IMT-2020 Channel Model (CM) Software User Manual

Editors: **Zhang Jianhua** **jhzhang@bupt.edu.cn**
Tian Lei **tianlbupt@bupt.edu.cn**
Mansoor Shafi **mansoor.shafi@spark.co.nz**

Document Version: V2.0
May 30, 2018

IMT-2020 CM_BUPT—— User License

Copyright(c) 2018 Zhang Jianhua Lab, Beijing University of Posts and Telecommunications.

The software platform is open and any person or group is allowed, free of charge, to obtain a copy of this simulation software and associated help documentation files. Users are permitted to use the platform without restriction. But users should subject the following conditions:

1. The above copyright notice and this permission notice should be admitted and retained in any copy of the software.
2. The software platform is developed for research of radio channel. If any person or group wants to apply the platform in industry or any other fields, Zhang Jianhua Lab of BUPT cannot give any guarantee of the accuracy about the result.
3. The software platform is developed by Zhang Jianhua Lab of BUPT. We reserve all the rights for the final explanation.

Contents

1 Introduction

The Zhang Jianhua Lab of BUPT provides the MATLAB implementation of the ITU-R M.2412-0[1] channel document. The channel modeling method and principle are explained in [JSAC][2] and detailed parameters and scenarios are described in [ITU-R M. 2412-0].The software is named as IMT-2020 CM_BUPT. It is a multi-link simulation platform which can generate a radio channel information between multiple Base Stations and multiple User Terminals. This document will describe the framework of the simulation software in detail and give some instruction about the function applied in the model. The more specific scenarios of channel model and parameters can be found in the ITU-R M.2412-0.

In IMT-2020 CM_BUPT, users can choose the model A or model B provided in ITU-R M.2412-0. All the scenario parameters are loaded in the platform. And users can set the number of antennas and choose the type of them. Channel matrices can be generated for multiple BS-UT links. And the path loss component is also included.

It should be noticed that the output of platform is the channel matrices. If users want the middle variable, other operations may need, which are beyond the scope of the implemented channel model.

2 Installation

IMT-2020 CM_BUPT simulation platform is based on the MATLAB software. The users have to install a MATLAB software in their computers. In our test in fact, the test system is Windows 7 x64 and the MATLAB version is R2016b. The main function is “IMT-2020_CM_BUPTv2.p”. Users can run the platform by “IMT-2020_CM_BUPTv2.p” or “IMT-2020_CM_BUPTv2.fig”.

The function includes the following modules:

```
%% IMT-2020 Channel Model Software
%% Copyright:Zhang Jianhua Lab, Beijing University of Posts and Telecommunications
(BUPT)
%% Editor:Zhang Jianhua (ZJH), Tian Lei (TL)
%% Version: 2.0      Date: May. 30, 2018

%% Antenna Configuration
%     AntennaModelBs          - Bs antenna pattern and calculate the antenna
%     AntennaModelUt          - Ut antenna pattern and calculate the antenna
%     AntennaArray            - Antenna type and how to place the antenna element
%
%% Scenario and Layout
%     Scenario                - Set the ITU-R M.2412-0 test environment parameters
%     Layout                  - Generate the network information about BS and UT
%     UtPosdistribution       - User's distribution
%     WrapAround              - Link information after wrapping
%
%% Path loss
%     GeneratePathloss        - Generate the path loss of links
%     LOSprobability          - Determine whether the LOS link
%
%% Channel Parameters
%     GenerateLSP             - Generate the large scale parameters
%     GenerateSSP             - Generate the small scale parameters
%     RayAngleOffset          - Set the fixed offset of cluster angle to ray angle
%
%% Channel impulse response
%     GenerateCIR             - Generate the channel impulse response
%
%% Utility functions
%     RMSDelaySpread          - Calculate the delay spread
%     AngleSpread             - Calculate the angle spread
%     prin_value_azimuth      - Limit the azimuth angle to -180:180 degrees
%     prin_value_zenith       - Limit the zenith angle to 0:180 degrees
%
%% Advanced functions
```

```
%     Blockage              -add blockage loss for per link according to blockage model B
%     GenerateCIR_SC        - Generate the channel impulse response using spatial consistency
%     GenerateSSP_SC        - Generate the small scale parameters using spatial consistency
%
%% Test Example
%     test                  - An example about how to create a simulation
```

3 Model Framework

3.1 Data Flow

The CM implementation structure is shown in the block diagram given in Figure 1. The core of the platform is to generate channel impulse response which contains three main modules. And the three main modules are antenna module, layout and scenario module and path loss module respectively. The antenna module aims to give the antenna locations and antenna responses. Different network layout which contains information of BSs and UTs, as well as parameters configuration in different scenarios, such as UMa, UMi and O2I is determined in the layout and scenario module. The path loss module can be modeled as a separate user-supplied function which aims to give the path loss and standard deviation of shadow fading per link.

The main data flow of the CM platform can be seen in the Figure 1. Input and output arguments are defined in more detail in the following section.

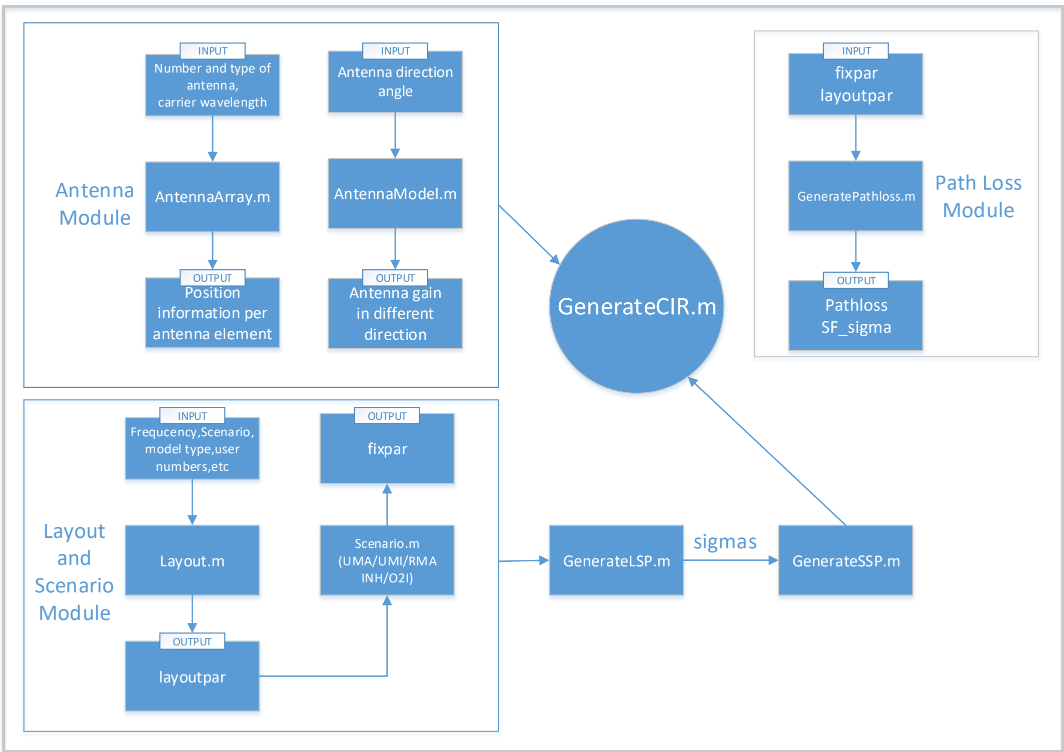

Figure 1 The structure and data flow of CM platform

3.2 Graphical User Interface description

The file "IMT-2020_CM_BUPTv2.fig" is the interface of the platform. Users can directly open this file to configure the simulation parameters and run the platform. The Graphical User Interface (GUI) of IMT-2020_CM_BUPT v2.0 is shown in Figure. 2.

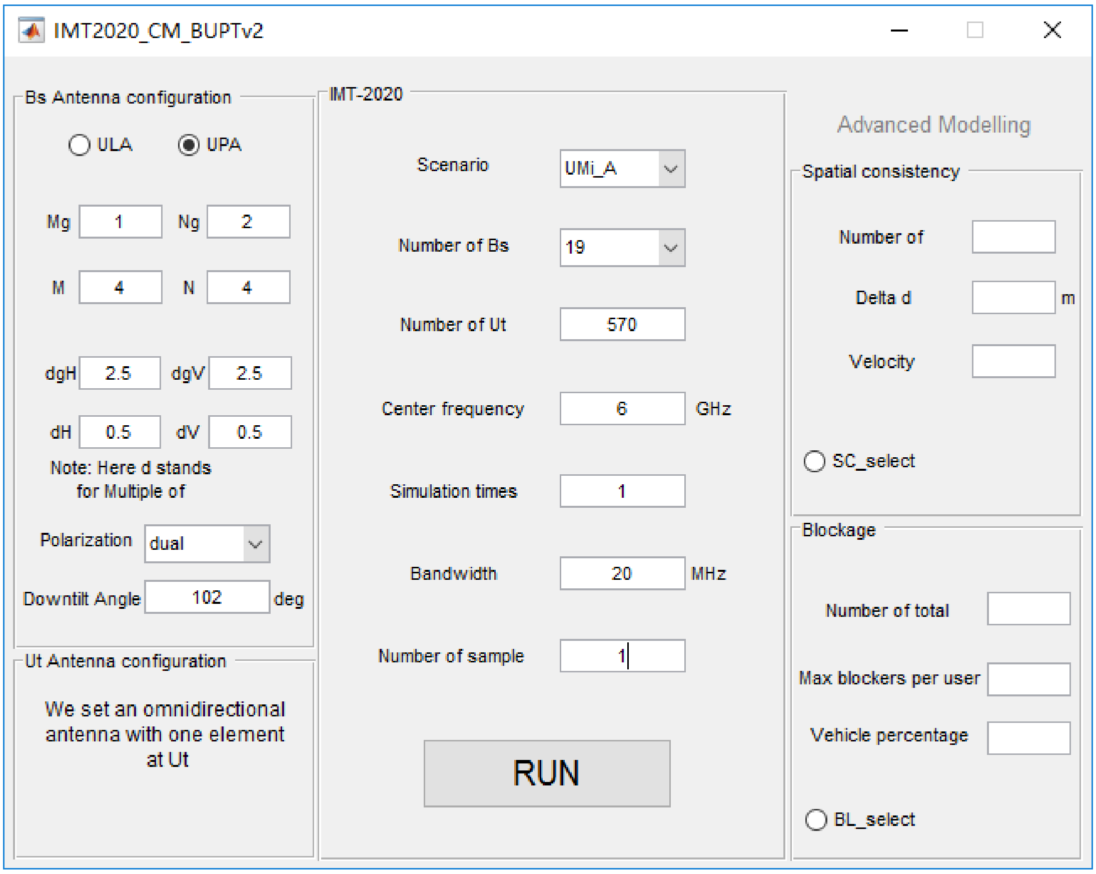

Figure 2 GUI of IMT-2020_CM_BUPT v2.0

3.2.1 Antenna parameter Input

The Ut antenna is set to be a single vertical-polarized omnidirectional antenna. The Bs antenna can be configured according to the specific requirement. For the description of specific parameters, you can refer to ITU-R M.2412 Page31.

Table 1 Antenna parameter configuration

Parameter name	Description	Note
ULA/UPA	Choice of ULA/UPA	When ULA selected, Mg, Ng, N will be automatically set to 1
Mg	Number of antenna panel rows	-
Ng	Number of antenna panel columns	-

M	Number of antenna element rows	-
N	Number of antenna element columns	-
dgH	The horizontal distance between the antenna panel	dgH should be greater than dH*(N-1) the unit is the length of wavelength.
dgV	The vertical distance between the antenna panel	dgV should be greater than dV*(M-1) the unit is the length of wavelength.
dH	The horizontal distance between the antenna unit	the unit is the length of wavelength.
dV	The vertical distance between the antenna unit	the unit is the length of wavelength.
Polarization	Choice of polarization	Single and dual polarization options
Downtilt Angle	Antenna downtilt angle	-

3.2.2 System parameter Input

The system parameters which are needed to be configured by users, are listed in Table 2.

Table 2 System parameter configuration

Parameter name	**Description**	**Note**
Scenario	Choice of scenario	According to ITU-R M.2412, the optional scenarios are included in the popup menu
Number of Bs	Number of base stations within the base station	According to the actual situation, the common used numbers of base stations are included in the popup menu
Number of Ut	Number of user terminal	-
Center frequency	Center frequency	-
Simulation times	Simulation times	-
Bandwidth	Bandwidth	-
Number of sample points	Number of sampling points	-

3.2.3 Parameters Input for advanced modelling components

Three advanced modelling components are implemented in the platform, which are "Spatial Consistency" and "Blockage".

Spatial Consistency Simulation Configuration

The spatial consistency part of this program is only applicable to the case of a single link.

When spatial consistency is selected, the 'Number of Bs' and 'Number of Ut' will be automatically set to 1.

Table 3 Parameter description for spatial consistency

Parameter name	Description	Note
Number of points	Set the number of inflection points in the Ut moving route.	-
Delta d	Set distance resolution	Should be less than 1 meter
Velocity vector	Vector of velocity	Each inflection point contains 3 parameters. The speed, horizontal moving direction, and vertical moving direction are respectively. The unit of speed is m/s. The unit of horizontal moving direction is deg. The unit of vertical moving direction is deg. The length of input should be equal to point*3. e.g. 10 45 90 10 45 0 Just enter the value in order is OK.

Blockage Simulation Configuration

The blockage part of this program is realized according to the blockage model II in ITU-R M.2412.

Table 4 Parameter description for blockage

Parameter name	Description	Note
Number of total blockers	Set the total number of blockers within the base station	-
Max blockers per user	Set the maximum number of blockers for a user	-
Vehicle percentage	The percentage of vehicle blockers in all blockers	-

3.3 Antenna Configuration

3.3.1 Antenna Array Geometry

The BS antenna is modelled by a uniform rectangular panel array, comprising Mg Ng panels, as illustrated in Figure 3 [1] with Mg being the number of panels in a column and Ng being the number of panels in a row. Furthermore, the following properties apply:

- Antenna panels are uniformly spaced in the horizontal direction with a spacing of dg,H and in the vertical direction with a spacing of dg,V.

- On each antenna panel, antenna elements are placed in the vertical and horizontal direction, where N is the number of columns, M is the number of antenna elements with the same polarization in each column.
- Antenna numbering on the panel illustrated in Figure 3 assumes observation of the antenna array from the front (with x-axis pointing towards broad-side and increasing y-coordinate for increasing column number).
- The antenna elements are uniformly spaced in the horizontal direction with a spacing of dH and in the vertical direction with a spacing of dV.
- The antenna panel is either single polarized (P =1) or dual polarized (P =2).

The rectangular panel array antenna can be described by the following tuple (M_g, N_g, M, N, P).

NOTE: The user antenna defaults to an omnidirectional antenna element.

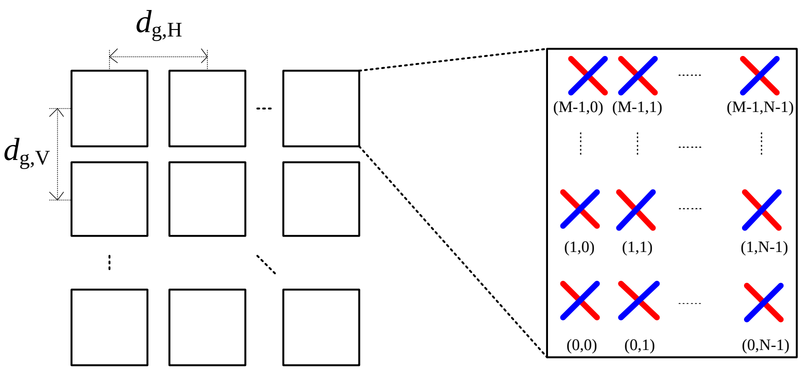

Figure 3 Bs antenna model [1]

More details about the function AntennaArray.m can be seen in Table 5.

The full syntax for AntennaArray function is:

AA=AntennaArray (Mg,Ng,M,N,dgH,dgV,dH,dV,lambda)

Table 5 Short overview of input and output arguments for AntennaArray.m

Argument name	**Type**	**Description**	**Default value**	**Note**
Mg	input	the number of panels in a column	-	-
Ng		the number of panels in a row	-	-
M		the number of antenna rows in a panel	-	-
N		the number of columns in a panel	-	-
dgH		Antenna panel spacing in horizontal direction	-	-
dgV		Antenna panel spacing in vertical direction	-	-

dH		Antenna spacing of one panel in horizontal direction	-	-
dV		Antenna spacing of one panel in vertical direction	-	-
lambda		Wavelength of used carrier	-	The default space between adjacent elements is half wavelength
AA	output	Information of antenna array	-	-

3.3.2 Antenna Response

Antenna Response can be expressed by elevation angle θ and azimuth angle φ. The detailed formulas can be seen from TABLE 9-11 in Report ITU-R M.2412-0. More details about the function AntennaModel.m can be seen in Table 6.

The full syntax for AntennaModelBs function is:
AntennaGain=AntennaModelBs(phi, theta).

NOTE: User antenna gain defaults to 0 dB.

Table 6 Short overview of input and output arguments for AntennaModelBs.m

Argument name	Type	Description	Default value	Note
phi	input	Azimuth angle of arrival or departure refer to each element	-180:1:180	-
theta		Elevation angle of arrival or departure refer to each element	0:1:180	-
AntennaGain	output	3D antenna element pattern	-	-

3.4 Scenario and Layout

3.4.1 Network Layout

CM implementation currently support system simulations for mutilple UT-BS links. So the network layout includes information about: the height of the BS and the UT, the distance between the BS and the UT, the LOS probability of the link, the frequency used in the simulation, etc. Layout.m function almost defines all the parameters decided by users. After implementing the function, all information required to generate LSP and SSP of each link can be obtained. More details about Layout.m can be seen in Table 7.

The full syntax for Layout function is:
layoutpar=Layout(Input.Sce,Input.C, Input.N-user,Input.fc,Input.AA).

Table 7 Short overview of input and output arguments for Layout.m

Argument name	Type	Description	Default value	Note
Sce	input	Simulation scenario that users choose	-	-
C		Elevation angle of arrival or departure refer to each element	1	Currently support one BS
N_user		Number of subscribers for all BS	-	-
fc		Carrier frequency in GHz	-	The range of frequency is 0.5-100 GHz
AA		Configuration of antenna array	-	-
layoutpar	output	Information of the network layout	-	-

3.4.2 Description of supported propagation scenarios

The function scenario.m defines the necessary parameters of different propagation scenarios. The supported scenarios of the platform are listed in Table 8. For details about the scenarios definitions see Report ITU-R M.2412-0. The scenario-dependent parameter is currently supported at center frequency of 0.5-100 GHz. More details about scenario.m can be seen in Table 9.

The full syntax for path scenario function is:
fixpar=Scenario(Input.fc, layoutpar).

Table 8 Supported scenarios of the current platform

Scenario	Type	LOS/NLOS/O2I	Frequency (GHz)	Note
InH	A/B	LOS/NLOS	0.5-100	InH 28G(Optional) is provided
UMa		LOS/NLOS/O2I		

			0.5-100	-
UMi		LOS/NLOS/O2I	0.5-100	-
RMa		LOS/NLOS/O2I	0.5-100	-

Note: For model A, when $0.5\text{ GHz} \le fc \le 6\text{ GHz}$, the type of channel model is A1; when $6\text{ GHz} \le fc \le 100\text{ GHz}$, the type of channel model is A2.

Table 9 Short overview of input and output arguments for Scenario.m

Argument name	Type	Description	Default value	Note
fc	input	Carrier frequency in GHz	-	-
layoutpar		Information of network layout	-	More details can be seen from Layout.m
fixpar	output	A structure contains parameters of different scenarios	-	-

3.5 Path loss

The path loss modelling is based on ITU-R M.2412-0. The path loss models and their applicability, including frequency ranges, are summarized in Tables A1-2 to A1-5 and the distance definitions are indicated in Figure 4.

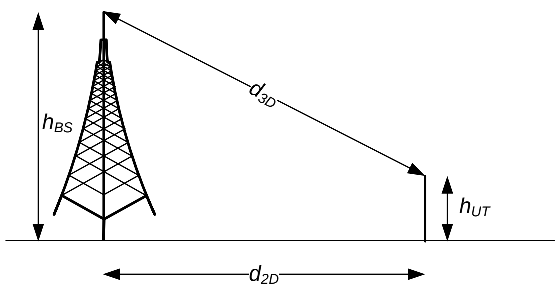

Figure 4 Definition of d_{2D} and d_{3D} for outdoor UTs

The full syntax for path loss function is:
[Pathloss, SF_sigma]=GeneratePathloss(layoutpar).

The detailed description of parameters is shown in Table 10.

Table 10 Short overview of input and output arguments for GeneratePathloss function

Argument name	Type	Description	Helper function	Note
layoutpar	input	Define positions of BS and UT, their assigned antenna arrays and gives links of interest for simulation.	layout.m	The function layout parameters should be defined by user. For example, the range of radius of cells and street width should be set.
Pathloss	output	Multiple-link path loss is supported currently.	-	-
SF_sigma		The number is the same as that in Scenario.m	-	Putting SF sigma here is convenient for adding shadow fading to the CIR later.

Note: The application for scenarios are supported in InH_x, UMa_x, UMi_x, RMa_x.

3.6 Large Scale Parameter

In the channel modeling, it is usually assumed that statistical parameters on the same link or different links have certain relevance. Usually these parameters include shadow fading, delay spread and angle spread. There are two different link correlations in the GBSM, one is the correlation between communication links formed by the same BS and different UT and the other is the link formed between different BSs serving the same UT. In the actual channel modeling process, the former is usually referred to as intra-site correlation, and the latter as inter-site correlation. In the standard GBSM channel model, it is common to measure, analyze, and model intra-station correlations, without regard for inter-station correlation.
The parameters are shown in Table 11.

Table 11 Descriptions of Large-scale parameters

Type		Parameter symbol	Description
LSP	Statistical correlaton parameers	SF[dB]	Shadow Fading, Log-normal Distribution Random Variable.
		K[dB]	The Rice factor ,defined as the ratio of LOS power to all NLOS power; if the link is NLOS transmission, the value is ignored or assigned as 0 [$-\infty$ dB].
		σ_τ	Root-mean-square (RMS) delay spread.
		σ_{ASA} σ_{ESA}	UT angle spread, root-mean-square (RMS) angle spread.
		σ_{ASD} σ_{ESD}	BS angle spread, root-mean-square (RMS) angle expansion.

The full syntax for large scale parameter function is:
sigmas=GenerateLSP(layoutpar, fixpar).

The detailed description of parameters is shown in Table 12.

Table 12 Short overview of input and output arguments for GenerateLSP

Argument name	Type	Description	Helper function	Note
layoutpar	input	Define positions of BS and UT.	Layout.m	The scenario information should be set by users.
fixpar		Extract the scenario information from fixpar for computing LSP.	Scenario.m	-
sigmas	output	Large-scale parameters	-	-

3.7 Small Scale Parameter

The small-scale fading parameters reflect the main characteristics of multipath clusters in a link, including delay, power and spatial information. It directly establishes the connection with the traditional GBSM channel modeling because all the delay and spatial information directly reflect the scatters distribution information of the traditional GBSM. In addition, it should be noted that these SSPs are also the key factors that reflect the characteristics of the entire wireless channel. For example, the delay information determines the channel bandwidth of the entire simulated channel, and the angle information determines the spatial spread information of the entire channel.
The small scale parameters are shown in Table 13.

Table 13 Descriptions of Small-scale parameters

Type	Parameters symbol	Description
SSP	$\mathbf{T}_{N\times 1}=[\tau_1\ \tau_2 \cdots \tau_3]^T$	Cluster relative delay, generally obeying the exponential distribution or uniform distribution
	$\mathbf{P}_{N\times 1}=[P_1\ P_2 \cdots P_3]^T$	The average fading power of a cluster from the PDS, is usually an exponential decay model.
	$\mathbf{\Phi}_{N\times M}^{AOA}, \mathbf{\Phi}_{N\times M}^{AOD}$	Horizontal dimension AOA and AOD angle of ray path from PAS, is generally Gaussian or Laplace distribution; Each ray path in the cluster has the same fading power and the ray angle is symmetrically offset from the mean.
	$\mathbf{\Theta}_{N\times M}^{EOA}, \mathbf{\Theta}_{N\times M}^{EOD}$	vertical dimension EOA and EOD angle of ray path from the PAS, is generally Gaussian or Laplace distribution.

	$\mathbf{K}^{VH}_{N\times M},\mathbf{K}^{HV}_{N\times M}$	The XPR of the ray path, is valid only for dual polarized antennas, obeyed log-normal distribution.

The full syntax for Small-scale parameters function is:
GenerateSSP(layoutpar, fixpar, Input.sim)

The detailed description of parameters is shown in Table 14.

Table14 Short overview of input and output arguments for GenerateSSP

Argument name	Type	Description	Helper function	Note
layoutpar	input	Define positions of BS and UT, their assigned antenna arrays and gives links of interest for simulation.	Layout.m	-
fixpar		Extract the scenario information from fixpar for computing LSP.	Scenario.m	-
sim		Number of simulations	-	Defined by users

3.8 Channel Impulse Response

Generate channel coefficients for each cluster n and each receiver and transmitter element pair u, s and the channel coefficients are given by:

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

Note: The current version is up to the user to decide whether to add path loss and shadow fading. The function of path loss is supported but it does not be added in the CIR. For LOS condition, see Report ITU-R M.2412-0.

Considering that $H^{\mathrm{NLOS}}_{u,s,n}(t)$ is a constant function of the variable t, computers cannot represent constant variable. So the platform samples CIR in the time domain according to Nyquist sampling theorem. The number of sampling points is set by users. During a coherent time, the sampling points of CIR are highly relevant. The number of sampling points during the coherent time is 2. Besides, the coherent time is decided by Doppler shift.
The full syntax for channel impulse response function is:
GenerateCIR(fixpar,layoutpar,Input.sim,Input.BW, Input.T).

The detailed description of parameters is shown in Table 15.

Table 15 Short overview of input and output arguments for GenerateCIR

Argument name	Type	Description	Helper function	Note
layoutpar	input	Define positions of BS and UT.	Layout.m	The scenario information should be set by users.
fixpar		Extract the scenario information from fixpar for computing LSP.	Scenario.m	-
sim		Number of simulations	-	-
BW		Bandwidth of simulations	-	-
T		Number of sampling points of CIR in time domain	-	-

4 Description of Output results

Outputs of the CM platform are saved in pre-established folder. The example of output is shown in Figure 5:

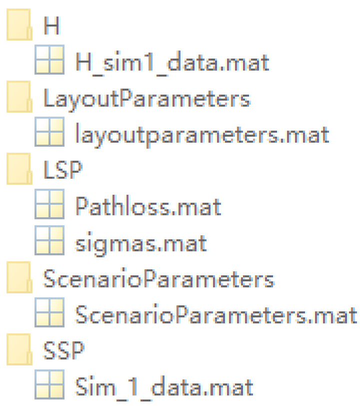

Figure 5 Example of outputs of CM platform

- Channel impulse response are saved in 'H' folder, CIR data consists of results of LOS link, NLOS link and O2I link. The index of each link can be seen when load Channel impulse reponse.The form of H is shown:
  H=(S, U, N_cluster, T, link);
  H is a Multidimensional matrix, S represent the number of transmit antennas, U represent the number of receive antennas, N_cluter represent the number of clusters, T represent

sampling points, linkindex represent the number of links.

- Layout parameters are saved in ‘LayoutParameters’ folder. Link information, such as propagation condition of each link can be seen in ‘LinkArray’ matrix. ‘Bs_sector_index’ matrix represents information about each Ut belonging to which BS and which sector.
  For ‘LinkArray’ matrix, the first row represents the link index, the second row represents the Propagation condition. For example, 0 represents NLOS, 1 represents LOS, 2 represents O2I.
  For ‘Bs_sector_index’ matrix, the first row represents link index, the second row represents Bs index, the third row represent sector index.
- The path loss information and correlated LSP parameters are saved in ‘LSP’ folder. Each row of ‘sigmas’ matrix stores ASD,ASA,DS,SF,KF,ESD,ESA. Each column represents each link. ‘Pathloss’ matrix stores path loss information.
- Scenario parameters are saved in ‘ScenarioParameters’ folder. It is a structure consists of some parameters defined in [1].
- Small scale parameters of each link are saved in ‘SSP’ folder.

5 Running example

Here provides an example of the main procedure on generating coefficients of channel and channel impulse response. In this example, the simulation frequency is at 6 GHz and UMi_A is selected as the simulation scenario. The running results of CIR are stored in the folder ‘H’.

```
%% Channel coefficient generation for link with default settings.
%Create folder to store data
cd ./SSP;
delete *.mat;
cd ../;
cd ./H;
delete *.mat;
cd ../;
Input=struct('Sce','UMi_B',... %Set the scenario (InH_x, UMi_x, UMa_x, RMa_x)
    'C',19,...                 %Set the number of Bs
    'N_user',570,...           %Set the total number of subscribers
'fc',6,...                     %Set the center frequency (GHz)
   'AA',[1,1,10,1,1,2.5,2.5,0.5,0.5,102],... %AA=(Mg,Ng,M,N,P,dgH,dgV,dH,dV,downtilt)
                               BS antenna panel configuration,unit of d and dg is wave length.
    'sim',1,...                %Set the number of simulations
    'BW',200,...               %Set the bandwidth of the simulation(MHz)
     'T',10 );                 %Set the number of sampling points of CIR in time domain

layoutpar=Layout(Input.Sce,Input.C,Input.N_user,Input.fc,Input.AA);
[Pathloss,SF_sigma]=GeneratePathloss(layoutpar);%Generate path loss and shadow fading.
fixpar=Scenario(Input.fc,layoutpar);%Generate scenario information.
sigmas= GenerateLSP(layoutpar,fixpar);
GenerateSSP(layoutpar,fixpar,Input.sim,sigmas);%Generate small-scale parameters.
```

```
GenerateCIR(fixpar,layoutpar,Input.sim,Input.BW,Input.T);%Generate the channel coefficient.
```

6 Reference

[1] Series M. Guidelines for evaluation of radio interface technologies for IMT-2020. REPORT ITU-R M.2412-0, 2017.

[2] Jianhua Zhang, Yuxiang Zhang, Yawei Yu, Ruijie Xu, Qingfang Zheng, Ping Zhang, “3D MIMO: How Much Does It Meet Our Expectation Observed from Antenna Channel Measurements?”, IEEE Journal on Selected Areas in Communications, vol. 35, no. 8, pp. 1887 – 1903, 2017.