Adding Dense Multipath Components to Geometry-Based MIMO Channel Models

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1. Introduction

In geometry-based stochastic channel models (GSCMs), the radio channel is created by placing clusters in the simulation environment to act as physical scattering objects. The clusters consist of groups of closely located multipath components (MPCs), and the directions, delays, and complex amplitudes of each MPC are directly computed based on the geometry of the simulation environment. Since GSCMs are inherently capable of modelling the spatial and temporal characteristics of radio channels realistically, they have become very popular in MIMO channel modelling. Examples of cluster-based GSCMs are the COST 259 [1], COST 273 [2], and WINNER [3] channel models.

One of the main open issues in the existing GSCMs is the incorporation of the so called dense multipath components (DMC) into the models. Even if the DMC are known to contribute significantly to the radio channel characteristics, a serious effort has not been put in adding the DMC to the existing implementations of the GSCMs. A part of the reason why the DMC have been omitted from GSCMs has been the lack of thorough understanding on the propagation characteristics of the DMC. However, results reported recently in [4] – [6] have brought the understanding on the underlying physical phenomena related to the propagation mechanisms of the DMC to a level at which it is possible to take further step in incorporating the DMC into the cluster-based GSCMs. In short, measurements have shown that for each cluster the DMC have an angular distribution similar to that of the specular components (SC), and, in addition, exhibit an exponential decay in the delay domain. Still it is somewhat of an open question how much the parameter estimation algorithm influences the specific characteristics of the DMC, but it can be concluded that the angular properties as well as the delay properties of the SC and the DMC are closely connected.

In this paper, we present a method of including DMC to GSCMs. The basic idea of the proposed method is to add MPCs representing the DMC around the center of each cluster. In the delay domain, the added DMC MPCs are associated with an exponentially decaying power delay profile (PDP); in the angular domain, the MPCs of the DMC are generated according to the same distribution as the SC, but with a larger deviation.

The remainder of this paper includes the following contents. Section 2 summarizes the recent findings on the characteristics of the DMC, thus forming a basis for the modelling approach proposed in this work. In Section 3, the methods of how the DMC are added to GSCMs are detailed. Finally, Section 4 concludes the work.

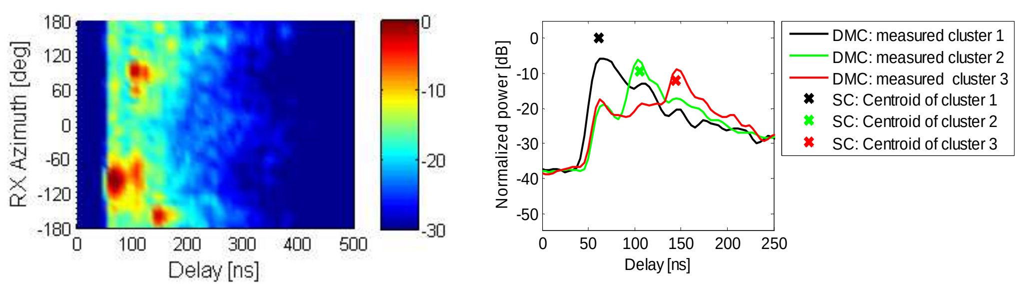
2. Characteristics of dense multipath components

The GSCMs are traditionally parameterized based on radio propagation path parameter estimates obtained from channel measurements. However, a commonly recognized fact is that none of the current parameter estimation algorithms, such as SAGE, RIMAX, or EKF, are able to fully capture the measured radio channel. They are all based on approximating the channel solely by a superposition of distinct plane waves, i.e. the SC, even though the residual part of the channel, i.e. the DMC, is known to carry a significant part of the energy, e.g. [4] – [7], [9].

The influence from a channel modelling point of view when omitting the DMC is that the multipath richness becomes underestimated; accordingly, the impact on the system level is seen as an underestimated channel capacity [7]. Similarly, the frequency correlation function might be overestimated when neglecting the contribution of the DMC. Even though different parameter estimation algorithms use somewhat different approaches for characterizing the radio channel, the same fundamental problem applies for each of them; Due to limited measurement resolution, practical computational resources, and the fact that the plane wave assumption does not always perfectly hold, resolving all of the huge number of the weak and closely located signal components is practically impossible.

In order to develop a model for the part of the channel classified as DMC, the physical propagation characteristics of the DMC need to be known in detail. Recent results presented in [4] – [6] have indicated that the DMC have large dependencies with the SC in both angular and delay domains. In particular, the energy is typically concentrated around the same angles and delays in both SC and DMC. The main differences between the SC and DMC are that 1) in the angular domain the DMC are spread over a wider range than the SC, and 2) in the delay domain the clusters of the DMC seem to obey an exponential decay while the SC are usually very concentrated with a narrow delay spread. Figure 1(a) shows an example of a power-angular-delay profile (PADP) of the DMC measured in an indoor environment [8]. The PAPD of the DMC was obtained by removing the contribution of the SC calculated by the EKF parameter estimation algorithm [9] from the total power and by applying beamforming in the angular domain and DFT with Hann-windowing in the delay domain for the residual part of the power. Three clusters can be clearly identified in the PADP. Figure 1(b) shows the spectral slices of the PDPs of the DMC at the angle of the maximum of each cluster. Also the centroids of each cluster of the SC are shown. It is clearly seen that the DMC have the same minimum delays as the SC but exhibit an exponentially decaying PDP.

These findings suggest that the DMC could be added to the GSCMs by manipulating the spread parameters of the existing clusters in angular and delay domains instead of attempting to create a fully detached part for the DMC.



(a) (b)

Figure 1: (a) Example of a power-angular-delay profile of the DMC. (b) Centroids of the SC clusters (crosses), measured PDPs of the DMC clusters (solid curves).

3. Relating dense multipath components to clusters

As mentioned in previous sections we propose a representation of the DMC closely connected to the SC and the clusters. To include the DMC to each cluster by additional MPCs has the following benefits. There is no need to create new, possibly complicated, concepts or make any significant changes to the existing GSMCs since their structure fully supports the proposed inclusion of DMC. Hence, the implementation of the proposed method is not a challenging task. In addition, the time evolution of the DMC is inherently modeled based on the geometry and the visibility regions, as is the case for the SC. Next, the method of how to include the DMC to GSMCs to get the desired behavior in angular and delay domains is explained.

3.1 Angular domain

Usually in GSCMs, clusters are generated by dropping clusters, i.e. groups of MPCs, into the simulation environment. The coordinates of individual MPCs belonging to the same cluster are assigned within an ellipsoidal area according to a truncated random distribution around the cluster center, as shown with the black squares inside the solid circles in Figure 2(a). In our approach, the MPCs of the DMC are dropped uniformly around the centroid of the SC cluster, but within a circular area. The MPCs for the DMC are distributed within the area that has the same center point than the SC cluster and the radius of r_{DMC}, as shown in Figure 2(a). The resulting response of the DMC in the angular domain is thus concentrated around the same angles as in the SC, however, with a wider angular spread; this is shown in Figure 2(b). The parameter value for the r_{DMC} needs to be adjusted based on measurements.

3.2 Delay domain

In order to achieve a desired behavior for the DMC in the delay domain, each MPC of the DMC is associated with an additional delay on top of the delay determined by the geometry, i.e. the cluster position. Hence, the delay time of the MPCs of the DMC can be expressed by

$$\tau_{\mathrm{DMC}} = \tau_{\mathrm{DMC,geometrical}} + \tau_{\mathrm{DMC,additional}}, \qquad (1)$$

where $\tau_{\mathrm{DMC,geometrical}}$ is the delay coming from the geometry and $\tau_{\mathrm{DMC,additional}}$ is a random additional delay that is added to each MPC of the DMC. The additional delay for the DMC is determined so that the DMC part of the clusters obeys an exponentially decaying PDP, as shown in Figure 2(c). *The base delay* of the DMC clusters is determined by the centroid of the SC cluster, and *the slope of the decaying* is extracted from measurements. *The peak power* of the MPCs for the DMC can fluctuate and be higher or lower than the power of the corresponding SC. The MPCs for the DMC in delay domain are obtained by generating Poisson-distributed random delay taps in the range starting at the base delay and ending at the delay time where the power of the DMC has decayed to a sufficiently low level. The delay range for the DMC needs to be limited in order to avoid complex and time-consuming simulations. The MPCs for the DMC are generated densely in the spatial domain, and hence also in the delay domain; however, the PDP of the DMC will be sampled according to the delay resolution defined by the system bandwidth. Finally, DMC for the local cluster with a uniform angular distribution and a low power decay factor is added (the local cluster is not shown in Figures 2(a) and (b) for clarity's sake). In this way it is possible to model also the propagation paths that are not regarded as SC clusters, i.e. the MPCs that have uniform and random angular distribution and also clusters that are weak for instance due to long delays.

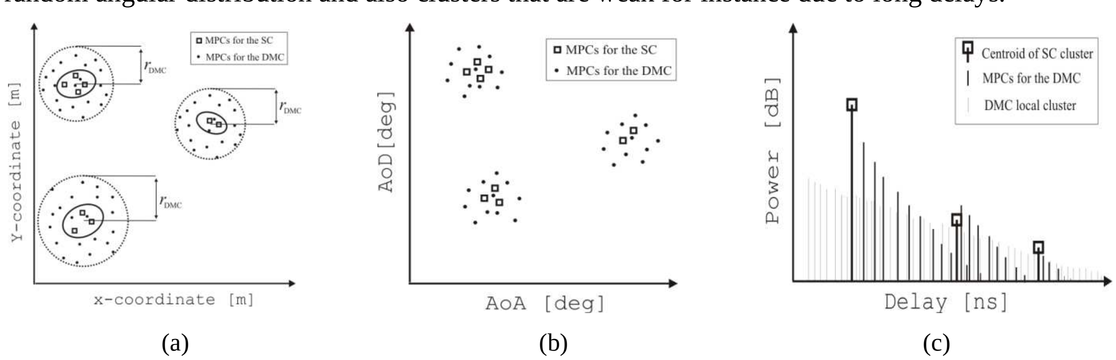


Figure 2: Illustration of the method to include DMC to the GSCMs. (a) In spatial domain, the MPCs of the DMC are placed around the SC clusters with a wider distribution than that of the SC. (b) The resulting angular distribution of the DMC is naturally wider than that of the SC. (c) In delay domain, each MPC of the DMC is associated with an additional delay in order to achieve exponential decaying for the DMC part of each cluster.

4. Conclusions

In this paper, a method to include DMC to GSCMs has been proposed. The basic idea is to add MPCs representing the DMC part of the channel around the clusters. By assigning DMC to each cluster, i.e. by additional MPCs within the existing clusters, has the following benefits: The structure of the existing GSCMs fully supports the DMC meaning that there is no need to create new, complicated, concepts or make any significant changes to the established structure of the current models. Hence, the implementation of the proposed method is not a challenging task.

In angular domain, a desired behaviour for the DMC is obtained by distributing the MPCs for the DMC around the cluster centroids but within a larger area than that of used for the SC. In the delay domain, each MPC of the DMC is assigned an extra delay time in addition to the delay determined by the geometry in order to achieve an exponentially decaying PDP for the DMC. DMC for the local cluster with a slowly and exponentially decaying PDP and a uniform angular distribution is finally added in order to take care of the weak un-clustered MPCs that probably have long delays.

At this time, we have presented a generic concept for the approach of how to include the DMC to the GSCMs. The extraction of the DMC cluster parameters and the validation of the proposed modelling methodology are to be covered in future publications.

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