Device-to-Device Extension to Geometry-Based Stochastic Channel Models

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***Abstract*—Increased interest towards direct Device-to-Device (D2D) radio communication has led to questions about the validity of standardised Geometry-based Stochastic Channel Models (GSCMs). D2D sets new requirements to channel models due to the different usage scenarios and different propagation environments. This paper discusses extensions to GSCMs for fulfilling the new requirements such as dual-mobility, spatial consistency, and lower antenna height compared to base stations. By using the sum of sinusoids method, significant savings on memory consumption can be achieved.**

***Index Terms*—channel model, propagation, D2D, 5G.**

I. INTRODUCTION

Direct Device-to-Device (D2D) communication is becoming more and more important due to the increased capacity, reliability, and latency requirements of future wireless applications. D2D covers any direct link between mobile devices, e.g., human-to-human, machine-to-machine, and vehicle-to-vehicle communications. D2D is actively discussed in 3GPP [1], [2] and several 5G research projects such as METIS [6].

The family of Geometry-based Stochastic Channel Models (GSCM), 3GPP SCM [6], WINNER II [7], IMT-Advanced [8] models are designed for cellular scenarios and are not suitable for D2D cases as such. The mobility of both link ends makes traditional cellular shadowing models obsolete. 3GPP has modelled dual mobility by adding velocity vector to both transmitter and receiver and thus achieving higher Doppler shift [2]. However, this model alone does not take spatial consistency and moving environment into account. Additionally, 3GPP has simplified the model by assuming uniform angle of arrival (104° azimuth spread) [2] and omni-directional antenna pattern [1]. These simplifications do not necessarily reflect reality.

Generally D2D links are affected by more severe shadowing because several objects such as vehicles, people, furniture are blocking the communication link between the TX and RX in the case of both TX and RX are located in low height (e.g. human users). Moreover, human interaction may be present at both ends of the link. The link is symmetric, meaning that both Tx and Rx see similar environment, and should have similar distributions for all parameters. As mentioned in [3] the importance of spatial techniques, as well as the density of links is expected to increase. In those cases the spatial consistency between links and multiple reflections between the devices should be taken into account.

Because in D2D communication both transmitter and receiver can be at any location, using of look-up tables of shadowing and path loss for simulations becomes impractical if the spatial consistency is required. This paper proposes an alternative method which does not require the look-up tables.

Since signal-to-interference and noise ratio (SINR) often dominates the radio link performance, it is crucial to emphasize the accurate shadowing model. This paper discusses on the low complexity shadowing model, dual-mobility and other D2D specific aspects, however not limiting to D2D.

II. D2D CHANNEL MODEL

A. Shadowing Model

This sub-section summarizes a method to generate jointly correlated shadowing values enabling spatial consistency in D2D scenarios. The method can be applied to other network layouts as well. In the case of two-dimensional locations of transmitter (x_1, y_1) and receiver (x_2, y_2), the possible combinations is four-dimensional matrix (x_1, y_1, x_2, y_2). When device height is taken into account, the transmitter and receiver locations are defined by (x_1, y_1, z_1) and (x_2, y_2, z_2), respectively. Then the shadowing map will be six-dimensional (6D). The 6D shadowing map enables consistent shadowing correlation for arbitrary 3D TX and RX locations. Anyhow generation of such a 6D map would lead to high computational complexity and extremely high memory consumption with the traditional noise filtering methods. An example description for generation of correlated parameter values to the 2D coordinate system is given in section 3.3.1 of [7]. A solution described in this sub-section is based on summing sinusoids [4], or actually waves in a 6D space. The method provides consistent joint correlation, and desired correlation distances and standard deviation for the shadowing process.

The shadowing is calculated for a link with TX and RX locations defined by a 6D location vector $\bar{D}$, in a coordinate system with arbitrary fixed origin, as follows

$$SF = \sqrt{\frac{2\sigma^2}{K}} \sum_{k=1}^{K} \sin\left(\bar{D} \cdot \bar{\beta}_k + \theta_k\right) \qquad (1)$$

where K is the number of waves, σ is the target standard deviation of SF in decibels, $\bar{D} = [x_u, y_u, z_u, x_v, y_v, z_v]$ is the location vector of Tx/Rx pair in 6D space, u and v coordinates refer to TX and RX locations, respectively, $\bar{\beta}_k$ is the wave vector of kth wave, θ_k is a random initial phase in range [0,2π]. Directions of wave vectors $\bar{\beta}_k$ are drawn randomly from the uniform distribution. In practice this is done by drawing randomly each of the six elements of vector $\bar{\beta}_k$ from distribution Uni~[-1,1]. The norm of all K wave vectors is scaled to

$$\|\bar{\beta}\| = \frac{2\pi\sqrt{2}\, arg\left(J_0(x)=\frac{1}{e}\right)}{d_{cor}} \qquad (2)$$

where d_{cor} is the target correlation distance in meters and $J_0(x)$ is the zeroth order Bessel function of the first kind. For $\arg\left(J_0(x) = \frac{1}{e}\right)$, where $J_0(x)$ is the 1D auto-correlation function, the value x can be found numerically..

The method is efficient in computational complexity and especially in memory consumption. Instead of a huge 6D matrix, only $K(6+1)$ real numbers have to be stored in the memory. In principle all the other (auto-) correlated large scale parameters could be generated with the method as well.

B. *Angular Parameters*

GSCM models have different angular parameters (angle spread, angle of arrival (AoA), angle of departure (AoD)) for BS and MS. For D2D case, the angular parameters of both link ends have the same statistical distributions, i.e. the angular parameters are symmetric. AoA and AoD are defined on the global coordination system, which means that the AoA and AoD seen by the device (local coordination system) depend on the device orientation. Additionally, effective angle spread is affected by device antenna pattern. Fig. 1 illustrates the D2D channel model with both user equipment (UE1 and UE2) moving towards their independent velocity vectors.

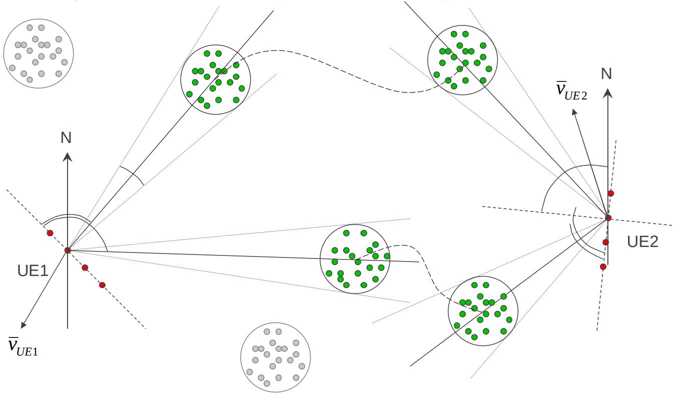

Fig. 1. D2D Channel Model.

C. *Doppler Effect*

The Doppler effect of cellular GSCM models is calculated from the velocity of UE and the angle between incoming ray and velocity vector. This approach is valid only in the case which both base station and environment are fixed. In the case of dual mobility, the Doppler shifts are calculated from the velocities and ray angles from both TX and RX as shown in the equation (3) [2].

$$v_{n,m} = \frac{\|v_{rx}\|\cos(\varphi_{n,m}-\theta_{vrx}) - \|v_{tx}\|\cos(\phi_{n,m}-\theta_{vtx})}{\lambda_0} \qquad (3)$$

where the cosines are taken from the angle differences between AoA/AoD of mth ray of nth path and the velocity vector, , and λ_0 is the wavelength of the carrier wave.

In the case of moving environment, we should take the additional Doppler shift term from reflectors/scatterers as well. This is especially true in the case of V2V communications as discussed in [5]. The V2V Doppler frequency shift can be multifold compared to cellular case due to the multiple reflections via moving vehicles.

D. *Antenna Effects*

3GPP assumes omni-directional antenna pattern which makes device orientation irrelevant. Omni-directional antenna pattern and uniform angle of arrival together lead to over-optimistic simulation results since they both increase the multi-path richness and thus decrease the correlation between antenna elements. Therefore, our suggestion is to use realistic antenna pattern with limited angle spread.

III. SIMULATION RESULTS

A three dimensional (3D) shadowing map is implemented by filtered noise method (Fig. 2) and sum of sinusoids (Fig. 3).Visual inspection shows rather good similar behaviour in the both figures despite the fact that absolute values at any position may be different.

The principle of generating correlated samples with the filtering method is as follow. The target volume (in this case a 6D space) to be modelled is sampled with a uniform grid. Gaussian random numbers are drawn to each grid point and filtered with a multi-dimensional filter. Finally any number of correlated samples can be extracted from the modelled volume.

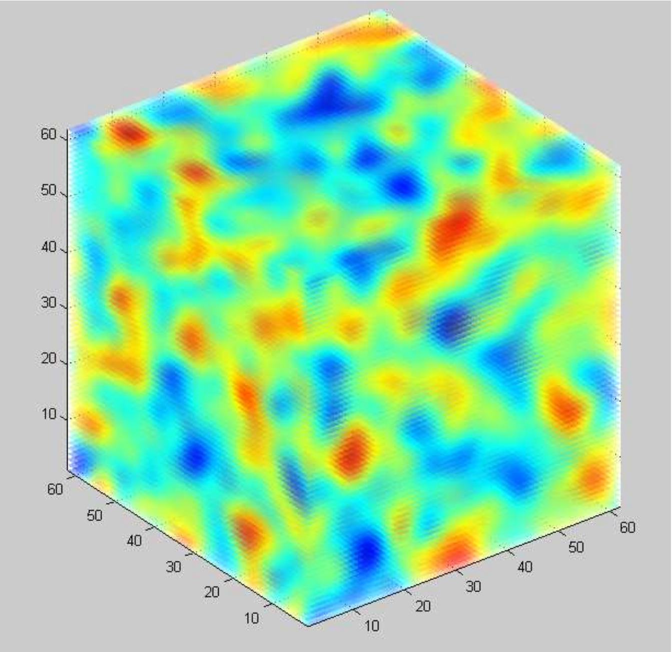

Fig. 2. 3D shadowing map implemented by filtered noise method.

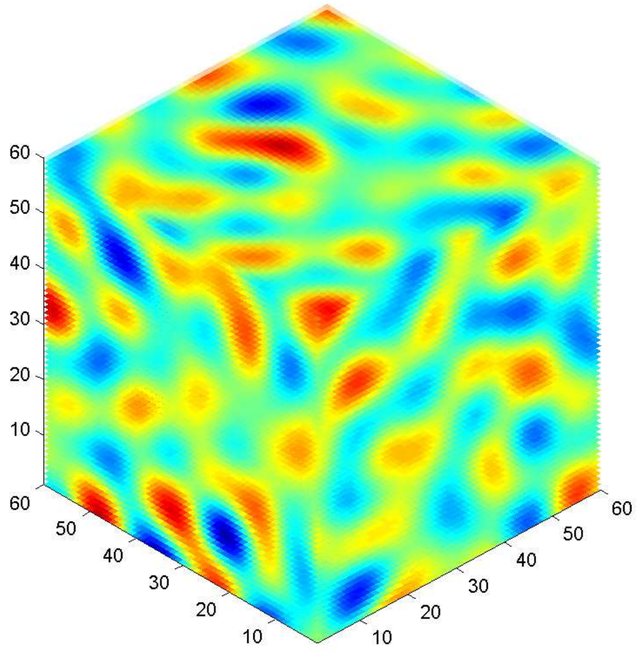

Fig. 3. 3D shadowing map implemented by sum of sinusoids method.

A simulation setup is illustrated in Fig. 4 with ten Tx locations in x-coordinates [0 2 4 8 16 32 64 128 256 512] m and a linear route of Rx location. Shadowing sequences along the Rx route generated with eq. (1) are depicted in Fig. 5. In Fig.6 the cross-correlation values between the first and all the ten sequences are plotted. The cross-correlation decreases with increasing spatial distance between Tx locations, as expected. The simulated auto-correlation functions for the ten sequences of shadowing are shown in Fig. 7.

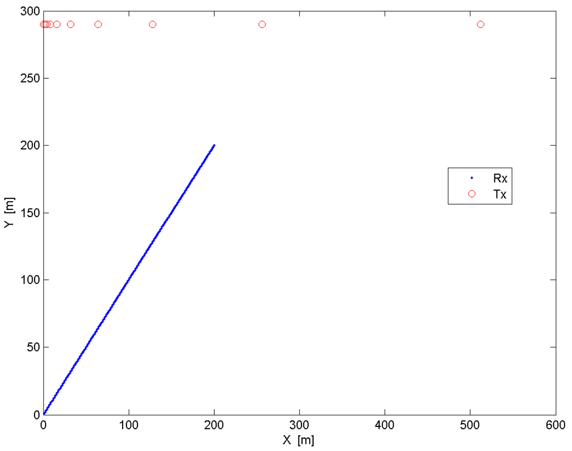

Fig. 4. Simulation setup with linear Rx route (blue) and ten fixed Tx positions (red) with inter Tx spacing of [2 2 4 8 16 32 64 128 256] meters.

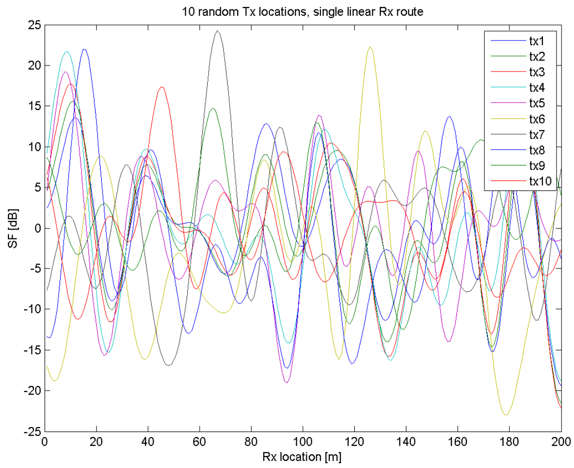

Fig. 5. Resulting shadowing values along Rx route for ten Tx sites.

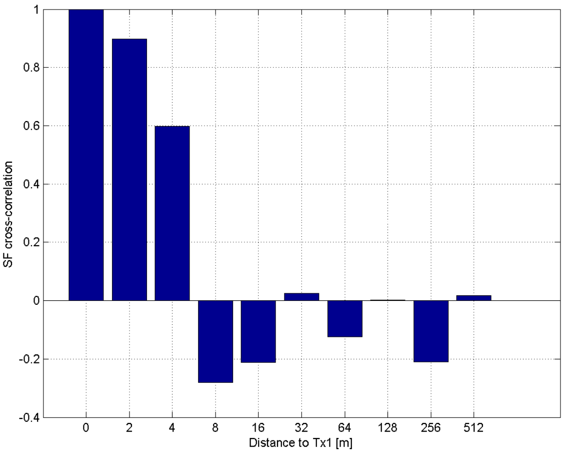

Fig. 6. Resulting cross-correlation coefficients for shadowing values.

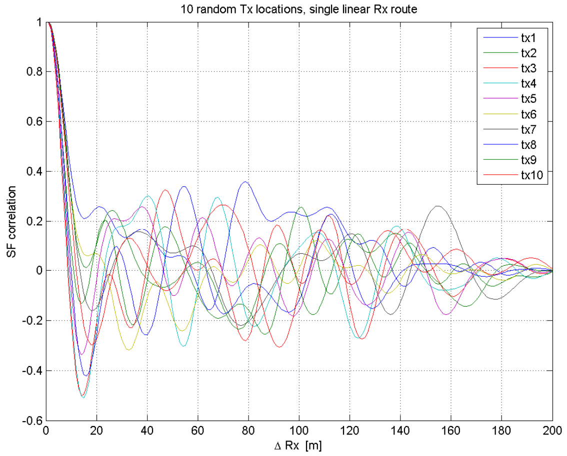

Fig. 7. Resulting auto-correlation functions for shadowing values.

IV. COMPLEXITY

Calculation of shadowing value based on sum of sinusoids method is faster than based on filtered noise [4]. However, the paper [4] did not discuss the much greater benefit of the sum of sinusoid method. It is the memory consumption. Sum of sinusoid method requires much less memory than the filtered noise method. This is the major advantage of the sum of sinusoids method. Fig. 8 shows the memory consumption of the two methods. The horizontal axis depicts the length of the side of the square shaped area in which all the devices are located. The area is the length X squared. In the case of 3D, the height dimension is limited to 30 metres. It is obvious that the size of the area to be simulation does not affect the memory consumption in the case of the sum of sinusoids method, but it affects dramatically in the case of filtered noise method.

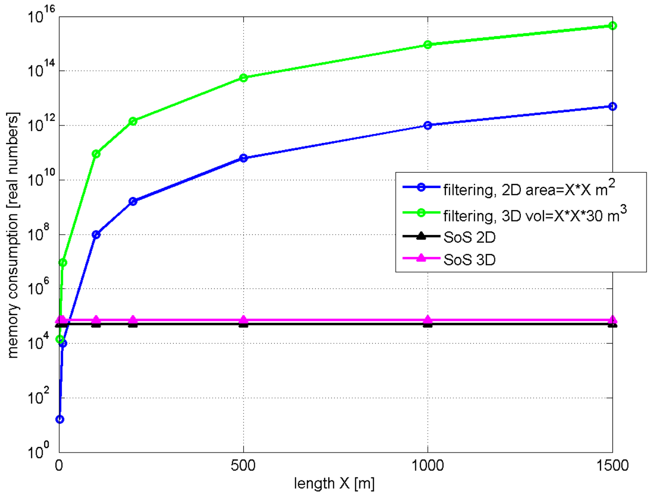

Fig. 8. Memory consumption of filtered noise (2D case and 3D case) and sum of sinusoids methods.

V. SIMULATION AND TESTING

The complexity issue regarding simulation and testing was discussed in section IV. In hardware testing of the device, a radio channel emulator needs to be programmed according to the D2D channel models. Both devices are connected to the channel emulator. One device can be tested by using a mobile device emulator and a channel emulator. Over-the-Air (OTA) testing is crucial when evaluating the real end-to-end performance including the antenna effect. In the OTA case, the channel model and mobility of one link end is emulated by a channel emulator, and the another link end is tested over the air. OTA testing of vehicles (V2V, V2I) requires much larger anechoic chamber, and a very high number of probe antennas. However, if channel model is know, a further simplification of test setup is doable. Therefore channel modelling is important also in the development of the test systems.

VI. DISCUSSION

New D2D channel models are needed for simulation D2D communication systems and testing of different D2D radios. This paper discusses the necessary changes to existing GSCM models. Shadowing consistency can be achieved by using sum-of-sinusoids method for shadowing coefficient generation. Other improvements include dual mobility, moving scatterers, and symmetric angular characteristics. The proposed models can be used in link and system simulations, conductive and Over-the-Air (OTA) testing.

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