The Method to Implement 5G Channel Model with Spatial Consistency

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***Abstract*—For the purpose of evaluating the performance of mmWave beamforming/tracking schemes, spatial consistency is regarded as a mandatory feature for 5G channel model. In this paper, the geometric stochastic modelling method for spatial consistency is implemented. And the specific modelling procedure is provided. By modifying the mmWave channel model in ITU-R, the spatial consistency is applied into the model. On the basis of it, the changes of cluster delays and angles as mobile station (MS) moving under a certain trajectory are researched. For comparing, the same research is operated on the platform without spatial consistency. It can be observed that delays and angles of cluster will change continuously and obviously with the trajectory. These analysis results can give insight into the performance of mmWave communication system.**

I. Introduction

With the development of communication technology, the volume of mobile traffic becomes more and more tremendous. The available resources of radio spectrum below 6 GHz are less than before. This problem pushes us to use the high frequency band from 6 GHz up to 100 GHz for communication [1]. To achieve this target, the fifth generation (5G) mobile communication system has been put forward on the research schedule which is also regarded as International Mobile Telecom system-2020 (IMT-2020) [2].

The channel, as a key part of the 5G communication system, needs to be researched. Nowadays, channel modelling technology has been developing for many years. The requirement for the accuracy of the model is higher than before. In the 3G communication system, a channel impulse response (CIR) model based on a tapped-delay line (TDL) model was given in which more attention was paid to the time delay and average power of the taps. Then, in the 4G communication system, ITU-R M.2135 [3] is released in which the horizontal angle is added into the channel model. After that, the 3rd Generation Partnership Project (3GPP) proposed the TR 36.873 [4] and TR 38.901 [5] which both add the elevation angle. The former is for low frequency under 6 GHz and the latter is for high frequency from 6 GHz to 100 GHz. These three kinds of channel model are all geometry based stochastic channel model (GBSM) which can be called drop-based model. Drop is channel segment representing a period of quasi-stationarity during which probability distributions of low-level parameters are not changed noticeably [6]. And all the channel parameters are dependent between two drops. In a drop, large scale parameter (LSP) are constant, but as the MS moving, the small scale parameters (SSP) are generated randomly and independently. Hence, the continuous information about the status of channel can not be provided.

However, in 5G era, the mmWave channel model attracts more attention. Some research progress and challenges are summarized on reference [1]. Among various technologies, hybrid beamforming and tracking technology are crucial [7]. They need the information about time variant channel. Hence, the spatial consistency procedure was provided in the newest standard by International Telecommunication Union-Radio (ITU-R) channel work group. It can model the time variant channel[8].

This paper will discuss the channel model proposed by ITU-R M.2412 [9] and its new feature spatial consistency. Then a simulation of new channel model will be implemented and the effect of spatial consistency will be studied. The overview paper is organized as follows: Section II introduces the spatial consistency and its main simulation methods. Section III will present the simulation flow of standard channel model. Section IV gives the implementation process of spatial consistency. Section V will provide the simulation result and analysis about cluster delays and angles. Finally, the conclusions are presented in Section VI.

II. Overview of Spatial consistency

Spatial consistency is a new advance feature of 5G channel model. It means that the cluster delays and angles of channel are spatially consistent for drop-based model as the MS moving. In traditional drop-based models, the generated process of cluster delays and angles are random. As the MS moving, they will change rapidly and can not reflect the continuity. So in the newest model 3GPP TR 38.901 [5] and ITU-R M.2412 [9] channel model, there are two kinds of spatial consistency methods for spatially consistent mobility simulation, one is the geometric stochastic approach that is Spatial Consistency Model I (SC-I), and the other is the spatially correlated random variable based method that is Spatial Consistency Model II (SC-II). SC-I and SC-II both focus on modifying the procedure of SSP generation in order to obtain the continuously change of cluster parameters. SC-I is a kind of iteration method which is used to update the cluster delays, powers and angles. While SC-II replaces the Step 5, 6 and 7 in [9] to ensure that the cluster delays and angles are spatially consistent. The former applies specific formulas to describe the changes of SSPs and is easily implemented.

In this paper, the implementation of SC-I method is provided. It can be used in the situation described as Fig. 1. Between each MS and base station (BS), the ligatures are called links. As the MS moves at a fixed speed in a trajectory, there are different links according to various positions of MS. And in the simulation, the moving distance Δd has to be limited within 1 meter for each Δt. More detailed simulation is introduced in Section IV.

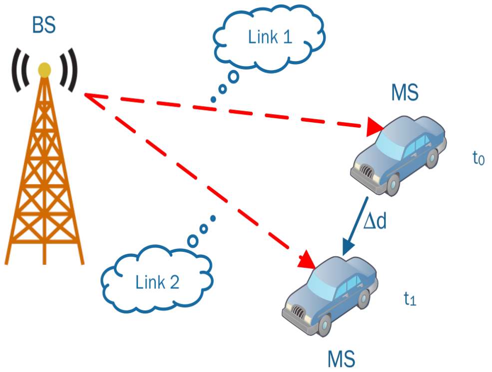


Fig. 1. Spatially consistent MS mobility

III. IMPLEMENTATION OF GENERAL CHANNEL MODEL

As wireless communication system has been developing, the theory of channel modelling becomes more mature and sophisticated. In the newest channel standard of ITU-R M.2412, the main procedure of channel coefficient generation has been provided as shown in Fig. 2. XPR and SF is the abbreviation of cross polarization power ratio and shadow fading. The whole procedure is divided into three main parts: General parameters, SSPs and Coefficient generation. Under the framework, spatial consistency is regarded as a component. Therefore, in this section, we will present the general implementation of channel model.

A. General parameters

General parameters include initial configurations and LSP generation. The first part is about the network layout including simulation scenarios and antenna parameters. Antenna type and number of antenna elements will be settled in this step. While the network layout is determinate, the propagation condition, for instance Non-Line of Sight (NLoS) and Line of Sight (LoS), will be calculated according to the distance between BS and MS with the expression in Table 3-8 [5]. The second part is the pathloss (PL) which has more intimate introduction in [9]. The last part is the LSP which includes root-mean-square delay spread, root-mean-square angular spreads, Ricean K-factor and shadow fading.

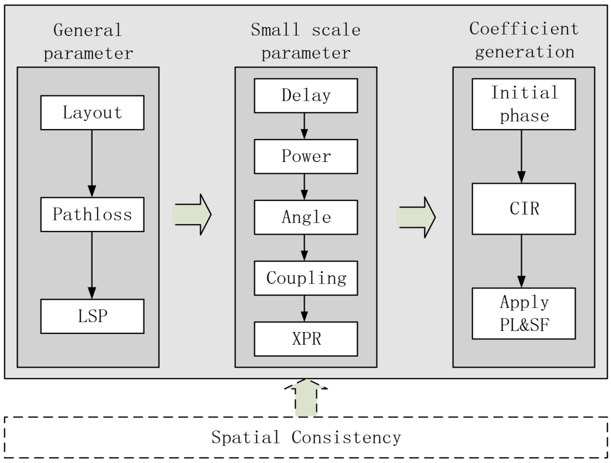


Fig. 2. Main procedure of generating the channel coefficient

B. Small Scale Parameters

SSP represents the main feature of multi-path clusters in one link. They mainly contain delay, power and spatial angular information. These SSPs are significant feature of wireless radio channel. For example, delay information determines the channel band of the simulation and angular information determines the spatial spread feature of the whole channel. More specific procedures are provided in [9].

C. Channel Coefficient Generation

According to the main procedure above, generating random initial phases is the first step of channel coefficient generation. For each ray within each cluster, initial phases have four different polarization types as below:

$$(\Phi_{n,m}^{\theta\theta}, \Phi_{n,m}^{\theta\phi}, \Phi_{n,m}^{\phi\theta}, \Phi_{n,m}^{\phi\phi}) \tag{2}$$

where $\Phi \sim U(-\pi, \pi)$ and $(\theta\theta, \theta\phi, \phi\theta, \phi\phi)$ represents four polarization combinations. Assuming the number of transmit antenna elements and receive antenna elements are S and U, the channel coefficient of n_{th} cluster from the transmit antenna s to the receive antenna u is a $U \times S$ channel complex matrix that can be expressed as Eq. 1 [10]. where

- $(\cdot)^T$ stands for matrix transposition.
- λ_0 is the wavelength of the carrier frequency.
- n, m is the index of cluster and ray respectively.
- P_n is the power of cluster and M is the number of ray.
- $F_{rx,u,\theta}$, $F_{rx,u,\phi}$ indicate the gain of receive antenna u in azimuth and elevation direction. $F_{tx,s,\theta}$, $F_{tx,s,\phi}$ indicate the gain of transmit antenna s in azimuth and elevation direction.
- $\Phi_{n,m}^{\theta\theta}$, $\Phi_{n,m}^{\theta\phi}$, $\Phi_{n,m}^{\phi\theta}$, $\Phi_{n,m}^{\phi\phi}$ represent initial phase for each ray m of each cluster n in four different polarisations.
- $\hat{r}_{rx,n,m}^T$ is the spherical unit vector with azimuth arrival angle and elevation arrival angle. $\hat{r}_{tx,n,m}^T$ is the spherical unit vector with azimuth departure angle and elevation departure angle.
- $\bar{d}_{rx,u}$ is the location vector of receive antenna element u and $\bar{d}_{tx,s}$ is the location vector of transmit antenna

$$H_{u,s,n}(t) = \sqrt{\frac{P_n}{M}} \sum \begin{bmatrix} F_{rx,u,\theta} \\ F_{rx,u,\phi} \end{bmatrix}^T \begin{bmatrix} exp(j\Phi_{n,m}^{\theta\theta}) & \sqrt{\kappa_{n,m}^{-1}} exp(j\Phi_{n,m}^{\theta\phi}) \\ \sqrt{\kappa_{n,m}^{-1}} exp(j\Phi_{n,m}^{\phi\theta}) & exp(j\Phi_{n,m}^{\phi\phi}) \end{bmatrix} \begin{bmatrix} F_{tx,s,\theta} \\ F_{tx,s,\phi} \end{bmatrix}$$
$$exp(j2\pi \frac{\hat{r}_{rx,n,m}^T \cdot \bar{d}_{rx,u}}{\lambda_0}) exp(j2\pi \frac{\hat{r}_{tx,n,m}^T \cdot \bar{d}_{tx,s}}{\lambda_0}) exp(j2\pi \frac{\hat{r}_{rx,n,m}^T \cdot \bar{v}}{\lambda_0} t) \quad (1)$$

element s.

- $\bar{v}$ is the MS's velocity vector.

IV. Implementation of Spatial Consistency

In this section, the SC-I, geometric stochastic approach of spatial consistency in [9], is the major research. It mainly modifies the steps of generating cluster delays, powers and angles. Other steps of general channel model generation should keep unchanged. The detailed procedure about the new feature can be introduced as follows.

A. Generation of Cluster Delay

In order to simulate the time evolution, time axis should be added. Assuming t_k is the k_{th} time point, Δt is the moving time interval. Then at t_k, the cluster delay can be written as:

$$\begin{aligned} \tilde{\tau}_n(t_k) &= \tilde{\tau}_n(t_{k-1} + \Delta t) \\ &= \tilde{\tau}_n(t_{k-1}) - \frac{\hat{r}_{rx,n}(t_{k-1})^T \bar{v}(t_{k-1})}{c} \cdot \Delta t \end{aligned} \quad (3)$$

where c is the speed of light, $\bar{v}(t_{k-1})$ is the MS's velocity vector and can be written as

$$\bar{v}(t_{k-1}) = \begin{bmatrix} V_X(t_{k-1}) & V_Y(t_{k-1}) & V_Z(t_{k-1}) \end{bmatrix}^T \quad (4)$$

$\hat{r}_{rx,n}(t_{k-1})$ is the spherical unit vector which had been defined in Eq. 1. It has the following form as:

$$\hat{r}_{rx,n}(t_{k-1}) = \begin{bmatrix} sin(\theta_{n,ZOA}(t_{k-1}))cos(\phi_{n,AOA}(t_{k-1})) \\ sin(\theta_{n,ZOA}(t_{k-1}))sin(\phi_{n,AOA}(t_{k-1})) \\ cos(\theta_{n,ZOA}(t_{k-1})) \end{bmatrix} \quad (5)$$

where $\theta_{n,ZOA}$ and $\phi_{n,AOA}$ are the arrival angles of a cluster in azimuth and elevation direction at t_{k-1}. The initial situation of iteration is that MS is dropped into the simulation network randomly. The time point is regarded as t_0. The cluster delay can be calculated as:

$$\tilde{\tau}_n(t_0) = \frac{d_{3D}(t_0) + c \cdot (\tau_n(t_0 + \tau_\Delta(t_0)))}{c} \quad (6)$$

where d_{3D} is the 3-Dimension distance between BS and MS, $\tau_n(t_0)$ is generated in Step 5 of [9], $\tau_\Delta(t_0)$ is 0 in the LoS propagation condition but minimum of τ'_n in Step 5 of [9] otherwise. Keeping the delay of first cluster be zero is necessary. However, the generation of delay needs to be replaced by

$$\tau_n(t_k) = \tau_n(t_{k-1} + \Delta t) = \tilde{\tau}_n(t_k) - min(\tilde{\tau}_n(t_k)) \quad (7)$$

B. Generation of Cluster Power

In Section III-B, the cluster power is generated. If considering about spatial consistency, the generation of cluster delay should be updated by Eq. 7. As for other steps of generating cluster power, no more change should be done.

C. Generation of Cluster Angle

In Section III-B, the formulas of cluster angles are provided. While the MS moves to next position, the angles are independent generated by a random distribution such as Gaussian distribution or Laplacian distribution. However, in the case of spatial consistency, the features of angle are correlated in adjacent time. For example, assuming there is only one MS. Firstly, at t_{k-1}, there is one channel link between the MS and BS. Since the MS moves at a certain speed, the status of the channel link at next time point t_k need be updated according to the status at t_{k-1}. The departure angle of cluster at t_k can be updated as following equations:

$$\phi_{n,AOD}(t_k) = \phi_{n,AOD}(t_{k-1}) + \frac{\bar{v}'(t_{k-1})^T \cdot \alpha}{r'_{n,3D}(t_{k-1})} \frac{180}{\pi} \Delta t \quad (8)$$

$$\theta_{n,ZOD}(t_k) = \theta_{n,ZOD}(t_{k-1}) + \frac{\bar{v}'(t_{k-1})^T \cdot \beta}{r_{n,3D}(t_{k-1})} \frac{180}{\pi} \Delta t \quad (9)$$

where α, β and $\bar{v}'(t_{k-1})$ can be denoted as

$$\alpha = \begin{bmatrix} -sin(\phi_{n,AOD}(t_{k-1})) \\ cos(\phi_{n,AOD}(t_{k-1})) \\ 0 \end{bmatrix} \quad (10)$$

$$\beta = \begin{bmatrix} cos(\phi_{n,AOD}(t_{k-1})) \cdot cos(\theta_{n,ZOD}(t_{k-1})) \\ cos(\theta_{n,ZOD}(t_{k-1})) \cdot sin(\phi_{n,AOD}(t_{k-1})) \\ -sin(\theta_{n,ZOD}(t_{k-1})) \end{bmatrix} \quad (11)$$

$$\begin{aligned} \bar{v}'(t_{k-1}) &= \begin{bmatrix} V'_X(t_{k-1}) & V'_Y(t_{k-1}) & V'_Z(t_{k-1}) \end{bmatrix} \\ &= R \cdot \bar{v}(t_{k-1}) \end{aligned} \quad (12)$$

In Eq. 12, R is the rotation matrix defined in [9]. As for $r'_{n,3D}$ in Eq. 8, it can be expressed by:

$$\begin{aligned} r'_{n,3D}(t_{k-1}) &= r_{n,3D}(t_{k-1}) \cdot sin(\theta_{n,ZOD}(t_{k-1})) \\ &= c \cdot \tilde{\tau}_n(t_{k-1}) \cdot sin(\theta_{n,ZOD}(t_{k-1})) \end{aligned} \quad (13)$$

Δt used in above is the moving time interval. When updating the arrival angle of cluster, we need use $\phi_{n,AOA}$, $\theta_{n,ZOA}$ and $\bar{v}(t_{k-1})$ in Eq. 8-9.

After updating the delays, powers and angles of the clusters, the channel coefficient with spatial consistency will be generated according to the subsequent operations in main procedure.

V. Analysis of Simulation Result

For the purpose to analyse the effect of spatial consistency, the same simulation is performed in both platforms that

TABLE I
CONFIGURATION OF SIMULATION

Parameters	Description
Scenarios	UMi
Carrier Frequency	28.0 GHz
BS antenna configurations	8 Tx, ULA, 0.5λ H spacing
MS antenna configurations	4 Rx, ULA, 0.5λ H spacing
Polarisation	X-pol at both BS and MS
MS velocity	0.8 m/s
Moving interval	0.1 m
Moving times	50

one with spatial consistency and the other without spatial consistency. Table I shows the specific configuration. The simulation scenario is urban micro-cell (UMi) NLoS and the center frequency is 28 GHz. Fig. 3 shows the trajectory of MS and BS is at origin of coordinates. The moving velocity of MS is 0.8 m/s. In the trajectory, we design three turning points which divide the trajectory into four parts. And in each part, in order to make the track reasonable and within the correlation distance in Table A1-26 [9], the MS moved 50 times and moving interval Δd is 0.1 m.

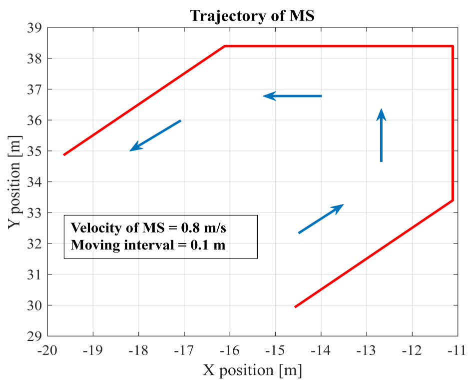


Fig. 3. The moving trajectory of MS.

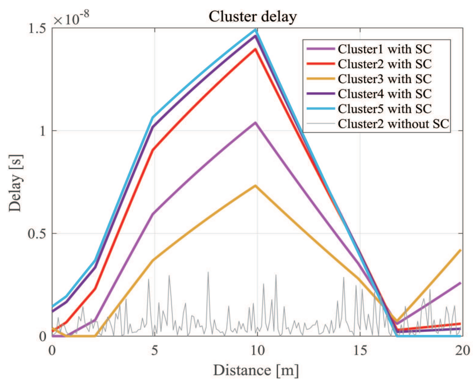


Fig. 4. The change of cluster delay.

Under this simulation configuration, we performed analysis on the delay, horizontal angle, and pitch angle of the first five

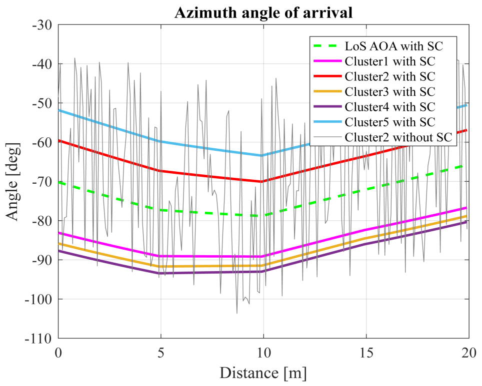
TABLE II
THE STD OF ANGLES IN SECOND CLUSTER

Angle of Cluster2	Std(with SC)	Std(without SC)
AOA	3.81	18.29
AOD	3.83	23.37
ZOA	0.72	3.34
ZOD	0.43	0.33

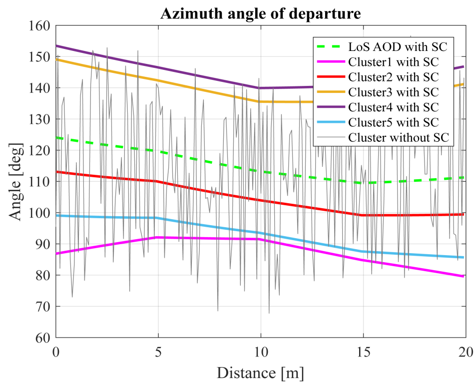
clusters with spatial consistency. For comparison, the results about change of the delay and angle of the second cluster are given without spatial consistency. Fig. 4 describes the change of cluster delays. Fig. 5(a-b) shows the azimuth angles of arrival (AOA) and azimuth angles of departure (AOD). Fig. 5(c-d) represents the zenith angles of arrival (ZOA) and zenith angles of departure (ZOD). Among all the Figs, the abscissa is the MS's travel distance from the start point and SC is the abbreviation of spatial consistency. The full lines represent angles generated from the simulation platform and the imaginary lines describe angles calculated according to geometric position. For example, LoS AOA means that we calculate the azimuth angles of arrival by connecting BS position and one of the MS positions directly on the coordinate system. It can be found that with spatial consistency the variation tendency of cluster angles consistent with the imaginary line which represents the angle change under direct glare condition. This reason is that the position and moving direction of MS are included in each iteration of angles. As the MS turns direction, it can be observed that cluster delays and angles will change together. Further, we choose the second cluster for comparison with or without spatial consistency. The delays and angles change rapidly and randomly without spatial consistency. And the change of moving direction has no obvious effect on angles. While considering the spatial consistency they change more smoothly and continuously in each part of trajectory. And in the turning point of trajectory, the angles have obvious change. Table II shows the difference of standard deviation (Std) in values. It can be seen that with spatial consistency the std of angels are small except the ZOD. The reason is that variance of ZOD is too small in both situations and the random factor may have effect on the specific value.

VI. CONCLUSION

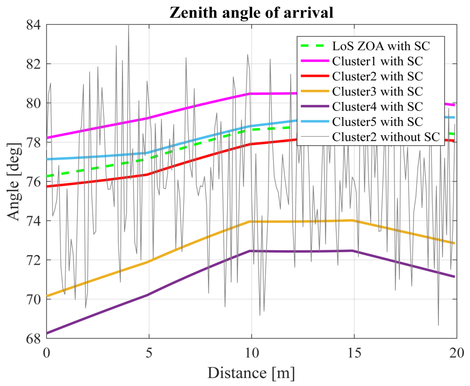
In this paper, a simulation implementation of the 5G channel model is given according to the new standardization of ITU-R M.2412 [9]. From various new features, the spatial consistency is chosen for researching and modeling method is also introduced. After researching the change of cluster delays and angles, it is obvious that applying the spatial consistency procedure can obtain continuous cluster delays and angles as the MS moving comparing without spatial consistency. In terms of standard deviation about angles, within spatial consistency the variation of cluster angles are smaller. And



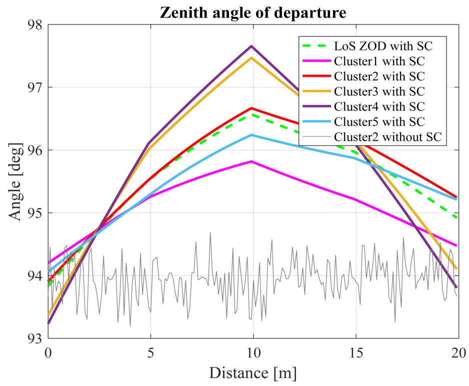
(a) The change of azimuth angle of arrival.



(b) The change of azimuth angle of departure.



(c) The change of zenith angle of arrival.



(d) The change of zenith angle of departure.

Fig. 5. The change of cluster angle.

this kind of continuity information about clusters is conducive to research of mmWave beam tracking technique.

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