WIDEBAND CHANNEL MEASUREMENT AND CHARACTERISATION FOR WIRELESS LOCAL LOOPS

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Abstract — The multipath characteristics of the WLL channel were studied over both short and long time periods in urban and sub-urban high-rise and small-house environments. Wideband measurements were performed at the centre frequency of 1.3 GHz with a sliding correlation measurement system using a chip rate of 15 MHz. The receiver was situated at regular cellular base stations, and the transmitter with an omnidirectional antenna was moved to several rooms in different buildings around the base station sites. During the recordings the movement of people in the measurement rooms was restricted.

The short-term results show a high degree of similarity in the multipath characteristics of the WLL channel in urban and sub-urban high-rise environments. The maximum measured values of delay spreads for the urban and sub-urban high-rise environments were 410 ns and 360 ns, respectively. For the sub-urban small-house environment the data indicates lower values of delay spread. The channel was shown to be very slowly fading, being in most situations essentially static over short time periods of the order of several tens of seconds. The variation of the channel characteristics over long time periods was shown to be significant.

I. INTRODUCTION

There are several cases in which the use of wireless connections in the local loop of the public switched telephone network is a viable alternative. In sub-urban and rural areas, where the subscriber density is low and the distances between subscribers are long, the cost of the access network is significantly increased by the use of copper wire. In cases where the need for a subscriber connection is temporary or urgent, and there are no fixed connections available, the use of a wireless connection is faster and less costly. Also, in the opening telecommunication market, the wireless local loop concept offers a simple way for several operators to coexist in the same area. The rapid deployment offered by the WLL solution is a significant advantage in developing countries.

The basic requirement in WLL system design is to provide transmission quality equivalent to that of the fixed connection. Many of the current WLL solutions are based on the principles and standards of cellular networks [1]. Due to the static nature of the propagation scenario the channel conditions in a WLL application can be expected to be more favourable than in cellular mobile communications. Therefore simplifications in the equipment can be achieved. The development of cost-efficient terminals and base stations requires accurate and realistic channel models, so that the technical solutions can be optimised for the WLL channel.

This paper presents research into wideband measurement and characterisation of the radio channel applicable to WLL systems. In particular it focuses on the short-term and long-term multipath characteristics of the WLL channel, extracted from wideband measurement results. The overall aim of the study is to produce a set of channel models to be used in system analysis and simulation. The channel models based on the results are currently under development. The motivation behind the work was the lack of published work on channel measurements and models applicable to WLL systems. The only other work with detailed wideband measurement results known to the authors is presented in [2].

The paper is organised as follows. The main characteristics of the measurement system are described briefly in Chapter II. Chapter III discusses the field measurements and the data recordings. The multipath characteristics of the WLL channel, as extracted from the recorded data, are presented in Chapter IV. Finally, Chapter V concludes the results.

II. THE MEASUREMENT SYSTEM

The measurement system used in the current work was originally designed and constructed for airborne use. The system and its performance was described in detail in previous documents [3, 4].

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Briefly, the measurement system is based on analog sliding correlation. The transmitter BPSK modulates a carrier with an m-sequence. The received signal is cross-correlated with a reference signal at a slightly lower chip rate, causing the two sequences to slide by each other. This process produces consecutive estimates of the channel impulse response, time scaled by a factor depending on the sliding rate. The complex impulse response estimates are sampled and A/D converted at a host computer and stored for later processing. The transmitter and the receiver are clocked by phase-coherent rubidium frequency standards, which allows both the amplitude and the phase of the impulse responses to be extracted. The main specifications of the system configuration applied in this work are given in Table 1.

Table 1. Specifications and performance parameters of the measurement system.

Operating centre frequency	1280 MHz
Carrier modulation	BPSK
M-sequence chip rate	15 Mchips/s
RF bandwidth (mainlobe)	30 MHz
Transmitter output power	10 W
Dynamic range of received power	–30…–84 dBm
Delay resolution	83 ns
Distance resolution	25 m
Maximum measurable excess delay	34.1 μs
Maximum path length difference	10.230 km
Impulse response storage rate	14 responses/s
Maximum measurable Doppler shift	±7 Hz
Impulse response dynamic range	25 dB
Effective output sampling rate	4 samples/chip
Sample quantization	16 bits
Storage capacity	1 GB

The choice of the centre frequency was a compromise between system limitations and national frequency administration requirements.

III. FIELD MEASUREMENTS AND RECORDINGS

The measurements were made in the city of Oulu, Finland, and it's surroundings. In all measurements the receiver site was located at an existing cellular base station. The choice of the measurement areas was governed by the locations of cellular base station sites. The transmitter was moved in different locations, so that several locations were examined at each receiver site. To obtain data from 3 different environments, the following receiver sites were selected: site A for urban environment, site B for sub-urban high-rise environment and site C for sub-urban small-house environment. The terrain around all measurement sites was flat. The receiver antennas at each site were shared with the cellular base station receiver.

The measurement transmitter was installed in a residence or other room, either in a small house or a larger building, depending on the receiver site in question. At each environment, several transmitter locations were examined. Whenever possible, the measurement was made both on the ground floor and on an upper floor. A number of antenna positions were measured in each room to ensure sufficient coverage and to make the results statistically reliable. The transmitter antenna was a horizontally omni-directional type installed at 1 m height above the floor.

The transmitter locations were chosen in such a way that the windows of the rooms always opened to the direction of the receiver site, resulting in either a line-of-sight (LOS) or obstructed line-of-sight (OLOS) topography. All the locations at any site were in the same antenna sector. The transmitter-receiver separations varied between 400 and 1550 meters.

Both short-term and the long-term impulse response recordings were carried out. A set of 1024 consecutive impulse responses, called a burst, was recorded at each transmitter location and antenna position. The duration of the burst was 69.8 s. These bursts constitute the short-term measurements.

The long-term measurements were carried out at one transmitter location on all receiver sites. Impulse responses were recorded over a 24-hour period without moving the transmitter antenna. This was done by recording bursts of 512 consecutive impulse responses (half the burst size of the short-term measurements) periodically with one burst every 6 minutes. The result was a set of 240 bursts in 24 hours.

All movement in the measurement rooms was restricted during the recordings. However, since the measurements were performed during day-time and often in public premises, there was no control over the eventual movement of people or any other objects outside the transmitter location room. Also, in some locations the room had no doors, so it could not be closed.

IV. WLL CHANNEL MULTIPATH CHARACTERISTICS

A. Data Processing and Parameter Extraction

The raw data recorded in the field was first filtered and reformatted into a format better suited for parameter extraction. A data reduction was also performed by binning the impulse responses as described in [5], reducing of the delay resolution (= bin width) to 0.1 μs. Subsequently, a bin exceeding the floor level of –25 dB relative to the strongest bin was referred to as a resolvable propagation path.

After these procedures, all data was gathered in bursts of either 1024 (for the short-term characterisation) or 512 (for the long-term characterisation) impulse responses. The number of short-term bursts surviving the filtering and reformatting stages was 56, 47 and 13 for sites A, B and C, respectively. Using the bursts as basic units of data, the following channel parameters were extracted for each burst:

- Power in dBm at the input of the receiver averaged over the burst P_{av}
- Scattering function
- Delay power spectrum, with
  - Rms delay spread L_{rms}
  - Multipath spread (total delay spread) L_{tot}
  - Number of resolvable propagation paths N_p
- Doppler power spectrum, with
  - Rms Doppler spread B_{rms}
  - Maximum Doppler shift B_{tot}
- Average delay (inter-path) correlation functions of adjacent multipath components in every impulse response, with
  - 0.5–correlation depths of the average correlation functions

For the short-term characterisation, these parameters and functions can then be presented on 3 different levels:

- Position level: results for each transmitter antenna position in a room (i.e. for each burst)
- Location level: results at each room around a site
- Site level: results at each environment type (base station site)

For the purposes of this paper, the short-term characteristics are presented in detail only on the site level. This shows the differences of WLL channel multipath characteristics in different environments. The long-term characteristics are best presented as plots of the variations of the parameters and functions over a 24-hour period.

B. Short-Term Characteristics

The site-level statistics of the multipath characteristics of the WLL channel are plotted in Fig. 1 and Fig. 2. The plots show the cumulative distribution functions (CDF) of the number of paths N_p and rms delay spread L_{rms} for urban (site A), sub-urban high-rise (site B) and sub-urban small-house (site C) environments.

The statistics show minor differences in the delay spreading characteristics of the WLL channel in different environments. However, the differences are noticeable only in the sub-urban small-house environment as compared to the other two cases. The data for this environment is not sufficient to allow firm conclusions to be made. Therefore the conclusion is that the delay spreading characteristics of the WLL channel are essentially equivalent in the urban and sub-urban high-rise environment. In the sub-urban small-house environment there is some indication of less severe delay spreading (lower values of L_{rms}).

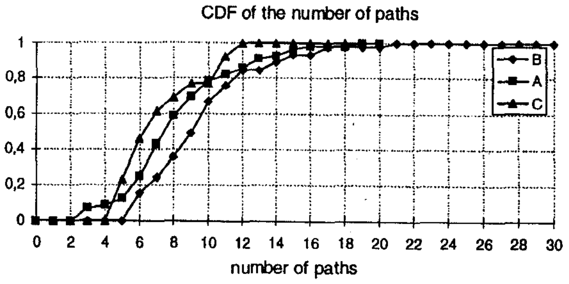

Fig. 1. Statistics of the number of paths at different environments.

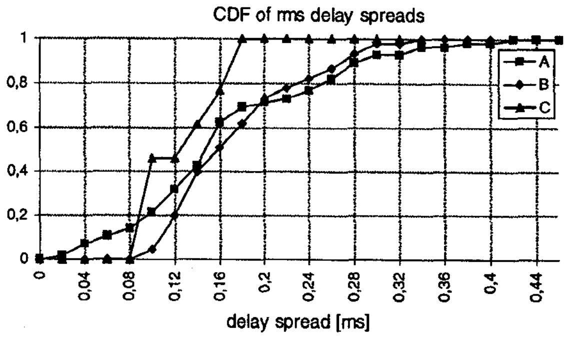

Fig. 2. Statistics of rms delay spread at different environments.

The 50%, 90% and maximum values of the CDF's are summarised in Table 2 for urban (U), sub-urban high-rise (SU hr) and sub-urban small-house (SU sh). The values of the delay spread are seen to be somewhat higher than in most indoor channels [6], but clearly lower than for the purely outdoor land-mobile channel [7].

Table 2. Summary of statistics of measured multipath characteristics of the WLL channel.

	U	*SU hr*	*SU sh*[1]
N_p 50% CDF	7	9	6
N_p 90% CDF	13	14	11
N_p max	19	21	12
L_{rms} [ns] 50% CDF	150	160	130
L_{rms} [ns] 90% CDF	280	270	170
L_{rms} [ns] max	410	360	180

[1] Due to the small number of data these values should be taken as indicative only.

The Doppler spreads were found to be very low. The maximum measured value of the rms Doppler spread was

0.39 Hz. However, for more detailed Doppler results the separation of the effect of the measurement equipment from the effect of the channel requires further work. Therefore these results are not presented in detail. In any case the results show that the channel is very slowly fading. In most situations the channel will be essentially static over short time periods of the order of several tens of seconds.

C. Long-Term Variation

The long-term variation of the key channel characterising functions and parameters is best presented by plotting the variation of the functions and parameters over the 24 hour period of measurement. As an example, the long-term variations of the average received power, the delay power spectrum (normalized to unity power of the strongest peak), the rms delay spread and the number of paths in the urban environment are shown in Fig. 3, Fig. 4, Fig. 5 and Fig. 6, respectively. In this recording the starting time was 12:08 p.m.

Looking first at the variation of P_{av}, the most distinctive feature of the plot is the decrease in mean value and peak-to-peak variation at approximately 8 hours from the start (about 8 p.m.). First the mean value is about –78 dBm and the peak-to-peak variation mostly about 2 dB. Then soon after 8 p.m. the mean value drops to about –79 dBm and the peak-to-peak variation to about 1 dB.

At the location in question the line of sight to the receiver passes a hotel parking area at short distance in front of the building. Furthermore, the measurement room was situated on the first floor. Thus a possible cause of the change in received power level is a large vehicle, for example a bus, that is parked in front of the measurement location.

The same change is seen also in the delay power spectra. From the beginning of the recording there are some clearly noticeable variations in the reflections between delays of 0.5 µs and 1.0 µs. At 8 p.m. these variations vanish, and for the rest of the recording the delay power spectrum stays essentially fixed. Also, the decrease in P_{av} experienced at 8 p.m. is seen as an increase in the observed power of the weak paths at approximately 1.5 µs and 2.25 µs. As a consequence of this, there is an increase also in the values of L_{rms} and N_p at 8 p.m.

In the example case the peak-to-peak variations for the parameters studied were –76 dBm to –80.5 dBm for the average received power, 0.28 µs to 0.08 µs for the rms delay spread and 16 to 7 for the number of paths. By inspection of the plots it is seen that the variations of the parameters show a white spectral nature; the degree of correlation between consecutive values (i.e. over the sample period of 6 minutes) is in general low.

The results show the same type of behaviour also for the other environments. In the sub-urban small-house environment the results indicate a slightly lower degree of variation. This can be attributed to the lower level of activity in a residential small-house area, as compared to urban and high-rise sub-urban, during day-time. In general, the results show significant variations in the WLL channel characteristics over long time periods, even in a static link with fixed terminal positions.

V. CONCLUSIONS

The measurement results show a high degree of similarity in the multipath characteristics of the WLL channel in urban and sub-urban high-rise environments. The statistics of the rms delay spread show the in 90% of locations the delay spread will be below 280 ns. The maximum measured values of delay spreads for the urban and sub-urban high-rise environments were 410 ns and 360 ns, respectively. For the sub-urban small-house environment the data indicates lower values of delay spread.

The short-term time variation (i.e. fading behaviour) of the WLL channel was characterised by the rms Doppler spread. Even in the worst case, the channel was shown to be very slowly fading. In most situations the channel will be essentially static over short time periods of the order of several tens of seconds. It should be noted however, that the measurements in this work were performed in situations where the movement of people in the measurement rooms was frozen.

The channel variations over long time periods was studied by measurements over 24 hours at 6 minute intervals. The results show significant variations in the WLL channel characteristics over long time periods, even in a static link with fixed terminal positions.

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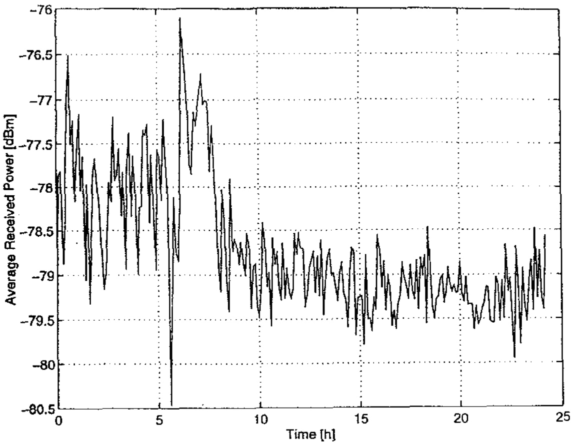

Fig. 3. Example of the long-term variation of the average received power.

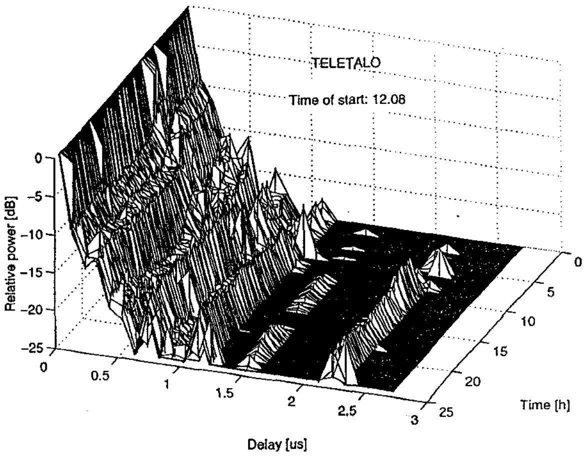

Fig. 4. Example of the long-term variation of the delay power spectrum.

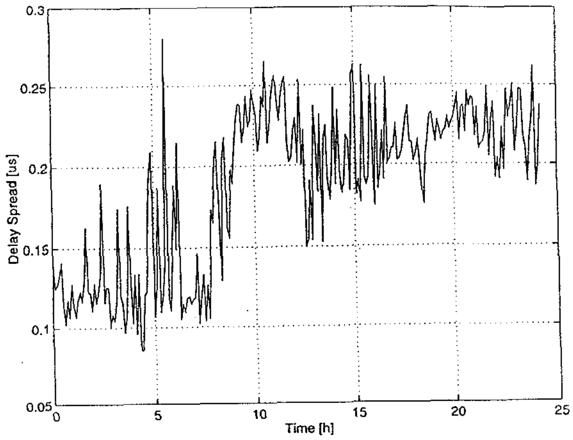

Fig. 5. Example of the long-term variation of the rms delay spread.

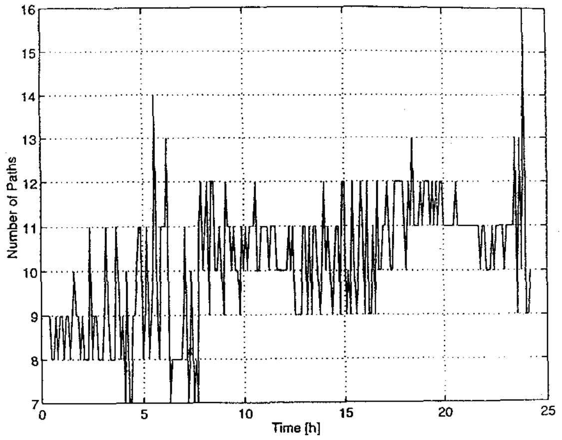

Fig. 6. Example of the long-term variation of the number of paths.