How typical is the "Typical Urban" channel model?

- Mobile-based Delay Spread and Orthogonality Measurements

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***Abstract*— Channel models for urban deployments are among the most commonly used in research, standardization, and dimensioning of cellular networks. The time dispersion has ever been an important characteristic of the channel, often being the determining factor when assessing performance such as bit error rate and achievable throughput. A related measure is the channel orthogonality factor. In this paper the urban radio channel is revisited and the measurement data is compared to well-known models. We find that rms delay spread and channel orthogonality factor derived from the measurement data are significantly lower than predicted by the "typical urban" radio channel model. Corresponding implications on e.g. capacity and coverage calculations and dimensioning guidelines are also discussed.**

***Index Terms*—Time dispersion, delay spread, orthogonality factor, radio channel characteristics, measurements.**

I. Introduction

The "Typical Urban" channel model [1] has been part of the toolbox for researchers and developers in the wireless communication business since the early years of GSM. This particular model was based on radio channel measurements performed within the COST 207 action and was initially used to determine the need and performance of the equalizer in GSM. These measurements were all performed long before any commercial GSM networks were put into operation although there existed systems based on analogue standards.

Later, when third generation systems were about to be standardized, the channel models in use in the GSM community were complemented by a set of models selected by the ITU [7]. In addition a set of "deployment models", which were basically the original models from GSM adapted to the higher bandwidth, were specified in 3GPP [2]. However, one notable difference was introduced: the "3GPP deployment TU" had half the time dispersion of the "GSM TU", 0.5 µs rms delay spread compared to 1 µs. The lower time dispersion was considered more "typical" in the light of additional channel measurements that had been published, e.g. [5]. It was also believed that some of the measurements that had been the basis for the GSM TU model had been collected in conditions that might be challenging to non-equalizer receivers by having higher than usual time dispersion.

More recent channel modeling activities have focused on the spatial characteristics of the channel that are relevant for multi-antenna transmitters and receivers, as well as at models suitable and realistic for system simulations with multiple base stations and terminals. One of these models is the COST 259 directional channel model [3], [4], whose heritage in the COST 207 models (GSM models) is evident in the naming of the sub-models: "Generalized Typical Urban" (GTU) etc. The COST 259 model also inspired the 3GPP/3GPP2 Spatial Channel Model (SCM) [6]. Common to both these models is that they model the variability of the rms delay spread using a distance-dependent log-normal distribution as originally proposed in [5], although the distance dependence was dropped in the 3GPP/3GPP2 SCM. Table I summarizes the delay spread characteristics of the different described models.

TABLE I. DELAY SPREAD CHARACTERISTICS OF SOME COMMONLY USED CHANNEL MODELS

Model	median rms delay spread [µs]	Distribution	Distance dependence
TU (GSM)	1	fixed	-
TU (3GPP)	0.5	fixed	-
RA (3GPP)	0.1	fixed	
GTU (COST259)	~0.4	lognormal	~sqrt(d [km])
GBU (COST259)	~1	lognormal	~sqrt(d [km])
Greenstein	0.4-1.0	lognormal	~sqrt(d [km])
3GPP SCM Urban Macro	0.65	lognormal	-
3GPP SCM Urban micro	0.251	lognormal	-
ITU Pedestrian A	0.045	fixed	-
ITU Pedestrian B	0.75	fixed	-
ITU Vehicular A	0.37	fixed	-
ITU Vehicular B	4	fixed	-

All of the described models have in common that they are based on measurements with dedicated channel sounding equipment. While the researchers performing the measurements have tried to replicate expected deployments as much as possible there is no guarantee that the channel conditions captured in the models are really representative of real world conditions in an operational wireless network. In particular, the growth in traffic and capacity demands have lead to wireless networks becoming denser with time such that the average cell size in an urban city today is only a fraction of what it was 20 years ago when the measurements in the COST

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207 action were performed. In other words, there is a need to validate the well-known and well-used channel models against typical radio propagation conditions of today.

The purpose of this paper is to report on a series of time dispersion measurements, and assessments of the channel orthogonality factor, that all have been performed recently with equipment recording the pilot channels transmitted in 3G (WCDMA) networks. The orthogonality factor measure quantifies the amount of self-interference and interference from orthogonal codes that a WCDMA Rake receiver experiences due to time dispersion. Using this equipment, the actual channel conditions as sensed by a mobile terminal in the network are extracted. The following sections contain a description of the measurements and a discussion of the obtained results in relation to the existing channel models.

II. TIME DISPERSION MEASUREMENTS

A. Equipment and measurement scenarios

The equipment used was a state of the art 3G-phone with additional capabilities for logging output from the path searcher. The accuracy of the channel estimates were assessed though lab measurements where the phone was connected to a single base station via a channel emulator. These tests verified that the phone, in a single-link scenario, provided accurate estimates of the instantaneous rms delay spread and channel orthogonality factor.

In a first measurement campaign, the rms delay spread and orthogonality factor were measured in one operator's network in the central-most parts of a large European city. The orthogonality factor and rms delay spread were also targeted in a second measurement campaign performed in a different operator's networks in a smaller/mid-sized European town and its rural vicinity. Measurements were performed while traveling by car using the mobile phone's built-in antenna, and include results from a large number of cells.

B. Measures of the time dispersion

Both the instantaneous rms delay spread and the instantaneous orthogonality factor are used as measures of the time dispersion in this paper. The rms delay spread is a general measure that is commonly used in channel characterization irrespective of what system is studied. Here the definition of orthogonality factor in [11] is used, where zero means full orthogonality and therefore no time dispersion, while higher values indicate higher time dispersion.

C. Results

An example of an instantaneous power delay profile is shown in Figure 1. During the rms delay spread calculations only peaks within 10 dB of the strongest peak were considered, as indicated in Figure 1. Additionally, only power delay profiles with a peak-to-noise ratio of at least 13 dB were used.

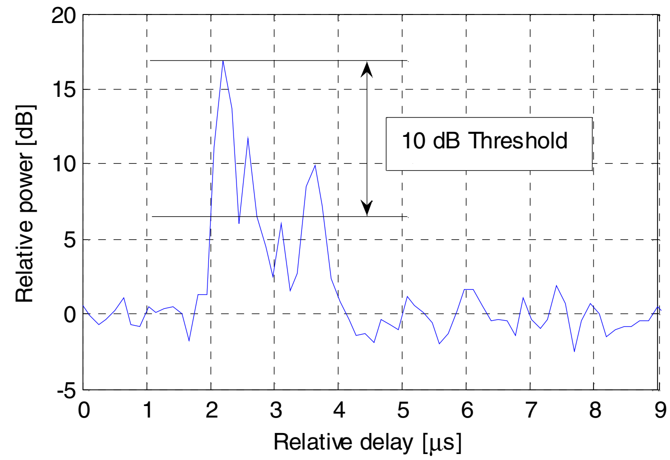

Figure 1. An example of a measured instantaneous power delay profile. This particular power delay profile has an rms delay spread of 0.54 µs when considering only those peaks that are within 10 dB of the strongest peak.

The distribution of the measured instantaneous rms delay spreads are shown in Figure 2. The results match a log-normal distribution quite well, although the limited resolution due to the 5 MHz bandwidth of WCMDA is evident in the truncation for low percentiles. The measured median rms delay spreads are around 0.10 µs, although one campaign results in a median slightly below 0.20 µs.

These delay spreads are in the same range as those of the 3GPP Rural Area (RA) channel model and somewhat higher than the ITU Pedestrian A (PedA) model, but significantly below the time dispersion that is modeled by the 3GPP Typical Urban (TU) model. The GSM TU model with its median rms delay spread of 1 µs would, if plotted, be even further from the measured results.

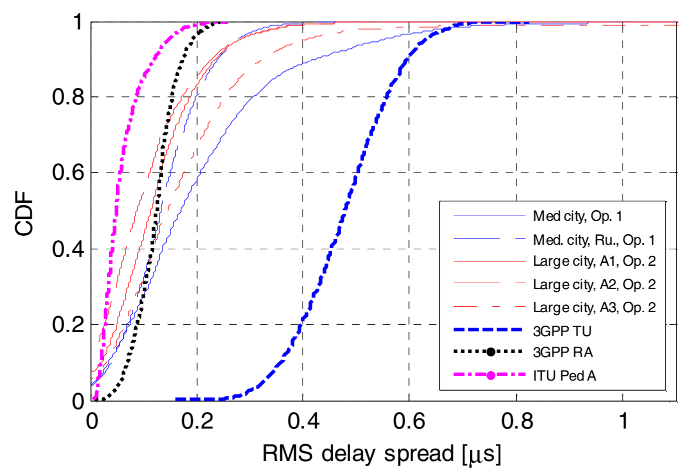

Figure 2. Cumulative distribution functions for the instantaneous rms delay spread measured in 3G networks in two different cities and two different operator networks. "A1", "A2" and "A3" denote data from different areas in the large city. "Ru" denotes data from rural areas in the vicinity of the mid-sized city. Simulated instantaneous rms delay spread distributions for three common channel models are plotted for comparison.

The results for the orthogonality factor are shown in Figure 3, where also orthogonality factor distributions generated using a few selected channel models are plotted for comparison. Clearly, the measured distributions are best matched by the models with significantly lower time dispersion than the 3GPP TU model.

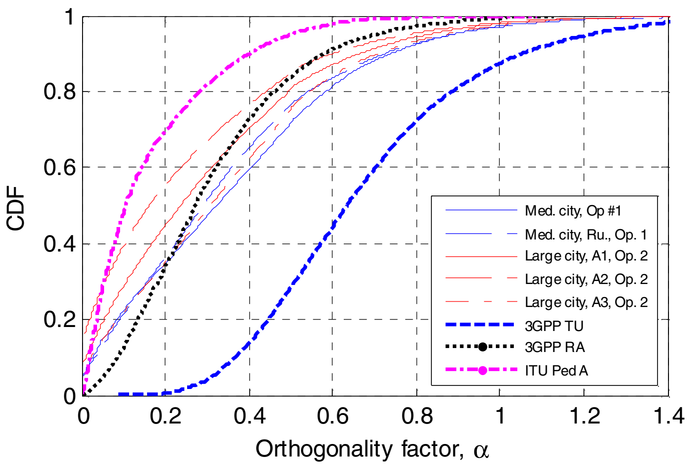

Figure 3. Cumulative distribution functions for the orthogonality factors measured in 3G networks in two different cities and two different operator networks. "A1", "A2" and "A3" denote data from different areas in the large city. "Ru" denotes data from rural areas in the vincinity of the mid-sized city. Simulated instantaneous orthogonality factors for three common channel models are plotted for comparison.

III. Discussion

The results presented in the previous section show that the rms delay spread in real urban 3G networks is clearly much smaller than the corresponding urban channel models. A possible explanation could be related to the cell sizes. As a modern urban 3G network is much denser than e.g. the early GSM networks, it is not unlikely that the channel models that were considered appropriate during the development of GSM may need to be reconsidered. Indeed, the findings by Greenstein et al. [5] led to a model where the rms delay spread is proportional to the square root of the cell radius. According to Table I, a cell radius of 0.2 km would give about 45% of the delay spread for a 1 km cell radius, or about 0.18-0.45 µs with the proposed settings in [5].

Another related cause of the smaller rms delay spread and lower orthogonality factors comparing data representing today's networks and early GSM networks could be the antenna positions. In e.g. early GSM deployment, antennas were located on a few rather high radio towers; the radio waves would propagate over the rooftops, and diffract or scatter down to potential street-level users. The likelihood of illuminating distant buildings that will act as reflectors giving rise to delayed echoes and a corresponding increased delay spread can be quite high for a high radio tower.

In later network deployment strategies, as traffic has increased and networks are planned denser, the current trend is that antennas are moved down from the radio towers to building rooftops, and even down to the street level, to support higher end-user bit rate and system capacity demands. For street-level users, now having most of the antennas in the immediate surroundings, e.g. wall mounted or on top of buildings with significant down-tilt, the propagation environment has changed to often comprise line of sight (LOS) situations. Due to the confined area in which the waves propagate, the reflections will occur at much shorter delays giving smaller time-dispersion. The main energy will therefore be confined to a few or even one tap in the finite-resolution impulse response that a WCDMA receiver works with. In general, the orthogonality will be better when the channel consists of fewer taps. This trend can be observed in Figure 3; "Ru" measurement, i.e. sparse deployment and tower-mounted antennas, shows higher rms delay spread values than seen for other denser deployed areas.

The model of [5] has also been used to predict the orthogonality factor and its dependence of cell size in [8] and [9], with identical conclusions regarding improvement of the orthogonality for smaller cells. In WCDMA, the quality target (γ) for a phone-to-base station connection can be simplified as $\gamma = P_{DPCH}/(\alpha \cdot P_{tot} + P_{other})$, where P_{DPCH} is the received DPCH power, P_{tot} is the total received power from own base station, and P_{other} is the received power from all other cells and the background noise. A detailed description is given in [13]. In a scenario where the interference from other cells is minor, given a fixed quality target, changed channel orthogonality forces the DPCH power to change accordingly. When a user increases its power, the overall interference is increased, thus the cell can serve fewer users. In another scenario, if the interference from other cells is significant, a change in orthogonality will not be as significant for the cell capacity.

Further support for the low delay spread values in urban areas is provided by the investigations reported in [10], where channel sounding measurements using existing UMTS site installations in the German cities of Hamburg and Hannover are described. The rms delay spreads [10, fig 4a] are generally below 0.5 µs, with a median value somewhere around 0.2 µs.

Some reported delay spread measurements, such as [12], also support the low rms delay spread in urban areas. In [12], a median rms delay spread of approximately 0.2 µs is found for urban areas.

Finally, it should also be noted that the method used in this report does not claim to measure and fully characterize the aspects of the radio propagation environment, but the environment as perceived by typical 3G-phones available on the market.

IV. Conclusions

The results presented in this paper indicate that the typical time dispersion in urban deployments is significantly smaller than what is experienced in the 3GPP TU channel model that is often used to represent such scenarios. The consequences of such a discrepancy are very important as dimensioning guidelines for existing standards, or even decisions in the standardization of e.g. long-term evolution of 3G (LTE) and 4G systems, might be affected. Impact on performance estimation simulations of new functionality and features should also be considered since e.g. different values of downlink orthogonality factor can affect capacity figures significantly.

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