

# Derivation and Application of Ray Entity Concept

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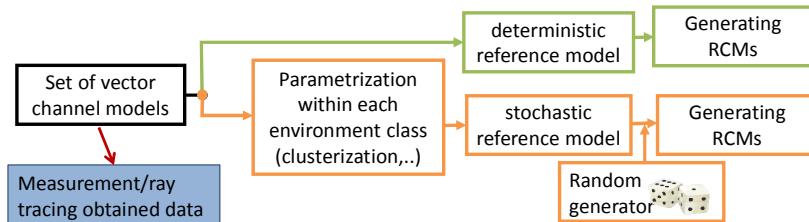
## Abstract

The concept of ray entity would enable compact presentation and interpolation of ray tracing data. Moreover, ray entity concept should enable ray tracing based deterministic reference channel models that would enable obtaining double directional channel matrix for arbitrary user movement in realistic propagation environment. In this paper recording of ray entities is presented, for entities with rays formed due to different series of propagation phenomena on various interaction objects.

## 1. Introduction

Reference Channel Models (RCM) are the platforms enabling realistic performance comparison and testing of advanced mobile and fixed wireless communication systems with MIMO air interface. In fact current RCMs are a kind of random radio channel generators which, based on previously calculated parameters, produce random radio channel characteristic [1-5]. They are also called “stochastic” since their output are channel transfer functions which come as a result of stochastic process. The main advantages of stochastic RCMs are in their simplicity, easy implementation and consequently low computational complexity.

In Figure 1 the process of obtaining the reference channel model is presented. The information about the representative channels are obtained either numerically (ray tracing) or by measurements. The stochastic RCM are build through complex parameterization process followed by generating arbitrary number of random realizations of the model while deterministic RCMs, which represents an alternative new approach, are based on direct use of already determined set of vector channel models.



**Figure 1: Process of obtaining reference channel models [6]**

Deterministic RCMs are based on measured and ray tracing analyzed channels from real world geometries [6]. They enable realistic performance testing of MIMO wireless systems by virtue of providing system simulations on pre-simulated set of double-directional geometry based radio channels. Using deterministic RCMs the unreliability due to the parameterization and due to implementation through random process of stochastic RCMs are overcome. Deterministic RCMs would consist of a large database of recorded paths, classified upon considered environments. In order to make it wideband, the record could in general for each point on a path contain data about directions of departure and arrival, attenuation, time delay, and polarization data for each ray present.

Ray tracing is very time consuming process with extremely high demands for memory capacities. It allows high-resolution simulations, thus providing a very detailed description of the radio environment and the propagation phenomena. The results are usually given in raw data with certain resolution that covers the analyzed area. Usually, the interpolation between the sample points is not considered, so the new and even more time and memory consuming

simulations are needed in order to increase resolution of the simulations. To overcome the high computational time, complexity, memory demands and increased resolution the new sample and interpolation scheme was proposed in [7]. The scheme is based on concept of ray entities (RE) which enable continuous interpolation of ray tracing data and reduce memory needed for storing data. The ray entity (RE) is a set of rays originating from the transmitter passing the same kind (eg. reflection, diffraction) of interactions on the same objects and falling to the Rx route. RE concept significantly reduces computational time and memory burden while enabling interpolation of receiver points ensuring even higher resolution than the one originally sampled.

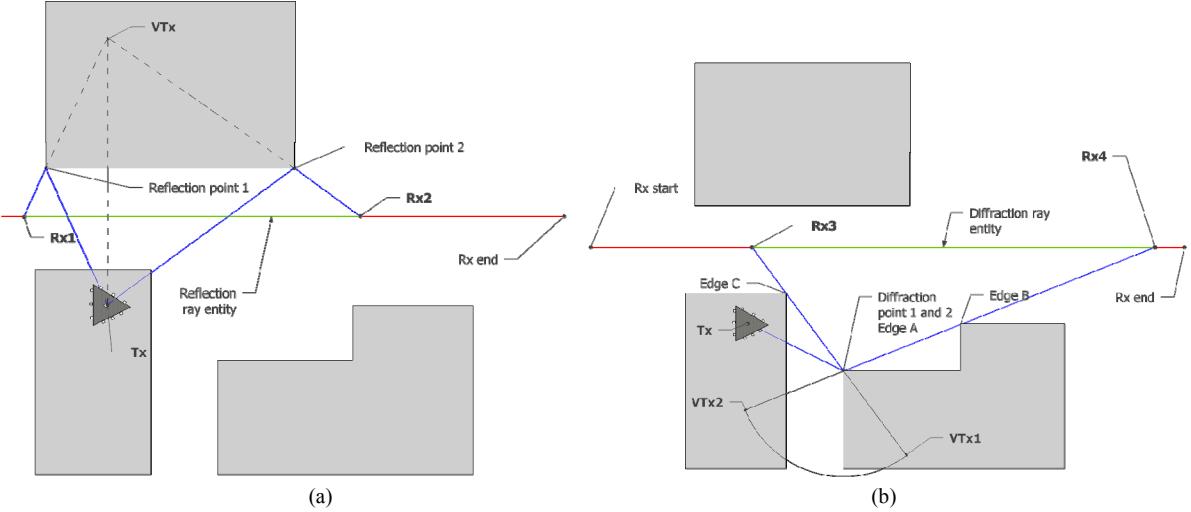
This paper is concentrated on the characterization of the ray entity and defining the location of virtual transmitter (VTx). RE is defined by parameters which uniquely describes sets of rays that undergo the identical propagation phenomena at the same objects while VTx is being defined as a point in ray's direction of arrival, as seen by the user, at distance corresponding to total path length from base station to the user, which represents location from where the identical ray would depart towards the user, in the case of unobstructed environment.

The paper is organized as follows. After the Introduction, the propagation phenomena on edges and surfaces are described and the concepts of ray entity and virtual transmitter are introduced. In the next section ray entity properties needed for result interpolation are defined and an illustrative case of memory saving using ray entity is given. Finally, concluding remarks are given in section 4.

## 2. Ray Entity Characterization

For using ray entities in order to be able to obtain near-continuous (i.e., of arbitrary resolution) double-directional channel response, there are two issues to be addressed; firstly, ray-tracing-sampled-environment data must be converted into ray entities and secondly, double-directional channel response for arbitrary receiver (Rx) location from ray entities' data has to be obtained. Recording of the REs for reflection and diffraction cases are described in the following paragraphs. The issue, regarding obtaining double-directional channel response component due to reflection and diffraction around arbitrary sloped edge, is tackled by resolving mathematical expressions for angle of arrival (AoA), angle of departure (AoD), time delay and power. Power within ray entity can be estimated by polynomial approximation using 5<sup>th</sup> degree polynomial fit causing a negligible residual fit error. Instead of storing individual data points only polynomial coefficients are stored which enables received power interpolation of arbitrary high resolution. Characterization of the AoA, AoD and time delay are especially important in MIMO communication systems. They are defined relative to the virtual transmitter and receiver position.

In Figure 2 a ground plane of a setting of one transmitter (Tx), receiver route of interest and three buildings is shown. The reflection propagation case describing reflection points, virtual source and ray entity describes Figure 2(a) while the diffraction phenomenon is described in Figure 2(b).



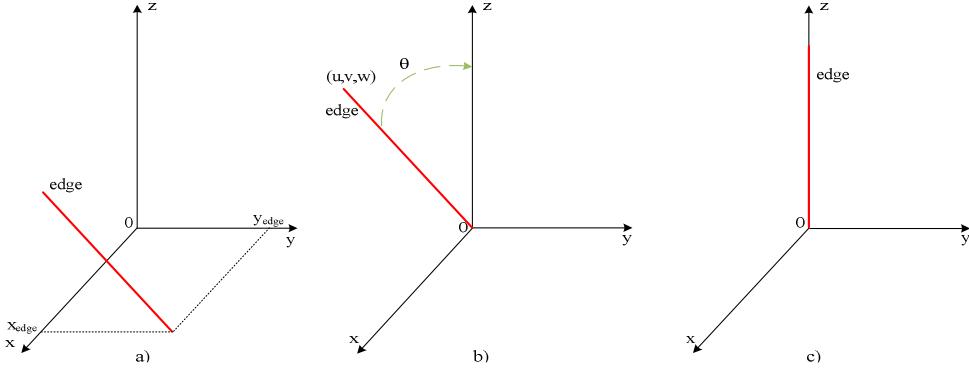
**Figure 2: Receiver route visibility and location of virtual transmitters, for: reflection ray entity (a), and diffraction ray entity (b)**

In the reflection case the set of rays from Rx1 to RX2 compose RE since all rays reflect from the same building wall and all rays arriving at the receiver comes from one stationary virtual transmitter VTx. Ray entity due to a

single diffraction at vertical edge in Figure 2(b) is presented at the receiver route between Rx3 and Rx4. Virtual source for diffraction from vertical edges for the whole entity is a section of a circle from VTx1 to VTx2 at the height of the transmitter and parallel to the ground and slides circularly as the receiver slides along the route section where entity rays are present.

In the case of multiple diffractions on vertical parallel edges virtual transmitter locus is again a section of a circle that can be easily calculated by extending the ray with the same elevation angle from Rx through last interaction point to VTx. For multiple interactions (reflection with diffraction/diffraction with reflection) the interpolation is simplified to one diffraction case by mirroring the transmitter/receiver against the reflecting wall.

In the case of the single diffraction around edge sloped against global coordinate system, the REs are formed similarly to other previously considered cases of single and multiple diffraction around vertical edges, except that data needed for recording of sloped-edge REs must contain few additional parameters (Table 1). For calculating VTx position in the case of the arbitrary oriented diffraction edge, the edge is converted to vertical edge by transformation from the global into the local coordinate system as depicted in fig. 3.



**Figure 3: Transformation of an arbitrary oriented edge to the vertical edge**

The procedure is composed of translation in x-y plane (Fig.3a), so that the edge passes through the origin, then space rotation about the z-axis and y-axis (Figs. 3b and 3c) so that the edge lies along the z-axis. Then VTx calculation and RE determination is performed in local cylindrical coordinate system and finally space back rotation and translation is done.

The procedure of detecting ray entities is based on grouping the rays with the same signature and neighboring each other at Rx side. Each ray signature contains types of interactions and the objects at which the interactions occur. Entity's minimal set of parameters for its description, listed in Table 1, is recorded. Using entity concept the number of rays belonging to the same ray entity can be stored as one ray entity which reduces required memory and enables retrieving RT results on arbitrary location between two adjoining Rx points of the same ray entity by interpolation. The sufficiency of the Rx resolution of the initial ray tracing can be determined by counting the number of entities formed at a single Rx. In addition, unnecessarily high resolution of the receivers in RT simulations does not increase ray entity storage needs. Therefore, ray entity approach is adjusted to the user needs as well as the available computer capacity.

### 3. Interpolation of RT Results using Ray Entities

The ray entity values needed for full description of a ray entity and interpolation of rays at the given arbitrary receiver location are given in Table 1. Procedure is composed of finding all entities existing at the location and recalculating all ray properties from parameters describing ray entity, Tx and Rx location.

**Table 1. Comparison of numbers of entities and number of rays, and number of values needed to describe them**

	ray	(multiple) vertical edge diffraction entity	sloped edge diffraction entity
Values necessary to describe a ray/entity	<ul style="list-style-type: none"> <li>• Ray length/time delay</li> <li>• AoA elevation angle</li> <li>• AoA azimuth angle</li> <li>• AoD elevation angle</li> <li>• AoD azimuth angle</li> <li>• Ray arrival location (integer index)</li> <li>• Ray power</li> </ul>	<ul style="list-style-type: none"> <li>• entity start (integer index)</li> <li>• entity end (integer index)</li> <li>• entity delay offset, i.e. virtual Tx locus radius (1 real)</li> <li>• last interaction (edge) x-y coordinates (2 real)</li> <li>• entity power polynomial interpolation - 5 coefficients (5 real)</li> </ul>	<ul style="list-style-type: none"> <li>• entity start (integer index)</li> <li>• entity end (integer index)</li> <li>• intersection point between edge line and x-y plane (2 real)</li> <li>• edge azimuth and elevation (2 real)</li> <li>• entity power polynomial interpolation - 5 coefficients (5 real)</li> </ul>
Values total	6 real + 1 integer	8 real + 2 integer	9 real + 2 integer

Table 1 also shows comparison between data required for storing a single ray against storing of single entity, both of sloped edge diffraction and vertical diffraction. For a rough saving estimate it is worth noting that number of entities is 8 to 10 times smaller than number of rays [7]. To store ray data for classical ray tracing simulations six real and one integer values are needed, while for storing ray entity nine real and three integers are required. It is shown that storing ray entity would require less than a double memory as for a ray. Thus considerable memory saving is gained, since number of entities is significantly smaller, comparing to number of rays. Hence, the overall memory usage saving is approximately 5-6 times. Additional memory saving can be obtained if edge properties are saved in look-up table, since many entities share same edges, and then index for look-up table would replace 2 real numbers for multiple vertical edges, and 4 real numbers for their sloped edge counterparts.

The main advantages of the entity interpolation ray tracing approach compared to classical ray tracing is in reduced memory usage and ability to interpolate results to an arbitrary high resolution. The interpolation feature is available after initial RT simulations and ray entity post-processing and can be applied to different user needs. Ray entity approach enables simulations of radio channel with arbitrarily moving user, with arbitrary modulation and coding scheme, in wide frequency band range and with arbitrary spatial resolution.

#### 4. Conclusion

The paper presents ray entity approach as a convenient method for storing ray tracing data and a tool for interpolation of ray tracing data to arbitrary resolution. Estimate of memory gain is given, based on amount of data necessary to describe rays and ray entities, and empirically obtained estimate of ratio between number of rays and number of entities. Common propagation artifacts are considered to form ray entities, such as multiple diffractions and reflections around and at vertical edges or sides, and single diffractions around a sloped edge.

It is worth noting that from ray entity data full MIMO channel matrix in time domain can be retrieved, so the concept enables radio model of user movement with arbitrary speed and calculation of MIMO channel matrix with arbitrary time resolution. These properties make it possible to construct some reference channel model based on realistic ray tracing simulations, that would enable investigation of new broadband radio systems, modulation and coding schemes, as a competing or complementing approach to currently popular stochastic channel models.

Still outstanding issues for deterministic reference channel models are models of multiple diffractions around non-parallel edges and realistic method of including diffuse scattering which has significant impact on time- and angle-dispersion characteristics of the radio channel in small cells and macrocells. Diffuse scattering is particularly relevant in MIMO or smart antenna mobile radio systems [8], and would require additional modeling and knowledge about properties of diffuse scattering source.

#### 5. References

1. A. F. Molisch, H. Asplund, R. Heddergott, M. Steinbauer, and T. Zwick, "The COST 259 Directional Channel Model – Part I – Overview and Methodology," *IEEE Transactions on Wireless Communications*, **5**, December 2006, pp. 3421-3433.
2. H. Asplund , A. A. Glazunov, A. F. Molisch, K. I. Pedersen, and M. Steinbauer, "The COST 259 Directional Channel Model – Part II – Macrocells," *IEEE Transactions on Wireless Communications*, **5**, December 2006 , pp. 3434-3450.
3. L. M. Correia, *Mobile Broadband Multimedia Networks (Techniques, Models and Tools for 4 G)*, First Edition, Elsevier, 2006, 600 p.
4. A. A. M. Saleh and R. A. Valenzuela, "A Statistical Model for Indoor Multipath Propagation," *IEEE Journal on Selected Areas in Communications*, **5**, February 1987, pp. 128-137.
5. Q. H. Spencer, B. D. Jeffs, M. A. Jensen, and A. L. Swindlehurst, "Modeling the Statistical Time and Angle of Arrival Characteristics of an Indoor Multipath Channel," *IEEE Journal on Selected Areas in Communications*, **18**, March 2000, pp. 347-360.
6. A. Katalinić Mucalo, R. Zentner, and N. Mataga, "Benefits and Challenges of Deterministic Reference Channel Models," *Automatika*, **53**, January-April 2012, pp. 80-87.
7. N. Mataga, A. Katalinić Mucalo, and R. Zentner, "Ray entity based post processing of ray tracing data for continuous modeling of radio channel," *Radio Science*, 2014, in press.
8. V. Degli-Esposti, D. Guiducci, A. de'Marsi, P. Azzi, and F. Fuschini, "An advanced field prediction model including diffuse scattering," *IEEE Transactions on Antennas and Propagation*, **52**, July 2004, pp:1717 – 1728.