

PROPAGATION CHARACTERISTICS AT 5 GHz IN TYPICAL RADIO-LAN SCENARIOS

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Abstract - In order to characterize the radio channel in typical WLAN scenarios a wideband measurement campaign at 5 GHz has been carried through. Four office and two large open space environments have been investigated. Impulse response shape and fading statistics have been analyzed. Moreover, the Doppler characteristics have been studied. It was found that the impulse responses basically had the shape of one exponentially decaying cluster. The measured Doppler spectra indicates a basically uniform distribution of radiowave direction of arrival. Measured rms delay spreads were in the range 10-100 ns.

I. INTRODUCTION

The prospects for wireless LANs (WLANs) to be a competitive alternative to fixed LANs are generally envisaged to be very good. An increasing activity on the field has been observed over the past years. Two standards at 5 GHz—ETSI HIPER-LAN 2 and IEEE 802.11—are presently under preparation. The success of any of these two standards depends crucially on the accuracy and realism of the underlying propagation modeling.

This paper comprises measurement results and models in typical WLAN scenarios. Indoor wideband measurements, with both omni and directive antennas, have been performed at 5 GHz.

II. MEASUREMENTS

Setup

A network analyzer (NWA) was used to sample the channel at 201 equidistant frequencies around 5 GHz. The bandwidth was between 80 and 200 MHz. The measurements were performed

mainly during night when there were no people in the buildings.

A schematic picture of the measurement system is shown in Fig. 1. A PC was used for data acquisition and instrument control. The output signal from the NWA was amplified with a 31 dB power amplifier (PA). Two different transmit antennas were used—one dipole with 2.0 dBi gain and one patch array antenna with 9.4 dBi gain and horizontal beamwidth of 28°. The latter antenna was mounted on a turntable to measure the channel response in different directions. At the receiver, a 2.0 dBi gain dipole antenna was mounted on a linear positioner to create a virtual array of 1.2-2 m length and with 20-201 elements. All antennas were vertically polarized in the measurements. The received signal was amplified with a 34 dB low noise amplifier. A total of 35 m RF cable, with an attenuation of approximately 1 dB/m, was used.

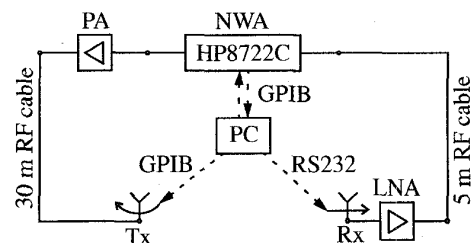


Figure 1. Schematic drawing of the measurement system.

Environments and Scenarios

WLANs are foreseen to be used in almost any type of indoor environment, and in many outdoor environments. Office and large open space environments—regarded as two of the most typical in

WLAN scenarios—were selected for the present measurement campaign.

The measurements were performed in four office buildings (O1-O3 in Gothenburg and O4 in Stockholm), all with floors of reinforced concrete. The inner walls are made of concrete in O1 (Fig. 2), chipboard in O2, and glass and plasterboard in O3 and O4. Three environments (O1, O2 and O4) have the same topology—a corridor with offices at both long sides. In these environments, the transmitter was placed in the corridor and the receiver in one of the rooms, at 14-26 m distance. In O3, the offices are located around an open area instead of a corridor.

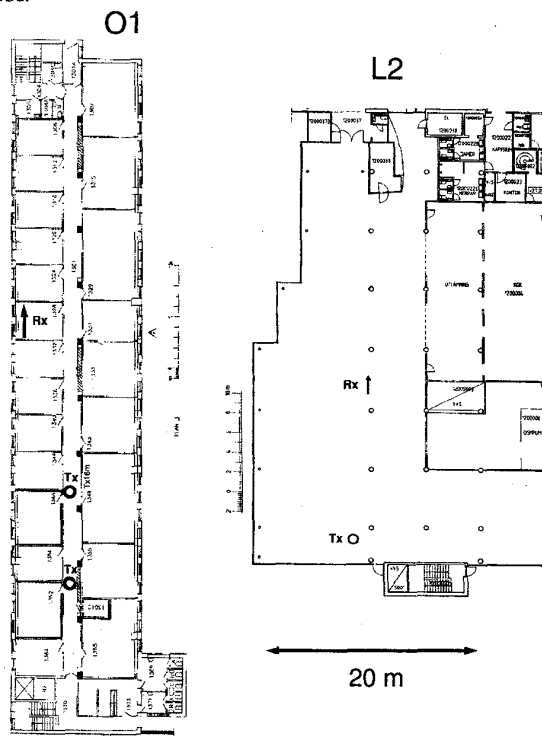


Figure 2. Drawings of the office O1 and the large open space environment L2. Receiver positions are indicated with Rx and arrows. Transmitter positions are indicated with Tx and circles.

Measurements were also performed in two large open space environments (L1 and L2 in Stockholm). The first, L1, is a glass covered pedestrian street (10x104 m) between two 6 storey buildings. Here, the transmitter and receiver were placed at 20 m separation on two bridges between the buildings (Fig. 3). The second, L2, is a staff canteen (30x40 m) with outer walls mainly of metallized glass, inner walls and floor of concrete, and ceiling

of metal (at 3.67 m height) with a suspended ceiling of light material at 2.67 m height (Fig. 2).

The receive antenna height was about 1.2 m in all measurements, and the transmit antenna height about 1 m in O1-O3 and 2 m in O4, L1 and L2.

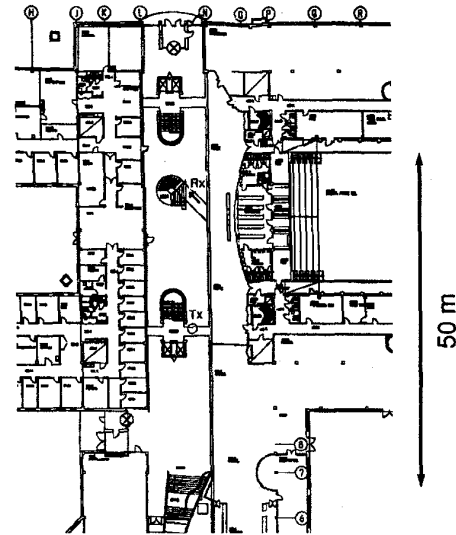


Figure 3. Drawing of the large open space environment L1.

III. MEASUREMENT RESULTS

Complex impulse responses (CIRs) were obtained by inverse discrete Fourier transformation of the measured frequency response data, using Hanning windowing [1] to suppress the side lobes. The results refer to measurements with the dipole transmit antenna, if not explicitly stated that the directive antenna has been used.

Power Delay Profiles

For each location of transmitter and receiver, average power delay profiles were obtained by summing the profiles corresponding to the space points of the virtual array (see Figs. 4 and 8). The profiles have basically an exponentially decaying shape. Some additional spikes can be observed, particularly in line of sight (LOS) conditions for zero excess delay (direct ray).

For each delay time, the corresponding spatial fading was analyzed (from space points in the virtual arrays). Assuming a Ricean distribution, the likelihood for the amplitudes was maximized with respect to the corresponding K factor. It should be

observed that the delay time for an incoming wave depends on the position in the virtual array and the angle of arrival. In order to not underestimate the K factors, the delay time has been compensated according to the angle of arrival with the smallest fading width i.e. the smallest difference between the largest and the smallest amplitude. In Fig. 4 is seen that the estimated K factors generally are small—in fact equal to K factors obtained for simulation data with Rayleigh statistics—except for zero excess delay in LOS conditions (cf. L1). This indicates—using the fact that the K factor means the power ratio between the strongest wave and the rest—that many waves of about the same power are received at each specific delay time. Similar results have been observed in [2].

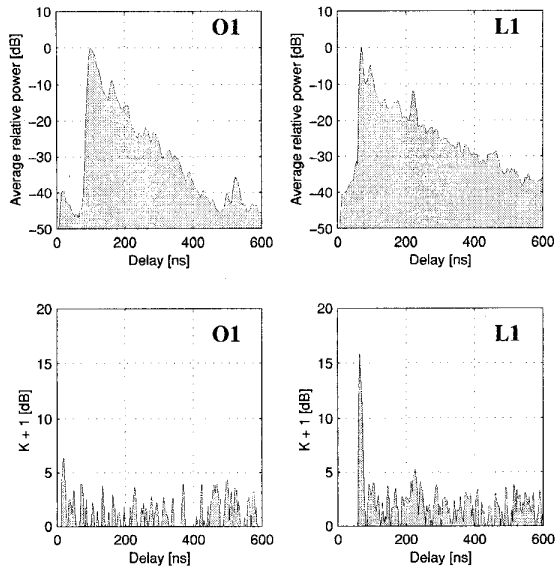


Figure 4. Measured average power delay profiles and the corresponding estimated Ricean K factors as function of delay, from O1 and L1. The measurement bandwidth was 160 MHz and the virtual array consisted of 201 positions on a 2 m section.

Doppler Spectrum

The space points of the virtual arrays correspond to movement of the receiver. The corresponding Doppler spectra have been determined by discrete Fourier transformation of the array data, applying Hanning windowing.

In Fig 5. is shown the normalized Doppler frequency (equal to the cosine of the angle of arrival) spectra for O1 and L1. These spectra are basically quite uniform, particularly in non line of sight

(NLOS) conditions (cf. O1). In LOS conditions there is a spike at zero excess delay and possibly a few more at larger delays corresponding to strong reflections (cf. L1).

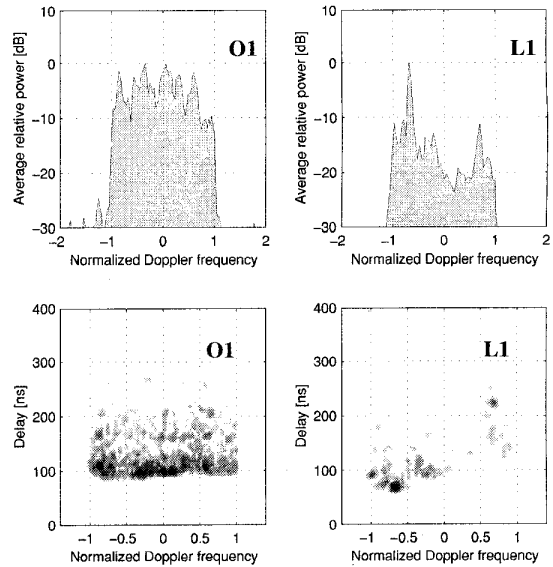


Figure 5. The corresponding Doppler data for impulse responses in Figure 4. In the two lower plots the relative power is indicated in gray scale where black corresponds to the highest power and white to 30 dB lower power.

Delay Spread

For each instantaneous impulse response, the rms delay spread has been calculated. In order to avoid the noise floor, data 30 dB below the peak value was cut away. In the office environments, the

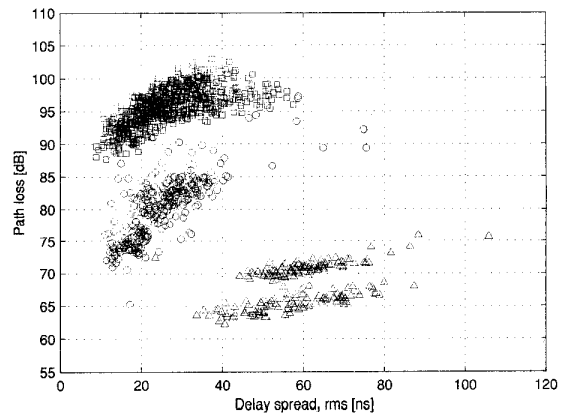


Figure 6. Path loss versus delay spread for instantaneous measured impulse responses. Squares correspond to O1 and O2, circles to O3 and O4, and triangles to L1 and L2.

measured rms delay spreads are between 10 and 60 ns (see Fig. 6). In the large open space environments, substantially larger values, ranging from 35 to 105 ns, are observed. These values are in agreement with those reported from other indoor measurements [3-4].

In a specific environment the delay spread seems to be correlated to path loss. The higher the path loss is, the larger the delay spread becomes.

Directive Antennas

In O1-O3, measurements were performed also with a directive transmit antenna which was rotated 360 degrees in steps of 10 degrees. Concerning fading statistics and shape of power delay profile, the results were very similar to those obtained with the dipole transmit antenna.

A surprising result from the corridor environments is that the difference in received power, between when the dipole antenna is used and when the directive antenna is used (highest power direction) at the transmitter, is exactly proportional to the

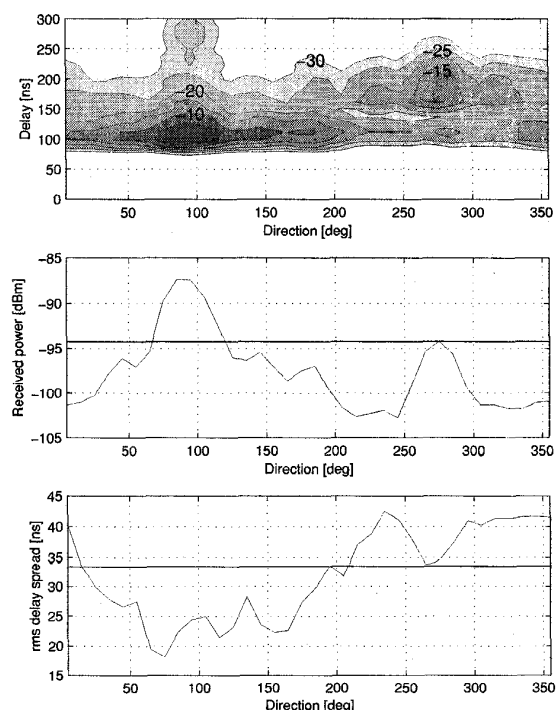


Figure 7. Relative power and delay spread versus transmit antenna direction (using directive antenna). The values obtained with the dipole antenna is indicated with straight lines in the two lower plots

difference in antenna gain (see Fig. 7). One would not expect that a NLOS channel preserves the directivity of the antenna. The explanation is probably that the corridor acts as a leaking wave guide since the highest power is obtained when the antenna points in the direction of the corridor towards the receiver.

Another striking result is that the delay spread, in comparison with omni antenna results, is significantly reduced/(increased) when the transmit antenna points towards/(away from) the receiver.

IV. MODELING

Ray Tracing

The propagation of radio waves is frequently predicted with ray tracing techniques. Commonly two basic propagation mechanisms are modeled. The first, the so-called geometrical optics (GO), describes specular reflection and refraction in plane surfaces between two different homogenous materials. The second is diffraction.

In Fig. 8, the power delay profile and Doppler spectrum from L2 is shown for both simulation data with ray tracing (pure GO, with software package described in [5]), and measurement data. The LOS wave and strong reflections seem to be well described with the simulation data. In the measurement data, however, a clear uniform background of waves in all directions and at all delay times is seen. This uniform background can not be explained by diffraction since corners and edges correspond to distinct directions and delay times. It can, however, be explained assuming that diffuse scattering is a significant process in indoor propagation.

Statistical Models

When the performance of a mobile communication system is evaluated in simulations it is important that the channel models used are statistically realistic, and representative. For this purpose empirical models are more reliable than ray tracing.

The herein presented measurement results indicate that it is possible to make simple and realistic statistical channel models for WLAN scenarios. This has in fact been done according to the following assumptions. It is assumed that the average power

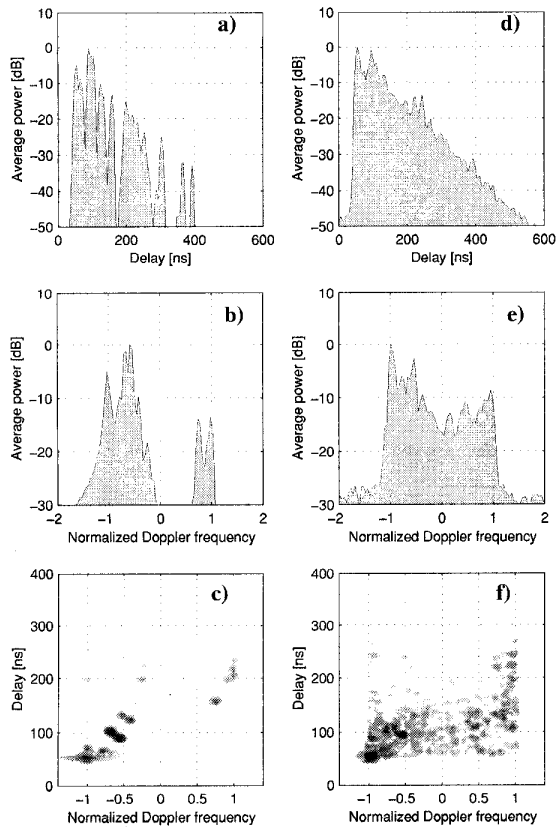


Figure 8. Average power delay profile and Doppler spectra from L2 at 1.8 GHz and 200 MHz bandwidth. Ray tracing simulation data is shown in a), b) and c), and measurement data in d), e) and f).

delay profile has an exponential decay. The spatial variation of impulse response amplitude, at specific delay times, is assumed to follow a Rayleigh distribution. Basically, a uniform distribution in angle of arrival is assumed, implying a classical Doppler spectrum. An additional spike, at zero excess delay and specific Doppler frequency, may occur in LOS conditions. In this case, the amplitude variations at zero excess delay follow Ricean statistics. A set of models of this type was adopted in the ETSI HIPERLAN 2 standardization. Four NLOS models with respectively 50, 100, 150 and 250 ns rms delay spread and 10 ns time resolution were designed. One fifth LOS model, which is the third model with a 10 dB spike at zero excess delay and a K factor of 10, was made.

V. CONCLUSIONS

It has been shown that the radio channel in typical WLAN scenarios can essentially be characterized with a few parameters. The average power delay profiles are basically exponentially decaying, with a spike at zero excess delay in LOS conditions. The spatial fading of impulse response amplitudes, at specific delay times, is essentially Rayleigh distributed, except for the LOS spike which can have a high Ricean K factor. The Doppler spectrum corresponds to a basically uniform distribution of angle of arrival. The range of rms delay spread values is between 10 and 100 ns and typically 20-30 ns in an office environment.

It was found that if the transmitter is placed in a corridor and the receiver in a neighboring room, the dominant radiowave pathway is along the corridor which acts as a leaking wave guide.

A comparison between ray tracing simulations and measurements indicates that diffuse scattering is a significant process in indoor propagation. This motivates efforts to include diffuse scattering in future ray tracing tools.

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