\sin\theta_{n,m,ZOA}\cos\varphi_{n,m,AOA}\\ \sin\theta_{n,m,ZOA}\sin\varphi_{n,m,AOA}\\ \cos\theta_{n,m,ZOA}\end{bmatrix}$$

where n denotes a cluster and m denotes a ray within cluster n.

$\hat{r}_{tx,n,m}$ is the spherical unit vector with azimuth departure angle $\varphi_{n,m,AOD}$ and elevation departure angle $\theta_{n,m,ZOD}$, given by:

$$\hat{r}_{tx,n,m}=\begin{bmatrix}\sin\theta_{n,m,ZOD}\cos\varphi_{n,m,AOD}\\ \sin\theta_{n,m,ZOD}\sin\varphi_{n,m,AOD}\\ \cos\theta_{n,m,ZOD}\end{bmatrix}$$

where n denotes a cluster and m denotes a ray within cluster n.

$\bar{d}_{rx,u}$ is the location vector of receive antenna element u and $\bar{d}_{tx,s}$ is the location vector of transmit antenna element s, $\kappa_{n,m}$ is the cross polarisation power ratio in linear scale, and λ_0 is the wavelength of the carrier frequency. If polarisation is not considered, the 2×2 polarisation matrix can be replaced by the scalar $exp(j\phi_{n,m})$ and only vertically polarised field patterns are applied.

The Doppler frequency component depends on the arrival angles (AOA, ZOA), and the UT velocity vector $\bar{\boldsymbol{v}}$ with speed v, travel azimuth angle φ_v, elevation angle θ_v and is given by:

$$v_{n,m}=\frac{\hat{r}_{rx,n,m}^T.\bar{v}}{\lambda_0},\ \text{where}\ \bar{v}=v.\left[sin\,\theta_v\,cos\,\phi_v\quad sin\,\theta_v\,sin\,\phi_v\quad cos\,\theta_v\right]^T$$

For the two strongest clusters, say n = 1 and 2, rays are spread in delay to three sub-clusters (per cluster), with a fixed delay offset.

The delays of the sub-clusters are

$$\tau_{n,1} = \tau_n$$
$$\tau_{n,2} = \tau_n + 1.28\ c_{DS}$$
$$\tau_{n,3} = \tau_n + 2.56\ c_{DS}$$

where c_{DS} is the cluster delay spread, the values for which are given in the document.

The twenty rays within these two clusters are mapped to three sub clusters as shown below:

Sub-cluster information for intra cluster delay spread clusters

sub-cluster # i	mapping to rays R_i	Power $\|R_i\|/M$	delay offset $\tau_{n,i} - \tau_n$
$i = 1$	$R_1 = \{1,2,3,4,5,6,7,8,19,20\}$	10/20	0
$i = 2$	$R_2 = \{9,10,11,12,17,18\}$	6/20	1.28 c_{DS}
$i = 3$	$R_3 = \{13,14,15,16\}$	4/20	2.56 c_{DS}

The channel impulse response is then given by:

$$H_{u,s}^{\mathrm{NLOS}}(\tau,t) = \sum_{n=1}^{2}\sum_{i=1}^{3}\sum_{m\in R_i} H_{u,s,n,m}^{\mathrm{NLOS}}(t)\delta(\tau-\tau_{n,i}) + \sum_{n=3}^{N} H_{u,s,n}^{\mathrm{NLOS}}(t)\delta(\tau-\tau_n)$$

where $H_{u,s,n,m}^{\mathrm{NLOS}}(t)$ is defined as:

$$H_{u,s,n,m}^{\mathrm{NLOS}}(t) = \sqrt{\frac{P_n}{M}} \begin{bmatrix} F_{rx,u,\theta}(\theta_{n,m,ZOA},\varphi_{n,m,AOA}) \\ F_{rx,u,\varphi}(\theta_{n,m,ZOA},\varphi_{n,m,AOA}) \end{bmatrix}^T \begin{bmatrix} \exp(j\Phi_{n,m}^{\theta\theta}) & \sqrt{\kappa_{n,m}^{-1}}\exp(j\Phi_{n,m}^{\theta\varphi}) \\ \sqrt{\kappa_{n,m}^{-1}}\exp(j\Phi_{n,m}^{\varphi\theta}) & \exp(j\Phi_{n,m}^{\varphi\varphi}) \end{bmatrix}$$
$$\begin{bmatrix} F_{tx,s,\theta}(\theta_{n,m,ZOD},\varphi_{n,m,AOD}) \\ F_{tx,s,\varphi}(\theta_{n,m,ZOD},\varphi_{n,m,AOD}) \end{bmatrix} \exp\left(j2\pi\frac{\hat{r}_{rx,n,m}^T.\bar{d}_{rx,u}}{\lambda_0}\right)\exp\left(j2\pi\frac{\hat{r}_{tx,n,m}^T.\bar{d}_{tx,s}}{\lambda_0}\right)\exp\left(j2\pi\frac{\hat{r}_{rx,n,m}^T.\bar{v}}{\lambda_0}t\right)$$

In the above equations, δ(.) is the Dirac delta function.

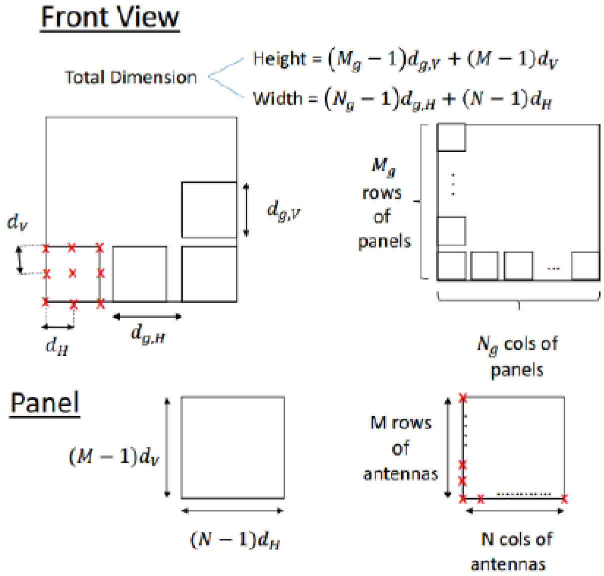
The channel response is generated by adding the LOS channel coefficient to the NLOS channel impulse response and scaling the two terms by the desired Ricean K factor K_R.

$$H_{u,s}^{\mathrm{LOS}}(\tau,t) = \sqrt{\frac{1}{K_R+1}}H_{u,s}^{\mathrm{NLOS}}(\tau,t) + \sqrt{\frac{K_R}{K_R+1}}H_{u,s,1}^{\mathrm{LOS}}(t)\delta(\tau-\tau_1)$$

Channel impulse response generation for antenna arrays (Multiple antenna panels at both tx and rx)

Arrangement of the antenna arrays

The antenna panel which is arranged in a uniform rectangular array and the cross-polarised elements within them are arranged as shown below.



where ,

- Mg and Ng are number of panels in a column and row respectively.
- Antenna panels are uniformly spaced with a center-to-center spacing of $d_{g,H}$ and $d_{g,V}$ in the horizontal and vertical direction respectively.
- Each antenna panel has $M \times N$ antenna elements (single or dual polarized), where N is the number of columns and M is the number of antenna elements with the same polarization in each column.
- The antenna elements are spaced uniformly with a centre-to-centre distance of d_H horizontally and d_V vertically.

In case of a single cross polarized antenna, $Mg = Ng = M = N = 1$. In case of a uniform rectangular array of cross polarized antennas with no sub arrays $Mg = Ng = 1$.

Vector channel response

Using antenna arrays at the transmitter and receiver results in a vector channel response. The LOS channel coefficient and NLOS channel impulse response for each cluster n is given below:

$$\mathbf{H}_n^{\mathrm{NLOS}}(t)=\sqrt{\frac{P_n}{M}}\sum_{m=1}^{M}\begin{bmatrix}F_{\mathrm{rx},\theta}\left(\theta_{n,m,ZOA},\phi_{n,m,AOA}\right)\\F_{\mathrm{rx},\phi}\left(\theta_{n,m,ZOA},\phi_{n,m,AOA}\right)\end{bmatrix}^T\begin{bmatrix}\exp\left(j\Phi_{n,m}^{\theta\theta}\right) & \sqrt{\kappa_{n,m}{}^{-1}}\exp\left(j\Phi_{n,m}^{\theta\phi}\right)\\\sqrt{\kappa_{n,m}{}^{-1}}\exp\left(j\Phi_{n,m}^{\phi\theta}\right) & \exp\left(j\Phi_{n,m}^{\phi\phi}\right)\end{bmatrix}$$
$$\times\begin{bmatrix}F_{\mathrm{tx},\theta}\left(\theta_{n,m,ZOD},\phi_{n,m,AOD}\right)\\F_{\mathrm{tx},\phi}\left(\theta_{n,m,ZOD},\phi_{n,m,AOD}\right)\end{bmatrix}\mathbf{a}_{\mathrm{rx}}\left(\theta_{n,m,ZOA},\phi_{n,m,AOA}\right)\mathbf{a}_{\mathrm{tx}}^{\mathrm{H}}\left(\theta_{n,m,ZOD},\phi_{n,m,AOD}\right)\exp\left(j2\pi v_{n,m}t\right)$$

$$\mathbf{H}_n^{\mathrm{LOS}}(t)=\begin{bmatrix}F_{\mathrm{rx},\theta}\left(\theta_{LOS,ZOA},\phi_{LOS,AOA}\right)\\F_{\mathrm{rx},\phi}\left(\theta_{LOS,ZOA},\phi_{LOS,AOA}\right)\end{bmatrix}^{\mathrm{T}}\begin{bmatrix}\exp\left(j\Phi_{LOS}\right) & 0\\0 & \exp\left(j\Phi_{LOS}\right)\end{bmatrix}$$
$$\times\begin{bmatrix}F_{\mathrm{tx},\theta}\left(\theta_{LOS,ZOD},\phi_{LOS,AOD}\right)\\F_{\mathrm{tx},\phi}\left(\theta_{LOS,ZOD},\phi_{LOS,AOD}\right)\end{bmatrix}\mathbf{a}_{\mathrm{rx}}\left(\theta_{LOS,ZOA},\phi_{LOS,AOA}\right)\mathbf{a}_{\mathrm{tx}}^{\mathrm{H}}\left(\theta_{LOS,ZOD},\phi_{LOS,AOD}\right)\exp\left(j2\pi v_{\mathrm{LOS}}t\right)$$

where $\mathbf{a}_{\mathrm{rx}}(\theta_{n,m,ZOA}, \varphi_{n,m,AOA})$ and $\mathbf{a}_{\mathrm{tx}}(\theta_{n,m,ZOD}, \varphi_{n,m,AOD})$ are the rx and tx antenna array response vectors respectively, of rays $m \in 1,2,\ldots,M$ in the cluster $n \in 1,2,\ldots,N$. They are given by:

$$\mathbf{a}_{\mathrm{tx}}\left(\theta_{n,m,ZOD},\phi_{n,m,AOD}\right)=\exp(j\frac{2\pi}{\lambda}(\mathbf{W}_{\mathrm{tx}}\mathbf{r}_{\mathrm{tx}}(\theta_{n,m,ZOD},\phi_{n,m,AOD}))),\forall n,m,$$

$$\mathbf{a}_{\mathrm{rx}}\left(\theta_{n,m,ZOA},\phi_{n,m,AOA}\right)=\exp(j\frac{2\pi}{\lambda}(\mathbf{W}_{\mathrm{rx}}\mathbf{r}_{\mathrm{rx}}(\theta_{n,m,ZOA},\phi_{n,m,AOA}))),\forall n,m,$$

where λ is the wavelength of the carrier frequency f, $\mathbf{r}_{\mathrm{rx}}(\theta_{n,m,ZOA}, \varphi_{n,m,AOA})$ and $\mathbf{r}_{\mathrm{tx}}(\theta_{n,m,ZOD}, \varphi_{n,m,AOD})$ are the corresponding angular 3 x 1 spherical unit vectors of the rx and tx, respectively.

$\mathbf{W}_{\mathrm{tx}}$ and $\mathbf{W}_{\mathrm{rx}}$ are the location matrices of the tx and rx antenna elements in 3D Cartesian coordinates, which are provided for an uniform rectangular array antenna configuration consisting of cross polarized antenna elements and for the arrangement discussed above earlier. For the uniform rectangular array configuration discussed above, $\mathbf{W}_{\mathrm{tx}}$ and $\mathbf{W}_{\mathrm{rx}}$ are matrices of the dimension $2NMN_gM_g$ x 3.

$\mathbf{W}_{\mathrm{tx}}$ for example, = [w_{ij}] i=1,2, . . , $2NMN_gM_g$, j =1,2,3, where

$$\mathrm{w}_{ij}=\begin{cases}0, \quad j=1\\ \left[\left(i-1-2N\left\lfloor\frac{i-1}{2N}\right\rfloor\right)\Big/2\right]\cdot d_H+\left[\left(i-1-2NN_g\left\lfloor\frac{i-1}{2NN_g}\right\rfloor\right)\Big/(2N)\right]\cdot d_{g,H}, \quad j=2\\ \left[\left(i-1-2NMN_g\left\lfloor\frac{i-1}{2NMN_g}\right\rfloor\right)\Big/(2NN_g)\right]\cdot d_V+\left[\left(i-1-2NMN_gM_g\left\lfloor\frac{i-1}{2NMN_gM_g}\right\rfloor\right)\Big/(2NMN_g)\right]\cdot d_{g,V}, \quad j=3\end{cases}$$

The spherical unit vectors are given by:

$$\mathbf{r}_{rx,n,m} = \begin{bmatrix} \sin\theta_{n,m,ZOA} \cos\varphi_{n,m,AOA} \\ \sin\theta_{n,m,ZOA} \sin\varphi_{n,m,AOA} \\ \cos\theta_{n,m,ZOA} \end{bmatrix}$$

$$\mathbf{r}_{tx,n,m} = \begin{bmatrix} \sin\theta_{n,m,ZOD} \cos\varphi_{n,m,AOD} \\ \sin\theta_{n,m,ZOD} \sin\varphi_{n,m,AOD} \\ \cos\theta_{n,m,ZOD} \end{bmatrix}$$

The Doppler frequency component $v_{n,m}$ depends on the arrival angles (AOA, ZOA), and the UT velocity vector $\bar{v}$ with speed v, travel azimuth angle φ_v, elevation angle θ_v and is given by:

$$v_{n,m} = \frac{\mathbf{r}_{rx,n,m}^T . \bar{v}}{\lambda_0}$$

$$\bar{v} = v.\left[\sin\theta_v \cos\varphi_v \quad \sin\theta_v \sin\varphi_v \quad \cos\theta_v\right]^T$$

Step 12: Path loss and shadowing

Apply path loss and shadowing for the channel coefficients.

Chapter 3

Prior Work

Simulations for self-evaluation

BWSimulator

The simulator for running the tests to evaluate the candidate RITs is provided by CeWiT, called the BWSimulator. It is an open source simulator, where we have access only to the direct executable file of the simulator along with some files where the evaluation configurations of the simulation scenarios are set. At the end of each simulation, we get the results of the KPIs which are compiled into an Excel sheet with date and time stamp, and the corresponding configuration parameters used. The results are then used to compile the self-evaluation report to be submitted. My project involved running simulations on this to carry out the evaluation procedure.

IITM 5G Testbed Simulator

IITM 5G test bed has been developing their own simulator for carrying out the evaluation procedures in Matlab. The advantage of this over the BWSimulator, being the control /access to which and how the configuration parameters can be modified while carrying out the simulations. My role in the project involved creating the 5G SCM channel model for the simulator, used to generate the channel coefficients across antenna array elements.

The channel model created is compliant with the procedure explained in the ITU-R M.2412 document.

Chapter 4

Performance Simulations and Key Results

Simulations done for Evaluation

The simulations were run on the servers in the lab for different Active Antenna System (AAS) Configurations and Antenna Configuration and Transmit Scheme. The possible usage scenarios for simulations were Dense Urban, Urban Macro, Rural and Indoor Hotspot. Each of these could be done for either of the downlink or uplink scenario. It also supports both Time Division Duplex (TDD) and Frequency Division Duplex (FDD) schemes and the simulation can be run incorporating either one of them.

For each of the test environments, the frequency can be chosen to be 700 MHz, 4 GHz or the Low Mobility Large Cell (LMLC) case. The implementation of LMLC has addressed specifically to rural requirements at low cost, by introducing a new Inter-Site Distance (ISD) of 6 km.

The simulation results done on different servers for a combination of the above cases for FDD and TDD respectively and compiled in Excel sheets are shown below.

RESULTS FROM SIMULATIONS RUN USING FDD

VIVADO Server:

VIVADO SERVER

Rural	DL	FDD		SPEC. Avg	Cell Edge	AAS Config	Ant Conf & Tx Scheme
	LMLC		Requirement	3.3	0.12	gNB: (M,N,P,Mg,Ng; Mp,Np) = (8,4,2,1,1; 1,4)	8x4 MU-MIMO
			22-11-2019	6.26412	1.7225		
			23-11-2019	6.50275	1.96005		
			26-11-2019	6.36996	1.81056		
	4GHz		Requirement	3.3	0.12	gNB: (M,N,P,Mg,Ng; Mp,Np) = (8,8,2,1,1; 2,8)	32x4 MU-MIMO
			28-11-2019	12.3175	3.59973		
URBAN	**DL**	**FDD**		**SPEC. Avg**	**Cell Edge**	**AAS Config**	**Ant Conf & Tx Scheme**
	4GHz		Requirement	7.8	0.225	gNB: (M,N,P,Mg,Ng; Mp,Np) = (8,8,2,1,1; 2,8)	32x4 MU-MIMO
			27-11-2019	13.3387	3.1819		
			30-11-2019	13.2103	2.96661		

FAPI Server:

Rural	**DL**	**FDD**		**SPEC. Avg**	**Cell Edge**	**AAS Config**	**Ant Conf & Tx Scheme**
	LMLC		**Requirement**	**3.3**	**0.12**	gNB: (M,N,P,Mg,Ng; Mp,Np) = (8,4,2,1,1; 1,4)	8x4 MU-MIMO
			21-11-2019 (1)	6.30799	1.87147		
			21-11-2019 (2)	6.32287	1.8744		
			23-11-2019	6.20877	1.78117		
			26-11-2019	6.26358	1.75856		
	700MHZ		**20-11-2019**	6.30877	1.41749	gNB: (M,N,P,Mg,Ng; Mp,Np) = (8,4,2,1,1; 1,4)	8x2 MU-MIMO
	4GHz		**Requirement**	**3.3**	**0.12**	gNB: (M,N,P,Mg,Ng; Mp,Np) = (8,8,2,1,1; 2,8)	32x4 MU-MIMO
			28-11-2019	12.1372	3.4856		
URBAN	**DL**	**FDD**		**SPEC. Avg**	**Cell Edge**	**AAS Config**	**Ant Conf & Tx Scheme**
	4GHz		**Requirement**	**7.8**	**0.225**	gNB: (M,N,P,Mg,Ng; Mp,Np) = (8,8,2,1,1; 2,8)	32x4 MU-MIMO
			29-11-2019	13.0164	2.72896		

THANOS Server:

Rural	**DL**	**FDD**		**SPEC. Avg**	**Cell Edge**	**AAS Config**	**Ant Conf & Tx Scheme**
	LMLC		**Requirement**	**3.3**	**0.12**	gNB: (M,N,P,Mg,Ng; Mp,Np) = (8,4,2,1,1; 1,4)	8x4 MU-MIMO
			20-11-2019	6.30877	1.41749		
			21-11-2019	6.30877	1.41749		
			22-11-2019	6.39571	1.83488		
			26-11-2019 (1)	6.38284	1.90624		
	700MHz		**26-11-2019 (2)**	6.30877	1.41749	gNB: (M,N,P,Mg,Ng; Mp,Np) = (8,4,2,1,1; 1,4)	8x2 MU-MIMO
			28-11-2019	6.30877	1.41749		
URBAN	**DL**	**FDD**		**SPEC. Avg**	**Cell Edge**	**AAS Config**	**Ant Conf & Tx Scheme**
	4GHz		**Requirement**	**7.8**	**0.225**	gNB: (M,N,P,Mg,Ng; Mp,Np) = (8,8,2,1,1; 2,8)	32x4 MU-MIMO
			23-11-2019	13.2647	3.05307		
			27-11-2019	13.2685	3.15899		
			28-11-2019	13.1334	2.94699		

THANOS (test.git):

Rural	DL	FDD		SPEC. Avg	Cell Edge	AAS Config	Ant Conf & Tx Scheme
	LMLC		**Requirement**	**3.3**	**0.12**	gNB: (M,N,P,Mg,Ng; Mp,Np) = (8,4,2,1,1; 1,4)	8x4 MU-MIMO
			20-11-2019	6.30877	1.41749		
			21-11-2019 (1)	6.30877	1.41749		
			21-11-2019 (2)	6.30877	1.41749		
			25-11-2019	6.30877	1.41749		
			27-11-2019 (1)	6.2877	1.79152		
			27-11-2019 (2)	6.23389	1.83698		
			28-11-2019 (1)	6.28698	1.78592		
			28-11-2019 (2)	6.28586	1.864		
	700MHz		**22-11-2019 (1)**	6.30877	1.41749	gNB: (M,N,P,Mg,Ng; Mp,Np) = (8,4,2,1,1; 1,4)	8x2 MU-MIMO
			22-11-2019 (2)	6.30877	1.41749		
			23-11-2019	6.32584	1.29099		
			26-11-2019	6.30877	1.41749		

URBAN	DL	FDD		SPEC. Avg	Cell Edge	AAS Config	Ant Conf & Tx Scheme
	4GHz		**Requirement**	**7.8**	**0.225**	gNB: (M,N,P,Mg,Ng; Mp,Np) = (8,8,2,1,1; 2,8)	32x4 MU-MIMO
			23-11-2019	13.2045	3.05664		
			27-11-2019	13.2833	2.95397		
			28-11-2019	13.1812	3.01611		

RESULTS FROM SIMULATIONS RUN USING TDD

SERVER THANOS(test.git):

				Requirement				17-11-2019	
				Avg	Cell Edge	AAS Config	Ant Conf & Tx Scheme	Avg	Cell edge
Rural	LMLC	DL	TDD	3.3	0.12	gNB: (M,N,P,Mg,Ng; Mp,Np) = (8,4,2,1,1;1,4)	8x4 MU-MIMO, 4T SRS , DSUUD	6.44265	2.2548
		UL	TDD	1.6	0.045		4x8 SU-MIMO, Codebook based, OFDMA, DSUUD	3.37045	0.002728
								21-11-2019	
								Avg	**Cell edge**
Dense Urban	4GHz	DL	TDD	7.8	0.225	gNB: (M,N,P,Mg,Ng; Mp,Np) = (8,8,2,1,1; 2,8)	32x4 MU-MIMO, 4T SRS , DSUUD	13.1528	3.06261
		UL	TDD	5.4	0.15		4x32 SU-MIMO, Codebook based, OFDMA, DSUUD	8.38221	3.47371

SERVER THANOS:

				Requirement				17-11-2019	
				Avg	Cell Edge	AAS Config	Ant Conf & Tx Scheme	Avg	Cell edge
Rural	LMLC	DL	TDD	3.3	0.12	gNB: (M,N,P,Mg,Ng; Mp,Np) = (8,4,2,1,1;1,4)	8x4 MU-MIMO, 4T SRS , DSUUD	6.44265	2.2548
		UL	TDD	1.6	0.045		4x8 SU-MIMO, Codebook based, OFDMA, DSUUD	3.37045	0.002728
								21-11-2019	
								Avg	**Cell edge**
Dense Urban	4GHz	DL	TDD	7.8	0.225	gNB: (M,N,P,Mg,Ng; Mp,Np) = (8,8,2,1,1; 2,8)	32x4 MU-MIMO, 4T SRS , DSUUD	13.1528	3.06261
		UL	TDD	5.4	0.15		4x32 SU-MIMO, Codebook based, OFDMA, DSUUD	8.38221	3.47371

SERVER VIVADO:

				Requirement				Simulated 16-11-2019	
				Avg	Cell Edge	AAS Config	Ant Conf & Tx Scheme	Avg	Cell edge
Rural	LMLC	DL	TDD	3.3	0.12	gNB: (M,N,P,Mg,Ng; Mp,Np) = (8,4,2,1,1;1,4)	8x4 MU-MIMO, 4T SRS , DSUUD	6.43671	2.24543
		UL	TDD	1.6	0.045		4x8 SU-MIMO, Codebook based, OFDMA, DSUUD	3.35642	0.002728

SERVER FAPI:

				Requirement				19-11-2019	
				Avg	Cell Edge	AAS Config	Ant Conf & Tx Scheme	Avg	Cell edge
Rural	LMLC	DL	TDD	3.3	0.12	gNB: (M,N,P,Mg,Ng; Mp,Np) = (8,4,2,1,1;1,4)	8x4 MU-MIMO, 4T SRS , DSUUD	6.43443	2.23068
		UL	TDD	1.6	0.045		4x8 SU-MIMO, Codebook based, OFDMA, DSUUD	3.36369	0.002728
								RESULTS-1	
								Avg	**Cell edge**
Dense Urban	4GHz	DL	TDD	7.8	0.225	gNB: (M,N,P,Mg,Ng; Mp,Np) = (8,8,2,1,1; 2,8)	32x4 MU-MIMO, 4T SRS , DSUUD	12.3326	3.05446
		UL	TDD	5.4	0.15		4x32 SU-MIMO, Codebook based, OFDMA, DSUUD	8.98736	4.32007

where *Mg* and *Ng* are number of panels in a column and row respectively at the transmitter side, *Mp* and *Np* are number of panels in a column and row respectively at the receiver side, N and M are number of antenna elements in the panel in a column and row respectively, P denotes single or dual polarised antennas.

The date of simulation, the antenna configuration and transmission scheme used at the transmitter for each simulation, the test environment (Rural/Indoor Hotspot/ Dense urban), frequency used (700MHz/ 4GHz/ LMLC) and the scenario (DL/UL) are specified as well.

Avg requirement and Cell edge requirement is the requirement for Average spectral efficiency and 5th percentile user spectral efficiency respectively, as defined in the ITU document M.2410. The corresponding values for both these KPIs from each simulation are mentioned as well. Those results which didn’t meet the ITU requirements are highlighted in red.

Average spectral efficiency is the aggregate throughput of all users (the number of correctly received bits, over a certain period of time) divided by the channel bandwidth of a specific band divided by the number of TRxPs. It is measured in bit/s/Hz/TRxP.

The 5th percentile user spectral efficiency is the 5% point of the CDF of the normalized user throughput. The normalized user throughput is defined as the number of correctly received bits over a certain period of time, divided by the channel bandwidth. It is measured in bit/s/Hz.

RESULTS FROM THE 5G SCM MATLAB CODE

1. The final H_coeff_NLOS generated is a 4-D array. We get (N+4) x (T+1) x (2NeT*MeT*NgT*MgT) x (2NeR*MeR*NgR*MgR). The H_coeff_LOS array is of the size 1 x(T+1) x (2NeT*MeT*NgT*MgT) x (2NeR*MeR*NgR*MgR)]

(N is the number of clusters, T is the total time taken)

2. After doing Sinc interpolation on the coefficients (H_coeff_NLOS and H_coeff_LOS) , to reconstruct a continuous signal from its samples, we get the H_final which is of the size (taps) x (T+1) x (2NeT*MeT*NgT*MgT) x (2NeR*MeR*NgR*MgR).

3. Each column in the H_final array gives a matrix of the size (2NeT*MeT*NgT*MgT) x (2NeR*MeR*NgR*MgR) at each time (0 to T). For each time instant we will have (taps) no. of values.

Chapter 5

Contributions

The initial version of the 5G SCM channel model created in Matlab for simulations is for the case of a single transmission link between single antenna elements at the transmitter and receiver. The extension of the same to the case when multiple antenna panels are used was later done. The final channel coefficient results are a 2-D array and a 4-D array respectively for the cases mentioned. My work specifically involved in creating the functions required for hardcoding the values needed for parameter generation and the functions required for executing Steps 4 to 7, and Steps 11 and 12(refer Pseudo code in Appendix)

Potential extensions and future work

Few aspects of the code are yet to be verified for a single UE and single channel link per sector. The coupling gain which includes the path loss, antenna gains and shadowing, between gNB and the UE has to be checked. Coupling gain doesn't include small scale or large scale fading, Doppler Effect or noise. It is just a measure of signal strength at the receiver. This coupling gain has to be measured between every antenna element pair and the values should be very similar. While employing the same in the simulator however, doppler and fading effects come into the picture and will lead to different channel effects for different elements.

The codes are yet to be verified in a simulation environment, which would involve transmitting a 5G signal from the devices, model the individual channels using the Matlab codes designed earlier and measure the SINR at every receiver. The verification of the correctness of the SINR measured and hence the channel model created, can be done by comparing it with results from previous simulations done, for example the BWSimulator.

But the Matlab code written is for the case of a single user in a sector. The code has to be extended to be able to support the simulation of multiple gNBs and UEs per sector. Once the codes for a single UE and a single channel link is verified, this extension needs to done and has to be verified in a similar manner, before using them for simulating the test environments for evaluation procedures and measuring the KPIs.

Also the channel model can be further improved for simulating certain test scenarios by incorporating advanced modelling components like Oxygen absorption, random cluster number, ground reflection, UT rotation, blockage, spatial consistency and modelling of propagation delay and intra cluster angular and delay spreads for incorporating large antenna size and large number of antenna elements.

The modelling procedure for the above mentioned advanced components along with the corresponding step in the channel generation procedure , in which it is to be incorporated and the recommended conditions in which they can be done in addition to the normal channel generation procedure are described in the ITU document M.2412.

Chapter 6

Summary

The evaluations are carried out to test the candidate technologies to be submitted for IMT-2020 evaluation from the 5G IITM Testbed. The evaluations were done using the simulator provided by CeWiT. To gain futher control over the simulation procedure and as part of the simulator that is being built by the testbed, a channel model compliant with the 3GPP SCM model had to be built to simulate the candidate technologies. Apart from being able to control configurations like dimensions of the antenna panel configuration, polarisation of antenna elements and the transmit antenna configuration and transmitting signal scheme, we get to exercise more control over the configuration parameters as unlike the executable file provided by CeWit with limited access to parameters, the channel model gives full access to all the configuration parameters.

The main advantage of the 3GPP geometry based stochastic channel modelling is that the scatterers are defined based on the angles of departure and angles of arrival, i.e. terminal perspective, rather than defining the physical position of the scatterers in the simulation area like a few other channel models. If physical positions are used , it is difficult to extract parameters using measurements contrary to the case of the GSCM channel model. Hence GSCM is currently more widespread and is the preferred candidate for 5G channel modelling in standardization efforts.

The channel code written is not fully spatially consistent, that is it fails to capture scenarios where the users are in close proximity, as the channels are generated independently for each user, regardless of the distance between users. This can be improved by incorporating the spatial consistency procedure as mentioned in Chapter 5 and [3].

Appendix

PSEUDO CODE FOR SCM CHANNEL MODEL GENERATION

Step 1

Set up these input parameters

- BS and UE co-ordinates
- Speed of UE(v)
- θ_v,ϕ_v: velocity vector direction
- Alpha (bearing angle), beta (downtilt angle), gamma (slant angle)
- f_c, Band width
- LOS or NLOS
- Number of taps, number of time samples(T)
- Profile (InH, UMa, UMi, RMa), channel model (A or B)

- MeT, NeT, MgT, NgT, MeR, NeR, MgR, NgR
    - Me x Ne is the dimension of each panel (no of elements) and Ng x Mg is the dimension of the overall arrangement of the panels. We have taken all of them to be 1 as of now (the single cross polarized antenna case). T and R denote the dimensions at the transmitter and receiver respectively.

- d_h, d_v, dg_H, dg_V
    - Took random values for the spacing between panels, dg_H and dg_V and spacing between elements d_H and d_V as of now. Values should be decided during the simulation.

Step 2

Set up the LOS probabilities and the number of clusters and rays in each cluster.

Functions used

1. **P_LOS = generate_probab_LOS(profile,d2D,hUT)**

To set up the LOS probabilities whose values depend on d2D and hUT for all profiles. Depending on the probability returned, LOS/ NLOS is set to be the propagation condition.

2. **[N, M] = clusters_and_rays(profile,LOS)**

    The number of clusters N and number of rays in each cluster M are hardcoded for all possible profile and LOS/NLOS propagation conditions.

Step 3

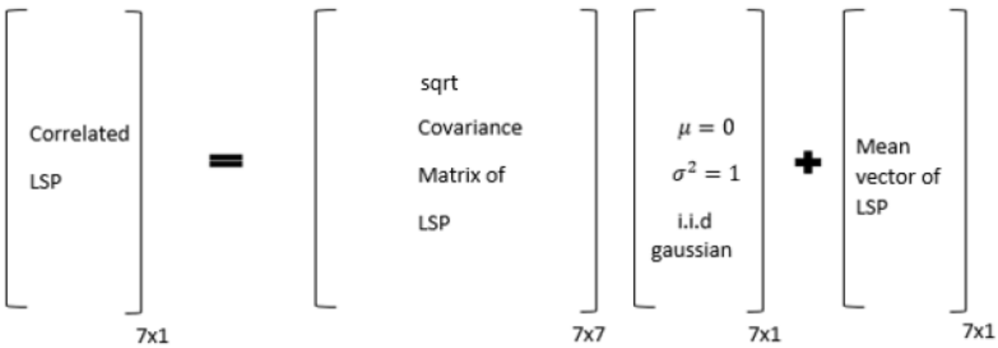
1. Calculate path loss using the “generate pathloss” function.

Functions used

1. pathloss = generate_pathloss (profile, fc, LOS, d2D, d3D, hUT, hBS);

Step 4

1. Calculate LSPs (Large scale parameters).
2. They are root mean square values (ASA, ASD, ZSA, ZSD, DS) and K, SF in dB
3. In the function used below, the mean and variance values of each parameter are taken from the ITU document.
4. A covariance matrix using mean, variance and the correlation matrix for the seven parameters is created.
5. Calculate values of these correlated parameters as shown below.



Functions used

1. [corr_LSP, C_ASA, C_ASD, C_ZSA, mu_offset, Delay_scaling, mu_ZSD, C_DS] = generate_corr_LSP (fc, LOS, profile, d2D, hUT, hBS);

Step 5

1. Generate delays of *n* clusters using delay scaling parameter (r_τ) and DS.

Functions used

1. delay = generate delay (N, DS, Delay scaling, K, LOS)

Step 6

1. Calculate the power of *n* clusters using the delays calculated above.

Functions used

1. P = Power (profile, LOS, Delay_scaling, K, DS, delay, N);

Step 7

1. Generate AOA, AOD, ZOA, ZOD angles of each ray in each cluster using the below mentioned functions.
2. Output of each function is of the size N (no of clusters) x M (no of rays)

Functions used

1. phi_AOA = generate_azimuth_AOA (LOS, N, M, PDF, P, K, phi_LOS_AOA, ASA, C_ASA);
2. phi_AOD = generate_azimuth_AOD (LOS, N, M, PDF, P, K, phi_LOS_AOD, ASD, C_ASD);
3. theta_ZOA = generate_elevation_AOA (LOS, N, M, model, P, K, theta_LOS_ZOA, ZSA, C_ZSA);
4. theta_ZOD = generate_elevation_AOD (LOS, N, M, model, P, K, theta_LOS_ZOD, ZSD, mu_offset, mu_ZSD);

Step 8

1. Divide the 2 strongest clusters (i.e. first two clusters as per document) into 3 sub clusters each.

2. For computational purposes the 1st sub cluster, 2nd sub cluster, 3rd sub cluster of the two strongest clusters are considered as three separate sets.

- Set1: size- 2 x 10;(10 rays)
- Set2: size- 2 x 6;(6 rays)
- Set3: size- 2 x 4;(4 rays)
- Set4: remaining clusters(N-2), size- N-2 x 20;(20 rays)

3. Shuffle the values in each row of all sets and then finally the values having the same indices are considered as coupled.

Functions used

1. "couple" function

Step 9

1. Generate cross polarization values in the size of the above mentioned sets using the mean and variance values from the ITU document.
2. The output of the function gives $\sqrt{k}{-1}$ values.

Functions used

1. [k1, k2, k3, k] = generate_cross_pol_power (N, M, profile, fc, LOS);
   (Note: The k values are inverse square-root)

Step 10

1. Generate all four initial phases uniformly in [-180,180] in sets of 4 (sizes: 2x10, 2x6, 2x4, N-2xM).

Step 11

1. Generate the term in the coefficient which is independent of time.
2. The term which is dependent on time is the doppler.

3. Use matrix operations as far as possible on all the required matrices for the computation of coefficients (to avoid for loop)

4. For computing the time dependency in the coefficient, use “for” loop of order T to get channel coefficients at each time index (0, 1…, T).

5. Generate the W matrix discussed in Chapter 2 for tx and rx required in the calculation of channel coefficients. The W matrix for tx is of the size (2NeT*MeT*NgT*MgT) x 3, while that of the rx is of the size (2NeR*MeR*NgR*MgR) x 3. They are the location matrices of the tx and rx antenna elements in 3D Cartesian coordinates.

6. The final H_coeff_NLOS generated is a 4-D array. We get (N+4) x (T+1) x (2NeT*MeT*NgT*MgT) x (2NeR*MeR*NgR*MgR).

7. [N is the number of clusters, T is the total time taken) and H_coeff_LOS is of the size 1 x(T+1) x (2NeT*MeT*NgT*MgT) x (2NeR*MeR*NgR*MgR)]

Step 12

1. Apply pathloss and shadow fading to the coefficients.
2. Use Sinc interpolation on the coefficients (H_coeff_NLOS and H_coeff_LOS) to get the H_final.
3. H_final is of size (taps) x (T+1) x (2NeT*MeT*NgT*MgT) x (2NeR*MeR*NgR*MgR).
4. Each column gives values at each time (0 to T). For each time instant we will have (taps) no. of values.

Functions used for hardcoding values required for parameter generation

1. **corr_matx = generate_corr_matrix(profile,LOS)**

   A correlation matrix using the correlations given for the seven parameters in the ITU document is created for all possible profile and LOS/NLOS propagation conditions.

   This is further used to create the covariance matrix by multiplying it with the matrix with variances for the seven parameters.

Setting the mean and variances for the seven LSPs

2. [mu_K,sigma_K] = K_factor(profile)

3. [mu_DS, sigma_DS, Delay_scaling,C_DS] = DS_Indoor_Hotspot(fc,LOS,profile)
   [mu_DS, sigma_DS, Delay_scaling,C_DS] = DS_Urban_macro(fc,LOS,profile)
   [mu_DS, sigma_DS, Delay_scaling,C_DS] = DS_Urban_micro(fc,LOS,profile
   [mu_DS, sigma_DS, Delay_scaling,C_DS] = DS_rural_macro(fc,LOS,profile)

4. [mu_ASD,sigma_ASD,C_ASD] = ASD_Indoor_Hotspot(fc,LOS,profile)
   [mu_ASD,sigma_ASD,C_ASD] = ASD_Urban_macro(fc,LOS,profile)
   [mu_ASD,sigma_ASD,C_ASD] = ASD_Urban_micro(fc,LOS,profile)
   [mu_ASD,sigma_ASD,C_ASD] = ASD_rural_macro(fc,LOS,profile)

5. [mu_ASA,sigma_ASA,C_ASA] = ASA_Indoor_Hotspot(fc,LOS,profile
   [mu_ASA,sigma_ASA,C_ASA] = ASA_Urban_macro(fc,LOS,profile)
   [mu_ASA,sigma_ASA,C_ASA] = ASA_Urban_micro(fc,LOS,profile)
   [mu_ASA,sigma_ASA,C_ASA] = ASA_rural_macro(fc,LOS,profile)

6. [mu_ZSD,sigma_ZSD,mu_offset] = ZSD_Indoor_Hotspot(fc,LOS,profile,d2D, hUT, hBS)
   [mu_ZSD,sigma_ZSD,mu_offset] = ZSD_Urban_macro(fc,LOS,profile,d2D, hUT, hBS)
   [mu_ZSD,sigma_ZSD,mu_offset] = ZSD_Urban_micro(fc,LOS,profile,d2D, hUT, hBS)
   [mu_ZSD,sigma_ZSD,mu_offset] = ZSD_rural_macro(fc,LOS,profile,d2D, hUT, hBS)

7. [mu_ZSA,sigma_ZSA,C_ZSA] = ZSA_Indoor_Hotspot(fc,LOS,profile)
   [mu_ZSA,sigma_ZSA,C_ZSA] = ZSA_Urban_macro(fc,LOS,profile)
   [mu_ZSA,sigma_ZSA,C_ZSA] = ZSA_Urban_micro(fc,LOS,profile)
   [mu_ZSA,sigma_ZSA,C_ZSA] = ZSA_rural_macro(fc,LOS,profile)

8. sigma_SF = SF_Indoor_Hotspot(fc,LOS,profile)
   sigma_SF = SF_Urban_macro(fc,LOS,profile)
   sigma_SF = SF_Urban_micro(fc,LOS,profile)
   sigma_SF = SF_rural_macro(fc,LOS,profile)

Setting up mean and variances for cross-polarisation

9. [mu, sigma] = cross_pol_indoor_hotspot(profile,fc,LOS)
   [mu, sigma] = cross_pol_Urban_macro(profile,fc,LOS)
   [mu, sigma] = cross_pol_Urban_micro(profile,fc,LOS)
   [mu, sigma] = cross_pol_rural_macro(profile,fc,LOS)

Setting up the location matrices of the tx and rx antenna elements in 3D Cartesian coordinates

10. WT = generate_W_matx(NeT, MeT, NgT, MgT, dH, dV, dg_H, dg_V)
11. WR = generate_W_matx(NeR, MeR, NgR, MgR, dH, dV, dg_H, dg_V)

Generate Antenna field radiation pattern in a given direction

12. [FP , FT , FHV] = field_pattern(phi,theta,profile,alpha,beta,gamma)

Where FP and FT are the field patterns in the azimuth and elevation direction respectively and FHV is the radiation pattern in the direction specified by phi and theta.

References

[1] **Report ITU-R M.2410-0**
Minimum requirements related to technical performance for IMT-2020 radio interface(s)

[2] **Report ITU-R M.2411-0**
Requirements, evaluation criteria and submission templates for the development of IMT-2020

[3] **Report ITU-R M.2412-0**
Guidelines for evaluation of radio interface technologies for IMT-2020

[4] **IST-WINNER II Deliverable 1.1.2 v.1.2.,** “WINNER II channel models, IST-WINNER2, Tech. Rep., 2008.