High Efficiency Wireless LAN for Multimedia Home Networks
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Abstract — This paper describes the problems of wireless LAN usage in the user's home with focus on media transmission. Results of channel measurements with respect to fading effects are presented. The resulting link data rates are analyzed. Methods for a transmitter based link adaptation are evaluated to increase the reliability of the physical data transmission.

I. INTRODUCTION
The IEEE 802.11 standard family is a good basis for building wireless A/V-networks in the home environment. With growing success of this technology mutual interference between nodes of the same household but also between nodes of adjacent networks will arise. In such high density networks, off-the-shelf WLAN systems will not be able to provide data rates and latencies required for high quality, real time video transmission.

In this paper we present results of our investigations towards enhancements for self-organizing home AV-networks based on IEEE 802.11. In order to allow an easy introduction to the consumer’s home, we focus on ad-hoc networks without any central station. Characteristics of the transmission channel as well as different concepts for link-adaptation of the OFDM-based physical layers are also presented.

II. MULTIMEDIA HOME NETWORKS WITH WLAN
The IEEE 802.11 standards are in permanent refinement. But from the technical point of view limitations still exist with respect to the MAC protocol and data transmission capabilities due to limitations of the physical layer.

A. Limitations of the standard MAC protocol
The medium access in IEEE 802.11 is realized using a CSMA/CA protocol. The collision avoidance is realized by means of one constant waiting period and an additional random waiting period between successive data packets.

The resulting best-effort like transmission is not well suited for transmitting constant rate A/V-data. Any occurring file transfer will potentially interfere with running media transmissions. The resulting breakdowns of the running program will not be tolerated by the user.

Simulations of this protocol as well as extensions solving the problems have been presented in [1].

B. Data transmission limitations
In many cases data rate fluctuations of an individual link as well as link breakdowns might occur. These effects very often originate from transmission channel properties. So knowledge about the channel’s characteristics in the house is necessary for development of data transmission enhancements.

III. LINK MEASUREMENTS
Recent literature [2],[3] mainly describes measurements in office environments. Comprehensive information for the home environment is rare. Thus we performed measurements of the transmission channel as well as resulting data rates.

A. Channel characteristics
We obtained the channel’s power density distribution in different home scenarios. The measurement set-up consisted of a signal generator emitting band-limited white noise at 2.45 GHz with a bandwidth of 100 MHz. This signal was received using a remotely controlled spectrum analyzer. The reception antenna was automatically positioned to several thousand positions in the house, so that a dense mesh of measurement points was created. Both non-line-of-sight (NLOS) as well as line-of-sight measurements (LOS) were analyzed with respect to attenuation and fading effects.

In this paper we exemplary present the results of a 3 story apartment in a multifamily residence. The measurements exhibit multipath fading depths of up to 40 dB in a 20 MHz channel. For worst case channel selection 50% of the positions have fading depths of more than 10 dB in the LOS case. For the NLOS situations the 50% value is at 12.5 dB. In Fig. 1 the cumulated density functions (CDF) for both LOS and NLOS transmission are depicted.

![Fig. 1. CDF for fading depths at 2.4 GHz in 20 MHz channels.](image)

The attenuation for crossing one ceiling (lightweight construction) is 9 dB and 20 dB for crossing 2 ceilings (1.: lightweight construction / 2.: concrete ceiling with an open stairway).

The power distribution in a room is non-uniform. In the NLOS case there is an averaged 14 dB higher reception power in the middle of the room compared to near-wall positions.
B. Data rates

One consequence of the channel’s characteristic is the resulting link data rate. We obtained these data rates for several short and long distance links in the apartment building. Standard IEEE 802.11g equipment was used here.

In Fig. 2 the CDF of the measured data rates are depicted for data transmission across two ceilings. It can be stated that in 75% of the measurement positions no data transmission is possible using 64-QAM with code rate R=3/4 (54 Mbit/s mode). Using QPSK with R=3/4 (24 Mbit/s mode) offered a data rate of more than 10 Mbit/s in 60% of all positions.

![CDF for measured data rates at different physical layer modes for data transmissions across 2 stories.](image)

Fig. 2. CDF for measured data rates at different physical layer modes for data transmissions across 2 stories.

IV. LINK ADAPTATION

The measurements of the physical transmission channel reveal that an adaptation of the physical link is necessary to overcome the apparent problems. For OFDM based transmissions a variety of transmitter based link adaptation principles is known from the literature [4]-[6]. The results of our channel measurements give advice and potential for applying the following methods.

A. Dynamic frequency selection (DFS)

The typical coherence bandwidth of the channel in the home environment is larger than the WLAN bandwidth. So if carriers are affected by fading the whole transmission can be shifted to another physical channel. In Europe there is the choice for 13 partly overlapping channels with a bandwidth of 20 MHz. For these parameters we identified a potential for increases of more than 20 dB. In any case dynamic frequency selection offers a gain of more than 2 dB.

B. Antenna diversity

The theoretical coherence length is usually 40% of the wavelength [2]. In our measurements at 2.4 GHz we analyzed the autocovariance of the channel’s amplitude for spatial shifts. For horizontal space shifts the autocovariance value falls below 0.5 for distances between 16 mm and 44 mm. This value is dependent on the direction of incidence. For vertical shifts the autocovariance value of 0.5 is reached for distances smaller than 40 mm.

From these investigations it becomes obvious that diversity reception with antenna spacing much smaller than the wavelength results in further gain. Exemplary values of the measurements is a maximum additional gain after DFS of 8 dB for 30 mm antenna spacing and up to 12 dB gain for 50 mm antenna spacing.

C. Subcarrier power and modulation adaptation

Investigations and simulations in our laboratories have shown that an equalization of the channel at the transmitter side further reduces the error rate of the transmission. Sometimes leaving out individual carriers results in an even higher improvements.

Changing the modulation on a subcarrier basis also offers further potential for improving the link quality, but is not compliant to current standards.

D. Transmit power adaptation

For short distances between two devices much less power than allowed is required to achieve a reliable transmission. As a result the overall spectral efficiency can be increased.

All presented methods for link adaptation show high potential for network improvements. Via in-band communication – probably using ACK-messages – but also via external networks the nodes may exchange information about the channel state. This information should be used to select an adequate channel and a carrier based pre-equalization. Furthermore antenna diversity will help to enhance the performance.

V. CONCLUSION

IEEE 802.11 and its extensions are good candidates for media transmissions in the home. Problems exist with respect to the MAC protocol and the reliability of data transmissions due to channel characteristics. The channel’s influence on the transmission can be reduced using methods of link adaptation. A high SNR gain is possible by means of dynamic frequency selection, antenna diversity, and pre-equalization. These approaches will increase the individual link data rate as well as the overall throughput. So a reliable distribution of A/V data will be possible in the home environment.

REFERENCES


