

# Location Dependent CDMA Orthogonality in System Level Simulations

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**Abstract** – In system simulations of WCDMA radio networks often a constant value for the orthogonality factor is assumed in the whole considered area of interest to determine the performance of WCDMA networks. This factor is used to scale the intra-cell-interference, which has an important impact on the network performance. However, the orthogonality factor is not constant, but depends on the individual channel profile between transmitter and receiver as well as on the receiver implementation. Therefore, this factor is different for every particular user. In a new approach presented in this paper, the orthogonality factor is calculated dependent on the above mentioned parameters for each receiver point individually. Furthermore, comparisons of this new approach with the simple constant value approach are presented. The results show that the assumption of a constant orthogonality factor within a cell may lead to unrealistic results in system level simulations, especially if interference sensitive high bit rate services are considered, e.g. the packet transmission technology HSDPA (High Speed Downlink Packet Access). Especially in the field of performance analysis for network planning and network design it is important to obtain an accurate performance estimate with a correlation to the predicted area instead of average values for the whole simulation area.

**Keywords** - Wideband Code Division Multiple Access; WCDMA; Multipath Channel; Orthogonality Factor; High Speed Downlink Packet Access; HSDPA

## I. INTRODUCTION

In WCDMA networks, signals from a serving base station transmitter to different users within one cell (downlink) are spread by orthogonal channelization codes. So, the desired signal can be separated completely from the other signals in the receiver assuming perfect channel conditions. But in real channels the signal is transmitted to the receiver via different propagation paths due to interactions (reflections, diffractions, scattering) with buildings, hills and other obstacles. Each propagation path carries a part of the transmitted signal and is characterized by an individual amplitude and time delay. The receiver sees time shifted replicas of the coded signal itself and also of the interfering signals. Due to this multi path propagation characteristic the orthogonality is decreased and intra-cell-interference arises (see fig. 1 and fig. 2).

The orthogonality degradation of the intra-cell-interference can be modeled with the help of a scaling factor. The factor, which is used to consider the degree of orthogonality between

the own cell signals at the receiver of a particular user is called the orthogonality factor  $\alpha$  (see Section II). This factor  $\alpha$  is different for each user in the system, mainly because it depends on the physical multipath channel profile between the transmitter and the individual receiver. Furthermore it also depends on implementation aspects of the Rake receiver, however in this context it is assumed that all mobile stations use the same receiver concept.

Within this paper the factor  $\alpha$  is defined with a range from  $\alpha = 0$  (orthogonality between the different signals is completely lost) and  $\alpha = 1$  (perfect orthogonality between the different signals). It should be mentioned that in some publications different definitions are used.

It is a common method in current WCDMA system simulators to set the orthogonality factor to a constant value for all receiver points in the whole simulation area. The reasons are that most simulation tools cannot determine individual multipath channel profiles for each mobile and an additional computation effort has to be spent to evaluate the channel information to determine the orthogonality factor. But especially if high data rate services are simulated, e.g. with HSDPA (High Speed Downlink Packet Access), the channel conditions are the crucial limiting factor for the achievable data rate.

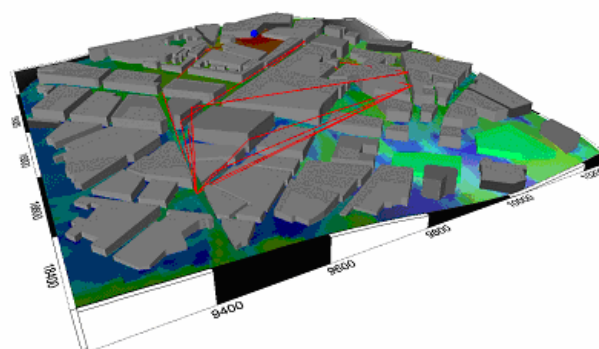


Figure 1. Example for multipath propagation in urban environments

HSDPA aims at extending the peak data rates and the capacity of WCDMA networks. Depending on the measured SNIR (Signal to Noise and Interference Ratio) at the receiver, the link between the base station and the receiver is optimized in terms of throughput (adaptive modulation and coding). Receivers with favorable radio channel conditions (high SNIR) have the possibility to get peak data rates of 10 Mbit/s or more. These high data rates can be reached by using higher order modulation schemes (16-QAM), which are quite interference sensitive. This paper will show that the SNIR, which depends on the channel conditions to the neighboring cells and the degree of orthogonality, must be determined for each user individually to get realistic performance simulations also for the achievable data rates.

The tool used for the simulations presented in this paper offers three different modes to consider CDMA signal orthogonality. First, a constant value for the complete simulation scenario can be specified. The second mode offers the possibility to use the specified value for all locations without line of sight to the transmitter (NLOS, Non Line of Sight), whereas in Line of Sight (LOS) areas ideal orthogonality is assumed. The third possibility is the location dependent determination presented in the following sections.

Sometimes the variation of the signal orthogonality is considered statistically by a random value with a given distribution. The statistical characteristics of the orthogonality may be calibrated with measurements, but with this method it is not possible to consider the orthogonality related to a specific location and mobile station. If network planning and network design aspects are to be considered, it is important to obtain a location depending performance assessment (e.g. data rates) instead of statistical evaluations for the complete simulation.

The method for the determination of the location dependent orthogonality factor  $\alpha$  is presented in section II of this paper. The comparisons between simulations performed with the presented approach and simulations performed with the simple constant value approach are presented in section III. All simulations were performed with a ray-optical prediction model [1] of a radio network planning tool [2]. In section IV, some modeling aspects concerning the HSDPA system simulations are highlighted and the influence of the two methods on HSDPA simulations is shown. An extended description of the HSDPA simulator can be found in [3]. Finally, the results are summarized in section V.

## II. THE ORTHOGONALITY FACTOR

The SNIR after despreading at the receiver can be approximated as the ratio of the power of the desired signal to the power of all interfering signals [4]:

$$SNIR = \frac{SF * P_{user}}{P_{own} * (1 - \alpha) + P_{others} + P_{noise}}, \quad (1)$$

where  $SF$  denotes the spreading factor,  $P_{user}$  is the received power of the desired user signal,  $P_{own}$  is the total received signal power from the serving base station,  $P_{others}$  is the total received power of all other base stations (called inter-cell-interference), and  $P_{noise}$  is the thermal noise power. The factor  $(1 - \alpha)$  is called the Multi-Path Loss (MPL) factor, which decreases the intra-cell-interference caused by  $P_{own}$ , due to the remaining orthogonality of the signals arriving at the receiver.

In general the channel impulse response can be expressed as a discrete time function [5] (tap delay profile):

$$h(\tau) = \sum_{f=1}^L a_f * \delta(\tau - \tau_f), \quad (2)$$

where  $a_f$  are the amplitudes of the  $L$  parts of the signal arriving with the delays  $\tau_f$  at the receiver due to the multipath channel. A formula for  $\alpha$ , depending on the channel profile and the implementation of the receiver, can be derived by using (2) and assuming a Rake receiver with  $F$  Rake fingers. It is assumed that the Rake receiver can allocate one of its  $F$  fingers for each major tap and that the part of the signal, for which a Rake finger is allocated, is, at the same time, not part of the intra-cell-interference.

Fig. 2 shows the multipath Channel Impulse Response (CIR) for one example receiver location as determined with a 3D ray-optical propagation model [1].

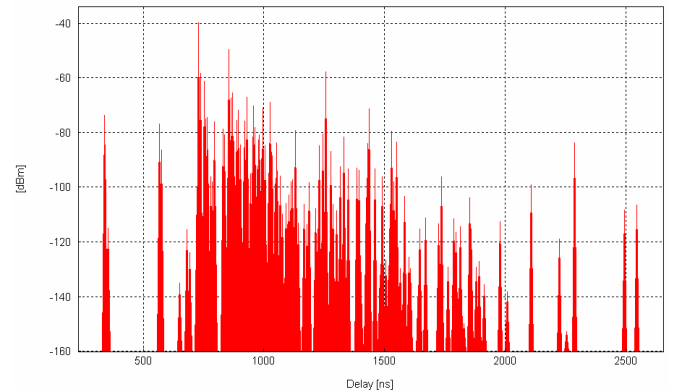


Figure 2. Channel Impulse Response computed with ray-optical propagation model

For the orthogonality factor the following expression has been derived ([4], [6]).

$$\alpha = 1 - \left[ \sum_{m=1}^F \frac{|a_m|^2}{\sum_{f=1, f \neq m}^L |a_f|^2} \right]^{-1} \quad (3)$$

Within the propagation model all propagation paths are considered for each receiver pixel. The number of contributions to the CIR depends on the chosen value for the maximum number of interactions (reflections, diffractions) and can reach hundreds or thousands of propagation paths.

To model the behavior of a Rake receiver; the multipath components have to be filtered in an adequate way, as a Rake receiver cannot separate incoming paths if their time delay is below a certain threshold. Therefore in the simulations all incoming paths are assigned to different time windows, depending on their individual delay. Each window has a duration in the order of a chip length. The received signal energies of all paths assigned to the same window are accumulated. Due to this filtering the channel profile is reduced to some few major power peaks. The  $F$  windows with the strongest power peaks are then assigned to the  $F$  Rake fingers. This models the Rake receiver allocating its fingers to the most significant parts of the signal. Finally,  $\alpha$  is determined referring to (3) for each receiver pixel.

### III. COMPARISON OF INTERFERENCE PREDICTIONS

Fig. 3 shows a fictitious WCDMA network in a dense urban scenario, consisting of seven transmitters/cells. The center cell (the blue colored area in fig. 3) is mainly considered in the following interference predictions. The other six neighboring cells are used to model inter-cell interference. In this section the influence of the two approaches for the consideration of the signal orthogonality, namely constant value and location dependent, are investigated. For this, only the interference levels have to be evaluated, because only the intra-cell-interference depends on the orthogonality factor. The interference is computed for both approaches. The inter-cell-interference is also considered, though it is independent of the orthogonality factor. This is necessary as in some areas close to the cell borders the inter-cell-interference dominates over the intra-cell-interference. So in these areas the SNIR will be nearly independent of the orthogonality factor (see (1)).

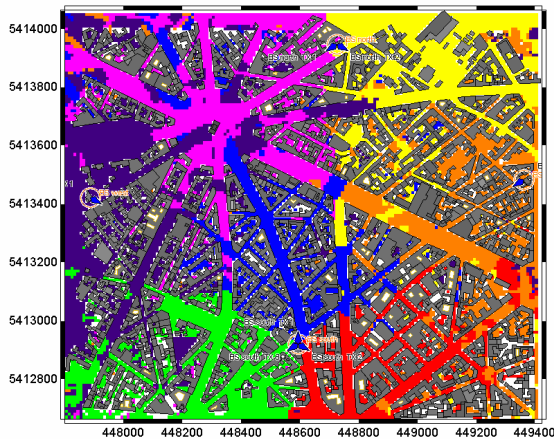


Figure 3. Cell areas of a fictitious WCDMA network

Fig. 4 shows the computed location dependent orthogonality factor for each receiver pixel using the new approach and (3). In fig. 4 the orthogonality factor is displayed only for areas where the center cell is the serving cell (i.e. the blue areas in fig. 3). Nevertheless, during the simulation the orthogonality for each cell is computed for an extended area,

because the serving areas of a cell may vary dynamically (CDMA cell breathing).

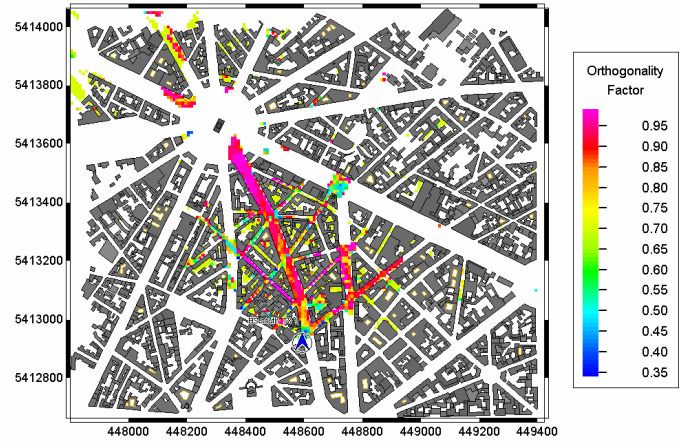


Figure 4. Location dependent orthogonality factors (only area of one cell is displayed)

For the comparison of the two approaches the interference prediction computed with constant  $\alpha$  was subtracted from the one computed with the location dependent  $\alpha$ . The result is shown in fig. 5. The mean value of the interference difference between new and simple approach could be reduced with a different selection of a constant orthogonality factor, but obviously the deviations remain.

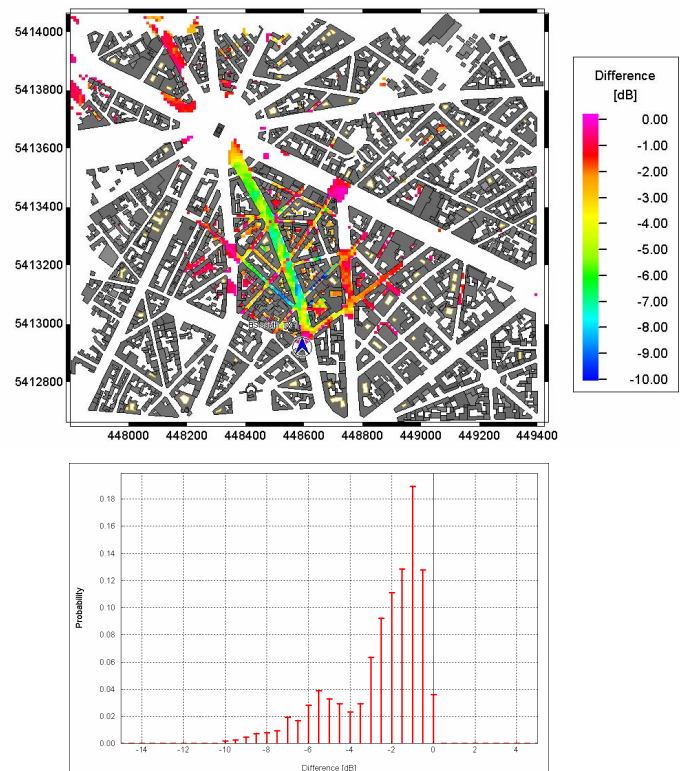


Figure 5. a) Difference: Interferences ((new appr.) - (simple appr.))  
b) Distribution of the differences

In fig. 4 it can be seen that the orthogonality factor calculated depending on the location with the presented approach is by far not constant in the whole cell area. In the main direction of the transmitter in the center of the cell a high degree of orthogonality occurs due to one or few dominating paths. In these areas some paths are less attenuated compared to other paths reaching the same receiver pixels. This can be observed in LOS areas but also in NLOS areas with one dominating path. In areas with smaller orthogonality such dominating paths do not occur.

Fig. 5 shows that the orthogonality has a considerable impact on the interference level, and thus also on the SNIR, especially in the center of the cells, where the intra-cell-interference dominates over the inter-cell-interference. At the cell edges the independence of the SNIR from the orthogonality can be observed. In this case the inter-cell-interference dominates over the intra-cell-interference. The influence of the difference in the predicted SNIR on the link performance in HSDPA system level simulations is shown and discussed in the following section.

It has been observed that the effect of the orthogonality factor on the interference levels in micro cellular networks can be even higher if there is only one omni directional transmit antenna located directly in the center of the cell. Note that in the scenario presented in this paper the antennas of the tri-sectorized cells are located at the sector border. Macro cellular and micro cellular networks have been analyzed separately to investigate the influence of typical cell topologies. Micro cells are often used as an overlay network to increase network capacity in areas with high traffic demands (Hot Spots).

#### IV. INFLUENCE ON HSDPA SYSTEM SIMULATIONS

Some general aspects of the HSDPA simulation model will be presented in this section. For further information about the HSDPA simulator please refer also to the information given in [3].

In a HSDPA system the mobile terminal measures the SNIR of a transmitted pilot signal of the serving base station and sends the result back in form of a so called Channel Quality Indicator (CQI), which is a quantized SNIR value. Depending on the reported CQI value, the base station assigns a Transport Format and Resource Combination (TFRC) to each mobile station individually. The TFRC determines the amount of user data that can be transmitted within one HSDPA radio sub-frame and it therefore also determines the user data rate. The reported CQI value can also be used for further network algorithms (e.g. scheduling). The achievable data rate per user therefore depends on the channel quality and the current network load which both influence the SNIR.

The link level performance is determined in detailed link level simulations which are imported into the system level simulation in form of look up tables. Therefore the block error rate (BLER) is determined depending on the SNIR for different TFRCs and for different channel profiles. The

channel profiles are set as tapped delay profiles according to the well known ITU profiles [7].

Fig. 6 depicts the main functional blocks of the HSDPA simulation chain. It includes generators for different packet sources as well as different radio resource management algorithms concerning scheduling, power assignment and packet processing (segmentation, concatenation). With all transmission powers being set dynamically, the current SNIR of each scheduled mobile terminal is determined and the current BLER and bit rate can be computed with the help of the Link Level look-up tables. Within SNIR computation some common channels are considered with a constant power level, but no dedicated channels are occupied in parallel to the HSDPA mobiles.

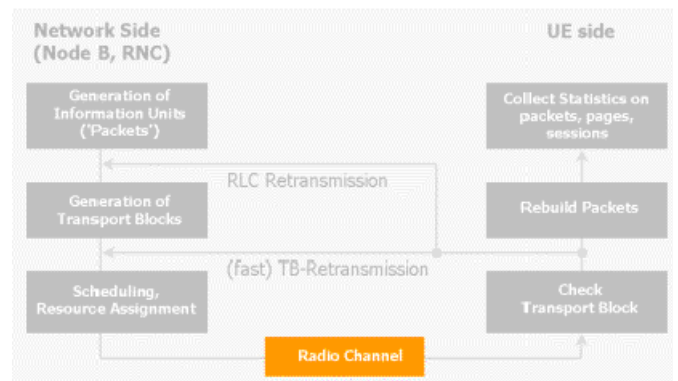


Figure 6. Main HSDPA simulation blocks

Within the presented simulations the base station selects the TFRC and the corresponding transmission power for each radio link to achieve a target BLER of about 10 percent. The power offset between the pilot channel and the data channel has to be considered. If there are not sufficient transmission resources (power limit, available number of codes) the TFRC is reduced accordingly.

To predict the maximum achievable user bit rate a fixed amount of transmission power is assumed to be available for the transmission to a single user terminal. All other sector transmitters produce a certain amount of (inter cell) interference. This can be done for all possible receiver locations in the simulation area. With the resulting SNIR the transport format with the highest corresponding effective user throughput is assumed and the achievable peak data rate can be determined for the given interference levels.

Higher TFRC values (larger HSDPA transport blocks) lead to a higher throughput for the user. The peak data rate depends quite heavily on the predicted interference level and therefore it depends also on the assumed CDMA signal orthogonality. In HSDPA simulations performed with the simple constant orthogonality approach too low TFRCs are chosen in areas with relatively good channel conditions resulting in too pessimistic throughput estimations. The new approach improves the SNIR calculation and therefore leads to more realistic simulations.

In the simple approach only the link level simulation results for one channel profile are used. For the given macro cellular scenario displayed in fig. 3 the ITU Vehicular A channel profile is used. Fig. 7 shows the provided HSDPA peak data rate.

In the new approach more link level simulation results are taken into account for a given scenario. Altogether, results of three profiles are provided, the ITU-Vehicular A, the ITU-Pedestrian A, and a LOS profile (a profile consisting of only one direct propagation path). The channel profiles occurring in the system simulation are assigned to one of these three channels depending on their orthogonality factor. Profiles with almost perfect signal orthogonality ( $0.98 < \alpha < 1$ ) were assigned to LOS, profiles with good signal orthogonality to Pedestrian A ( $0.75 < \alpha < 0.98$ ) and all other profiles to Vehicular A. These thresholds were chosen after extensive link level simulations in which the characteristics of BLER tables of different channel profiles with different orthogonality factors were compared. Fig. 8 shows the HSDPA peak data rate simulated with the new approach. Significantly higher data rates can be observed for receiver pixels with good channel conditions.

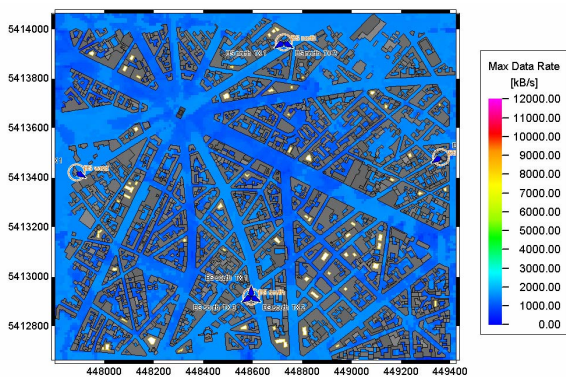


Figure 7. HSDPA peak data (simple constant value approach used)

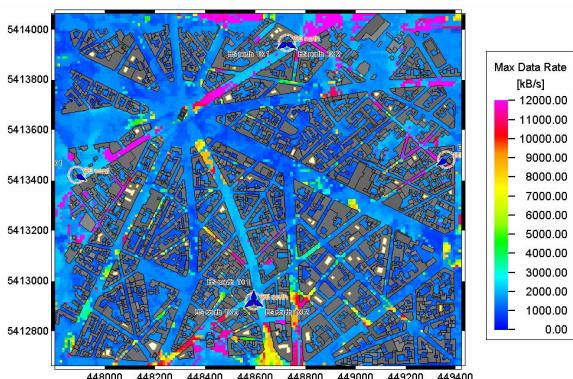


Figure 8. HSDPA peak data (new approach used)

## V. CONCLUSION

The results in fig. 4 (section III) show that the orthogonality factor calculated depending on the location is by far not constant in the whole area of a cell. Thus assuming the orthogonality factor to be constant is an inaccurate simplification. In the main direction of the transmitting antenna a high orthogonality factor occurs due to a dominating path. Fig. 4 shows that the orthogonality has a considerable impact on the interference levels, and thus also on the SNIR, especially in the center of the cells, where the intra-cell-interference dominates over the inter-cell-interference. This difference in the predicted SNIR directly influences the link performance in the HSDPA system simulation in terms of throughput (chosen TFRC, resulting BLER). For more realistic simulations of interference sensitive high data rate transmissions the additionally effort for a location dependent calculation of the orthogonality factor must be spent. This is obviously important if the performance prediction is required with a correlation to the physical location as it is in most network planning tasks.

Besides the orthogonality factor the modeling of the channel profile selection and the applied physical layer performance simulations is a second major influence on the HSDPA performance. As the channel profiles are used already within the link level simulations the proper set of BLER simulations has to be chosen during system simulation. It is also possible to select one profile out of a set of given profiles location depending in the system simulation. Currently this is done based on the determined orthogonality factor and the orthogonality factors that correspond to the given profiles. A smooth transition between the different discrete profiles can be investigated in the future.

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