UNDERSTANDING GEOMETRICALLY BASED MULTIPLE BOUNCE CHANNEL MODELS

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Abstract

This paper looks into various ways of extending a Geometrically Based Single Bounce Channel Model into a Multiple Bounce one, the main motivation being to overcome some of the limitations of the former models. Three different strategies to implement the way rays are bounced are described and compared, a comparison between diffuse scattering and specular reflection being also investigated; as expected, specular reflection leads to higher power values for the arriving rays, with impact on the delay spread. Some initial results are presented; it seems that more than 2 bounces only enlarges the delay spread.

1 Introduction

Geometrically Based Single Bounce Channel Models (GBSBCMs), such as the COST 259 channel models [2], have been used for many years, because of their low complexity and quite good accuracy. In such models, a multipath signal is constructed by creating a scattering environment, where scatterers are placed randomly. A signal is then transmitted from the transmitter (Tx) to the receiver (Rx) via scatterers, their different location creating different path lengths, which results in multipath signals at the Rx.

One of the drawbacks of single bounce channel models is that the Angle of Arrival (AoA) can be related to the Angle of Departure (AoD) and the Time of Arrival (ToA) of the multipath components. It has also been suggested that a single bounce scattering model does not provide a rich enough multipath signal, especially in pico-cells and indoor environments [6]. In order to overcome these drawbacks, double and even multiple bounce models have been suggested. Almers et al. [1] propose a method for calculating a virtual scatterer in single bounce models, which has the same AoA and ToA as the multiple bounce equivalents. In Hofstetter et al. [5], a twin cluster concept was proposed to decouple AoA, AoD and delay characteristics. Svantesson [9] follows a different approach, by creating an area of scatterers around both the Tx and the Rx, instead of having a single area of scatterers, which leads to a double bounce channel model. The drawback of this method is that an increase in distance between Tx and Rx leads to a decrease in sub-path correlation, decreasing the system capacity.

This paper follows a different approach, by basing its work on an existing GBSBCM [7], developed at IST/TUL. The main motivation for developing a multiple bounce model is described in Section 2. There are several ways to implement multiple bounces into the channel model, and Section 3 compares three different bounce strategies. Initial results, based on measurement data from literature, are shown for a micro-cell Line-of-Sight (LoS) scenario in Section 4. Conclusions of this work, although the research is still ongoing, are given in Section 5.

2 Multiple bounces

Hofstetter et al. [5] stated that, despite the fact that real life propagation is dominated by single bounce multipath components, multiple bounce multipath components can not be neglected when modelling Multiple Input Multiple Output (MIMO) system performance. Also, in [7], it was found that when modelling the propagation in a hallway or a street, the delay spread of a single bounce channel model is too small, compared with measurement results. In such environments, a larger delay spread can be expected, due to the street waveguiding effect. In order to maintain a single bounce channel model, an effective street width was assumed, emulating multiple specular reflections through longer distanced single reflections. However, by widening the street, hence, widening the elliptical environment, the AoA and AoD are also affected, which gives too optimistic angular spreads. By introducing multiple bounces, the path length of received ways can become much larger, leading to an increase in delay spread. However, the angular spread at the receiver is not affected, since the ellipse is not widened, which is the case when the effective street width factor is being used.

3 Multiple Bounce Strategies

As stated, the proposed model is based on the GBSBCM developed at IST/TUL [7], but the rays bounce on multiple scatterers before reaching the receiver. Note, that the received signal contains both single and higher order bounce components.

3.1 Specular reflection or diffuse scattering

The GBSBCM relies on specular reflection of rays on the scattering object, which is based on the assumption that the scatterer/object is much larger than the wavelength of the reflected signal. However, if the same scatterer is used for single and double bounce components, pure specular reflection can no longer be assumed, as there are multiple outgoing waves, each with a different direction, Figure 1.

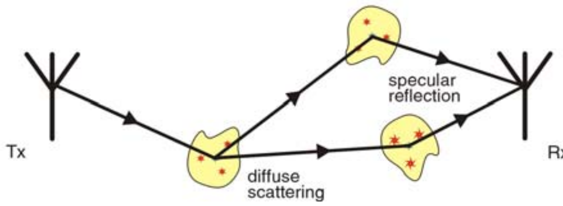

Figure 1 Diffuse scattering and specular reflection.

A model for diffuse scattering for urban propagation prediction is presented in [4], but the presented method is based on the ray-shooting approach, where each scatterer has an associated scattering coefficient.

The approach in the model presented in this work is to have separate scatterers for single and multiple bounce components. However, this means that for higher order bounce components, scatterers still have the problem of multiple outgoing waves from each one. Two solutions were found and are under investigation. The first method is to assume diffuse scattering of the rays at the scatterers. The second method is to bounce only from one scatterer to another, so that pure specular reflection can still be assumed. In this case, "virtual" scatterers are co-located with scatterers that have the same characteristics, but are used to reflect the signal towards a different cluster, hence, the model can still assume specular reflection.

3.2 Multiple bounce strategies

Three different multiple bounce strategies have been investigated and compared: All Scatterers, Random Scatterers, and Centroids Scatterers.

In the All Scatterers strategy, the signal at each scatterer is transmitted to all other scatterers that are not part of the same cluster, see Figure 2. The number of multipath components for this strategy, N_{all}, is then given by

$$N_{all}(M) = \sum_{m=1}^{M} \binom{N_c}{m} \cdot m! \cdot N_{sc}^{m} \qquad (1)$$

where N_c is the number of clusters, N_{sc} is the number of scatterers per cluster, and M is the maximum number of bounces. The number of multipath components is mainly dependent on N_{sc}.

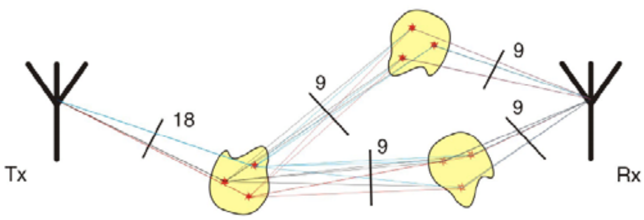

Figure 2 All Scatterers Strategy.

In both the Random and Centroid Scatterers strategies, Figure 3 and Figure 4 respectively, rays only bounce towards a single scatterer in the other clusters. The difference between the two strategies is that, in the Random Scatterers strategy a single scatterer from the cluster is selected, while in the Centroid Scatterers one an average reflection coefficient of the cluster is calculated and the location of the (virtual) scatterer is the centre of the cluster. Both strategies have the same number of multipath components given by:

$$N_{rnd}(M) = N_{cnt}(M) = \sum_{m=1}^{M} \binom{N_c}{m} \cdot m! \cdot N_{sc} \qquad (2)$$

where N_{rnd} and N_{cnt} are the number of multipath components for the Random and Centroid Scatterers strategies, respectively. For these strategies, the number of multipath components is mainly dependent on N_c.

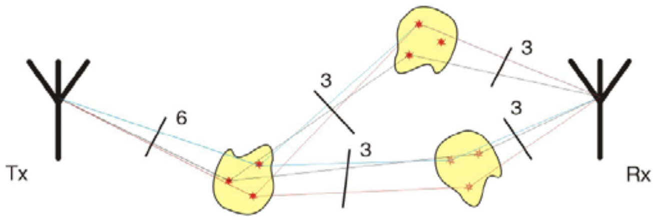

Figure 3 Random Scatterers Strategy.

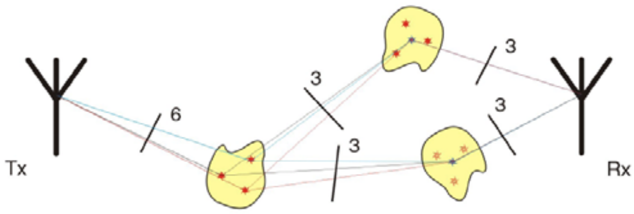

Figure 4 Centroid Scatterers Strategy.

The number of multipath components is a measure of the computational complexity of the simulator, Table 1 showing the number of multipath components for all strategies.

M	N_{all}	$N_{rnd} = N_{cnt}$
1	48	48
2	2 064	384
3	74 640	2 400
4	2 251 920	12 480

Table 1 Number of multipath components for a number of bounces with N_c =8 and N_{sc} =6.

It should be noted that the All Scatterers strategy requires a much higher computational complexity than the other two. Between the Random and Centroid Scatterers strategies, the latter is only marginally less complex, as the (virtual) centroid scatterer only has to be calculated once at the beginning of each simulation.

As expected, multiple bounces allow for larger path lengths, which has an immediate effect on the delay spread. With only 2 bounces, the path length can become more than 3 times the one of the LoS component, which makes it very hard to control the delay spread. Therefore, a limit for the distance a wave can be bounced back into the direction of the Tx was introduced. The limit is set to half the LoS path length, but there is ongoing research for a more effective solution.

4 Initial Results

4.1 Initial considerations

The results produced here are initial ones, which already give a good insight into the effects of reflection vs. scattering and the various scatterer strategies. For the initial results, a street scenario was defined, based on the measurement campaign carried out by Telenor R&D in Olso, Norway [8] for the LoS case (Prinsens Gate), using the elliptical micro-cell model.

The distance between Tx and Rx was set to 100 m, and the real street width was set to 20 m (the street width of Prinsens Gate was approximated). The channel model was simulated for a carrier frequency of 2 GHz, and a Tx power of 1 W was assumed. The obtained delay spread, σ_τ, for the measurements was 20 ns with an angular spread, σ_ϕ, of 11.8º. The specific parameters for the single bounce model are given in Table 2.

Parameter	Value
N_c	10
N_{sc}	10
Effective street width factor	3.5

Table 2 Single Bounce Channel Model parameters.

The multiple bounce channel model has different parameters for N_c for first, second and higher order bounce multipath components. Also, N_{sc} is adjustable between the multipath components from different bounces. The specific parameters for the multiple bounce channel models are given in Table 3.

Parameter	Value			
Bounce	1	2	3	4
N_c	10	4	4	4
N_{sc}	10	3	3	3

Table 3 Multiple Bounce Channel Model parameters.

All presented values are the average of 1000 simulations.

4.2 Specular reflection or diffuse scattering

This section evaluates the assumption of specular reflection or diffuse scattering for the higher order bounces. In case of specular reflection, different (but co-located) scatterers are used to create multiple bounces. The average results of various simulations for diffuse scattering and specular reflection are shown in Table 4. The channel richness parameter [3], ω_{DCIR}, is an indication for the quantity of relevant AoA per relevant time unit, being defined by:

$$\omega_{DCIR}\left[rad/\mu s\right] = \frac{\sigma_\phi}{\sigma_\tau} \quad (3)$$

	Single bounce	Diff. scattering	Spec. reflection
σ_τ [ns]	21.46	1.86	19.83
τ_{max} [ns]	73.60	195.60	367.15
σ_ϕ [º]	35.61	10.74	10.82
ω_{DCIR} [rad/μs]	28.01	92.62	11.70
Avg. power decay	1.28	1.24	1.22

Table 4 Initial results of specular reflection vs. diffuse scattering.

In order for the single bounce model to have a delay spread comparable to the measurement data, an effective street width factor of 3.5 is used, but as pointed out in Section 2, this gives too optimistic results for the angle spread. The specular reflection model, with a maximum number of 2 bounces, does not show this effect, as both the delay spread and angular spread give comparable results to the measurement data. Note however that the excess delay spread for the multiple bounce specular reflection model is much larger than for the single bounce model, but there was no data available in the aforementioned paper on this property. The multiple bounce diffuse scattering model uses the same parameters as the specular reflection multiple bounce one, but due to the diffuse spread of power in all directions at the scatterers, almost no power is received, which causes a very small delay spread. The angular spread, however, did not see drastic changes, which can be explained by the fact that both models used the same environment (width of the ellipse). It is also interesting to note that the angular spread is mostly dependant on the single bounce scatterers.

4.3 Multiple bounce strategies

This section evaluates the different multiple bounce strategies for the Oslo scenario for a maximum of 2 bounces.

	All	Random	Centroid
σ_τ [ns]	33.23	20.38	19.52
τ_{max} [ns]	354.17	347.48	343.84
σ_ϕ [º]	10.68	10.87	10.87
ω_{DCIR} [rad/μs]	7.19	12.44	12.45
Avg. power decay	1.19	1.22	1.22
Simulation time [s]	62.10	45.40	32.70

Table 5 Initial results of the multiple bounce models with different bounce strategies.

Both the Random and Centroid Scatterers models show very similar results. The All Scatterers strategy has a larger delay spread than the other two, but with a very similar angular spread, which also explains the smaller channel richness. The All Scatterers strategy has the largest complexity and the Centroid the lowest.

4.4 Single bounce versus multiple bounces

The channel model supports up to an unlimited number of bounces, so it is interesting to look at the effect of having more bounces. The results are just for the multiple bounce channel model with the Centroid Scatters strategy, Table 6.

	Max. number of bounces			
	1	2	3	4
σ_τ [ns]	1.84	19.83	28.71	31.51
τ_{max} [ns]	6.60	367.15	627.76	669.48
σ_ϕ [º]	10.69	10.82	10.87	10.88
ω_{DCIR} [rad/μs]	93.22	11.69	7.11	6.32
Avg. power decay	1.24	1.22	1.22	1.21
Rec. power [%]	88.77	5.94	2.13	0.38

Table 6 Impact of the number of bounces on the channel model for the Centroid Scatterers strategy.

Due to the very small street width (no effective street width ratio was used), compared to the distance between Tx and Rx, the delay spread of just single bounces is very small, but it increases as the number of bounces increases. The same behaviour holds for the excess delay spread. The angle spread depends more on the environment than on the number of bounces, being more or less constant. The channel richness becomes smaller as the number of bounces increases, due to the decrease of the delay spread. The average power decay is more or less constant. Most of the power at the Rx is due to single bounce components, and the additional power corresponding to the 3rd and higher order bounces is almost negligible. Note that the row of percentage of receives power does not sum to 100%, as the remaining percentage is received from the LoS component (zero-bounces).

5 Conclusions

This paper describes and compares various ways in which a GBSBCM can be extended to a multiple bounce model. A model with diffuse scattering for higher order bounces is compared with one with only specular reflection. It is shown that diffuse scattering in a multiple bounce model does not increase the delay spread, as the amount of received power from diffused ray components is very low. The delay spread for a multiple bounce model is one order of magnitude larger compared to a single bounce model without effective street width factor for the simulated micro-cell scenario.

Introducing multiple bounces increases the computational complexity, depending on the multiple bounce strategy used. This paper compares three different scatterers strategies, i.e., All Scatterers, Centroid Scatterers and Random Scatterers. The All Scatterers strategy, where a ray is bounced from one scatterer to all scatterers in other clusters, has the highest computational complexity; whereas the Centroid Scatterers strategy, where a ray is only bounced from one scatterer to another has the lowest. The complexity of the All Scatterers strategy is mostly dependent on the overall number of scatterers, whereas the other two strategies are mostly dependent on the number of cluster.

The amount of received power from a bounce decreases, as the number of bounces increases, and it seems that more than 2 bounces only enlarges the delay spread, but does not increase the received power much.

Note, that the initial results are based on a LoS micro-cellular scenario only, and compared with values in literature. It can be expected that the results for pico- and macro-cells are different, as the model of the environment is very different from the micro-cell one.

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