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Vuokko Nurmela
Nokia Research Center
Otaniementie 19
FIN-02150 Espoo, FINLAND
vuokko.nurmela@nokia.com

Tommi Jämsä, Pekka Kyösti
Anite Telecoms Oy
Tutkijantie 6
FIN-90590 Oulu, FINLAND
Phone: +358-40 1988 xxx
Email: firstname.lastname@anite.com

Channel Modelling for Device-to-Device Scenarios

Vuokko Nurmela[1], Tommi Jämsä[2], Pekka Kyösti[2], Veikko Hovinen[3], Jonas Medbo[4]
[1)] Nokia Research Center, Finland
[2)] Anite Telecoms Oy, Finland
[3)] University of Oulu, Finland
[4)] Ericsson Research, Sweden

Abstract: **This TD discusses questions concerning a radio channel modelling framework for simulations on possible fifth generation (5G) communication systems. The main focus of this paper is set on a test case for device-to-device (D2D) communications of the METIS project. Special requirements of the test case are investigated and suitability of existing channel model(s) is assessed. The contribution of the TD is to identify research question on the topic.**

1. INTRODUCTION

The overall goal of the METIS project is to lay the foundation for the beyond 2020 5G mobile and wireless communication systems by providing the technical enablers needed to address the requirements foreseen for this time frame [1], [2]. A number of test cases are defined in the METIS project [2]. One of the most important test cases is the so called *Dense urban information society*. One of the propagation scenarios of the *Dense urban information society* test case is the urban Device-to-Device (D2D) scenario including any direct link between mobile devices (e.g. human-to-human, machine-to-machine, vehicle-to-vehicle).

Our current understanding is that none of the existing channel models necessarily covers the D2D scenario with adequate accuracy in all dimensions. With this TD we want to bring questions to and initiate discussion in the COST IC1004 forum.

2. METIS D2D SCENARIO

The METIS scenarios were briefly introduced in [3] and more detail in unpublished document [4]. D2D is a direct connection between two mobile devices. We consider D2D as any device-to-device communication, e.g. human-to-human (H2H), vehicle-to-vehicle (V2V), V2H, machine-to-machine (M2M). As described in [3], D2D is considered in eight (8) different propagation scenarios. It was recognized from literature that geometric D2D models are generally not available.

Most propagation research has been concentrating on the link between base and mobile stations. The D2D propagation model should be compatible with the corresponding cellular channel model so that comparison of these two technologies is fair, which means that the channel model should not bias the comparison results by giving unjustified advantage to either of these technologies. This does not necessarily mean that the cellular and D2D models should be identical, if the BS height is different to the MS height.

D2D propagation differs from cellular in two ways. In D2D both terminals are typically low at the street level, and both terminals can be moving. Moreover, human interaction, such as shadowing may be present in both ends of the link. This has implications in propagation. Path loss typically is higher than in the cellular case and LOS is less likely at a given distance. The link is symmetric, meaning that both Tx and Rx see a similar environment, and should have similar distributions for all parameters.

Because in D2D both Tx and Rx are mobile and can be at any location, it is problematic to use pre-calculated location-based look-up tables, like path loss or shadowing maps in simulations. Such maps would require information from every point (x1,y1) to every other point (x2,y2) (in 2D simulation case), and thus would require a 4D matrix corresponding to all possible combinations (x1,y1,x2,y2), which in practice is not feasible because of memory consumption.

There is the need to model D2D connections in almost every TC and environments specified in [2]. In addition the models should mostly cover the cases Outdoor-to-Outdoor (O2O), Outdoor-to-Indoor (O2I) and Indoor-to-Indoor (I2I). Test cases are often used in different environments: Dense Urban, Urban, Suburban, Highway and Rural. To limit the combinations, we assume that the suburban environment is left away totally, and for all the TCs one (sometimes two) proper environments are specified. Additionally the commonly used urban environments Urban Micro-cell and Urban Macro-cell are left aside, taking into consideration the more severe Dense Urban environment.

For simplicity in the initial phase of METIS we will specify the D2D channel models as special cases of the cellular 3D channel models. Statistical distributions like angular spreads need to be equal at both ends of the link. We recommend using those from low antenna height. Reliable measurement and ray-tracing results are lacking at the moment. During the project these parameters will be based on measurement and/or ray-tracing results from METIS and other sources.

3. GEOMETRY BASED STOCHASTIC CHANNEL MODELS

3.1 WINNER approach

In WINNER channel models (see [5] and [6]) the basic principle is that for every link the large scale parameters (like angular spreads) are taken from a map. In that way the correlation properties of those parameters are matched with those observed in measurements. However, the small scale parameters (like angles of arrival and departure) are randomly drawn from a distribution, independently for each link. This means that even close-by links have independent values for e.g. AoA and AoD, which is of course not the case in reality. This spatial inconsistency wasn’t problematic with the quasi stationary modelling of WINNER (drop concept), but it has an impact on performance with e.g. multi-user MIMO case.

The spatial inconsistency also means that the WINNER approach does not handle time evolution very well. New set of parameters are randomly drawn at each location of a mobile, and there is no smooth transition between two locations. This means that dynamic simulations are problematic. Interpolation between two locations is of course possible. The interpolation can be done by drawing random small scale parameters, like cluster delays, powers, directions, etc., to two UE locations and linearly interpolating parameter values in between locations. A problem may result because interpolated values are always between the original values, and thus with interpolation all distributions become narrower.

WINNER models also don’t specify transitions between different propagation environments (urban, rural, outdoor, indoor, etc.) or between LoS and NLoS, which also creates spatial inconsistency and unrealistic transients. These transitions are better handled by the Quadriga channel model (see [7]), and also some interpolation method can be used with WINNER model.

3.2 3GPP D2D

In December 2012, a Study Item on LTE Device to Device Proximity Services was established in 3GPP. Several channel models were proposed for D2D in 3GPP RAN1 meetings in Malta, Chicago, and Fukuoka during the first half of 2013 and the agreement was as follows.

- Symmetric angular spread distribution and dual mobility corrections
    - Amend the ITU-R UMi/InH model to incorporate dual mobility
        - V_{TX} (UE1) and V_{RX} (UE2) parameters separately with phase change per sub-path
- Direction of Travel (velocity vector) independent and random
- Doppler is determined by path AOA/AOD

- Uniform AoA spread of 104 degrees

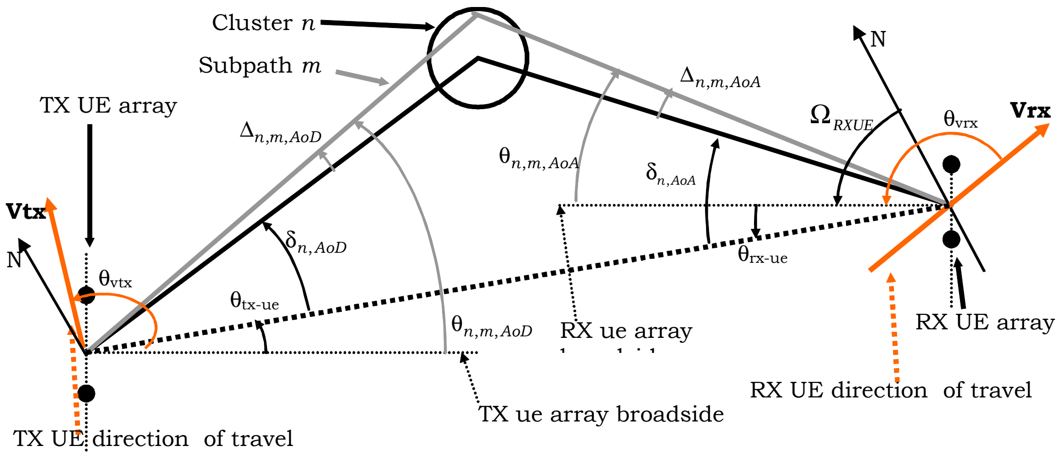

Figure 1. D2D model in 3GPP (source: 3GPP R1-132803).

Equations below show how to calculate the channel coefficients.

$$V_{n,m} = \frac{\left\| Vrx \right\| \cos\left(\theta_{n,m,AoA} - \theta_{Vrx}\right) + \left\| Vtx \right\| \cos\left(\theta_{n,m,AoD} - \theta_{Vtx}\right)}{\lambda_0}$$

$$h_{u,s,n}(t) = \sqrt{\frac{P_n \sigma_{SF}}{M}} \sum_{m=1}^{M} \left(\begin{array}{l} \sqrt{G_{TX-UE}\left(\theta_{n,m,AoD}\right)} \exp\left(j\left[kd_s \sin\left(\theta_{n,m,AoD}\right) + \Phi_{n,m}\right]\right) \times \\ \sqrt{G_{RX-UE}\left(\theta_{n,m,AoA}\right)} \exp\left(jkd_u \sin\left(\theta_{n,m,AoA}\right)\right) \times \\ \exp\left(jktVn,m\right) \end{array} \right).$$

where

- $\mathbf{v}_{rx}$ is the velocity vector of a receiver
- $\mathbf{v}_{tx}$ is the velocity vector of a transmitter
- θ_{vrx} is the direction of Rx velocity vector
- θ_{vtx} is the direction of Tx velocity vector
- λ_0 is the wave length on carrier center frequency
- P_n is the power of the *n*th path.
- σ_{SF} is the lognormal shadow fading.
- M is the number of subpaths per-path.
- $\theta_{n,m,AoD}$ is the the AoD for the mth subpath of the nth path.
- $\theta_{n,m,AoA}$ is the the AoA for the mth subpath of the nth path.
- $G_{TX-UE}\left(\theta_{n,m,AoD}\right)$ is the Tx antenna gain of each array element.
- $G_{RX-UE}\left(\theta_{n,m,AoA}\right)$ is the Rx antenna gain of each array element.
- j is the square root of -1.
- k is the wave number $2\pi/\lambda$ where λ is the carrier wavelength in meters.
- d_s is the distance in meters from BS antenna element s from the reference (s = 1) antenna. For the reference antenna s = 1, d_1=0.

- d_u is the distance in meters from MS antenna element u from the reference (u = 1) antenna. For the reference antenna u = 1, d_1=0.
- $\Phi_{n,m}$ is the phase of the mth subpath of the nth path.
- $\|\mathbf{v}\|$ is the magnitude of the MS velocity vector.
- θ_v is the angle of the MS velocity vector.

The 3GPP approach is not complete and has the same limitations as WINNER described below.

3.3 Other possibilities

According to our understanding the so called geometry based stochastic channel modelling (GSCM) principle could still be applied for METIS purposes. Anyhow to guarantee spatial consistency the clusters of the model, sets of interacting objects in COST terminology, should have co-ordinates or locations on a virtual map. This is similar to the existing COST channel model family.

Motion of a short distance, e.g., few meters should maintain the radio channel parameters, such as shadowing, PDP, Ricean K-factor, etc., consistent between the locations.

4. SPECIAL REQUIREMENTS FOR D2D MODELING

Direct device-to-device (D2D) connections between two mobiles are widely discussed both in the METIS project and elsewhere. However, most existing channel models are not as such suitable for modeling D2D. Compared to cellular, D2D links have two special features:

1. Both ends of the link are typically at low heights.
2. Both ends of the link can be moving.
3. Both ends of the link are subject to shadowing by the user.

Because of this dual mobility, both ends of the link can be at arbitrary location, which has its impact on channel modeling requirements.

In many channel models (e.g. [5], [6] and [7]) pre-calculated 2D look-up tables are used to indicate the value of a large scale parameter (e.g. shadowing) in each geographic location (x,y). This approach models well cross-correlation between two links, autocorrelation properties of one link in dynamic simulations, and also cross-correlations between different large scale parameters. In D2D case, we need to model a link between two UEs, which can be at any location. Thus the same look up-table would be 4D (x_{UE1},y_{UE1},x_{UE2},y_{UE2}), which is not feasible due to practical reasons like memory requirements.

However, realistic modeling of correlation properties would be beneficial to evaluate system level performance realistically. There are some shortcuts proposed in the literature (see [8], [9] and [10]). Realistic correlation properties can also be obtained without a pre-calculated map of large scale parameters, if the model relies more on geometry having clusters located on a map. An example of such is the COST model family.

4.1 Applying COST approach to D2D

The COST modeling approach is as such not necessarily aimed to D2D, because COST channel models are designed with one end of the link fixed.

The channel model could be composed of a set of randomly drawn clusters with all the parameters drawn from probability distributions which are extracted from channel measurements. Cluster would have visibility regions as in the COST model. Each cluster would be coupled to a sub-set of other clusters. If two radios enter visibility regions of coupled clusters the radio signal propagates interacting with the clusters. A consistent model has a proper number of “active” clusters with proper characteristics for each possible set of locations of transceivers. Some clusters can also be moving.

An ideal channel model would be closer to ray tracing than the existing GSCMs. Anyhow we wouldn’t like to get as many parameters as possible statistical and extracted from channel measurements. Also the complexity aspect must be taken into account when designing the channel modeling framework.

5. DISCUSSION AND RESEARCH TOPICS

The aim of the propagation modelling task force in METIS is to create a model that can be used to model the connections in 5th generation (5G) network, including D2D. The existing models are not sufficient for that purpose, and new models need to be developed. The channel modelling framework needs to support arbitrary locations for both ends of the link.

We have a list of research topics that need to be discussed:

- Can the COST channel modelling principle be applied in D2D connections?
  - What are the modifications possibly needed in the COST modelling framework to adequately describe D2D link?
  - How to extend the COST concept of twin cluster to a larger set of coupled clusters?
  - Can we extract the required parameters from measurements, e.g. coupling of clusters?
- Can the model be implemented with reasonably low complexity?

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