IEEE 802.11B WLAN CAPACITY AND PERFORMANCE MEASUREMENTS IN CHANNEL WITH LARGE DELAY SPREADS

Aki Silvennoinen
Communications Laboratory
Helsinki University of Technology
aki.silvennoinen@hut.fi

ABSTRACT

IEEE 802.11x wireless local area network (WLAN) systems are quite popular in office indoor environment and urban outdoor environments but suburban or rural environments can still offer unexploited possibilities to certain user groups. The radio channels of these environments have large delay spreads that pose limitations for IEEE 802.11b signal usage. In this study IEEE 802.11b WLAN capacity and performance is evaluated based on measurements of two different commercial vendors' WLAN products. Throughput and packet error ratio is studied as a function of excess delay. The radio channels are simulated using radio channel simulator. We find that IEEE 802.11b WLAN systems' capacity and performance decreases as excess delay increases, and the systems cannot efficiently operate in channels where the excess delays are larger than symbol duration.

INTRODUCTION

IEEE 802.11x wireless local area network (WLAN) systems provide an easy and cost-effective way to exploit broadband wireless communication in different licence-free frequency bands. These systems have become quite popular especially in office indoor and urban outdoor environments. Suburban and rural environments are largely neglected in WLAN usage, especially with 802.11x family products. However, these environments provide unexploited possibilities to certain user groups. Rural or suburban environments pose a different kind of propagation environment, which effect to the existing WLAN system is still unexplored. In these environments there are typically fewer reflecting surfaces in the propagation path than in an office of urban environment. Therefore, the radio channels have typically large delay spread and only few multipath components.

In this study the IEEE 802.11b WLAN system behaviour in such a channel is evaluated by measuring system capacity and performance of two commercial vendors' products. System throughput and packet error ratio is measured as a function of excess delay using a simulated radio channel. The IEEE 802.11b signal theoretically limits the receiver's excess delay tolerance to the duration of one symbol. We find that the IEEE 802.11b WLAN systems capacity and performance decrease the as excess delay of the radio channel increases, and that systems cannot efficiently operate in channels where the excess delays are larger than symbol duration.

IEEE 802.11B IMPLEMENTATION

The IEEE 802.11b uses direct sequence spread spectrum (DSSS) modulation where the spectrum is spread intentionally by increasing the modulation rate. In the original IEEE 802.11 the transmitted data bit sequence is combined with a 11-bit Barker code chip sequence. The entire Barker word is used as a chipping sequence to encode each bit. The Barker code offers good autocorrelation properties; the autocorrelation function at the receiver operates as expected in a wide variety of environments and is relatively tolerant to multipath delay spreads. The achieved processing gain is equal to 10.4 dB. Different transfer rates (1 and 2 Mbit/s) are achieved by using different modulation methods. The basic symbol rate is 1 Mbit/s, which corresponds to the symbol duration of 1 µs. At a transfer rate of 1 Mbit/s, DBPSK modulation is used, while the use of DQPSK modulation doubles the transfer rate to 2 Mbit/s [1]. The higher bit rates of IEEE 802.11b are achieved by using complementary code keying (CCK) and increasing symbol rate to 1.375 Mbit/s, which corresponds to a symbol duration of 727 ns. CCK modulation is used for bit rates of 5.5 and 11 Mbit/s [2].

In the DSSS systems, symbols are sent one after another, and no guard period is included between symbols. As a result, all multipath components regardless of their delays introduce intersymbol interference (ISI) at the receiver. The usage of advanced countermeasures, like adaptive equalizers or a RAKE receiver structure, can compensate ISI to some point. However, the symbol duration is an important factor affecting system performance, since excess delays larger than the symbol duration in the channel cause the symbol energy to spread over multiple symbols and tolerance to ISI is even more reduced. In addition, the receiver implementation is left open in the IEEE standard and multiple solutions are probably available in the market.

MEASUREMENT SETUP

In this study the IEEE 802.11b WLAN behaviour is evaluated in a channel that has a large delay spread. The evaluation is based on laboratory measurements of two different vendors' products. The radio channel is simulated, and throughput and packet error ratio (PER) is measured while increasing the excess delay of the channel. The radio channels are simulated using a PropSim+ radio channel simulator by Elektrobit Group Plc.

The measurement setup consists of two WLAN transceivers, the PropSim+ radio channel simulator, RF circulator, RF power splitter, and isolators, attenuators and cables. The measurements are one-way; the data is transmitted to one direction only. Also, the radio channel simulator is used only in this direction. The other direction is used for packet acknowledgements, which are sent in a constant channel. Attenuators are used to attenuate the signal properly to achieve received signal strengths of ca. -60 dBm in both directions, and a signal-to-noise ratio (SNR) above +40 dB. Isolators and the RF circulator are used to prevent circling of the signal in the circuit. The measurement setup is shown in Figure 1.

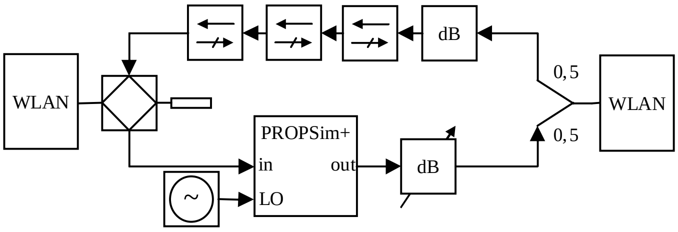

Figure 1 Measurement setup

The radio channels used for these measurements are selected carefully to ensure that only the desired effect, i.e. the effect of the excess delay increase, is measured. A non-varying channel model is selected to minimise channel estimation failures due to a fading channel. For simplicity, a 2-tap model is selected, so the receiver only needs to process two components, the main and the delayed component. Also for simplicity, the amplitudes of the taps are selected to be equal (relative power of 0 dB) and the phase shifts between the taps are set to zero. The impulse response of the radio channel is of the form

$$\begin{aligned} h(\tau) &= a_1 e^{j\phi_1}\delta(\tau-\tau_1) + a_2 e^{j\phi_2}\delta(\tau-\tau_2) \\ &= \delta(\tau) + \delta(\tau-\tau_2) \end{aligned}, \qquad (1)$$

where a_n is the amplitude, ϕ_n is the phase and τ_n is the excess delay of the nth tap. The frequency response of the channel is

$$\begin{aligned} H(f) &= a_1 e^{j\phi_1} e^{-j2\pi f\tau_1} + a_2 e^{j\phi_2} e^{-j2\pi f\tau_2} \\ &= 1 + e^{-j2\pi f\tau_2} \end{aligned}. \qquad (2)$$

The frequency response of the channel has a variable number of very deep notches within the system bandwidth, depending on the excess delay value τ_2. However, since the IEEE 802.11b is a DSSS system, the nonlinearity of the correlation process decreases the effect of these notches.

In the measurements, the first tap has no delay and the excess delay of the second tap is increased from 0 ns to 1 µs in steps of 25 ns or its multiples. Throughput and PER are measured for each channel using Iperf v.1.7.0 freeware, a software tool to generate and measure TCP or UDP transmission bandwidth performance. In this study, UDP packets of 1470 bytes are used. The measurement time is selected to be 150 seconds. The IEEE 802.11b RTS/CTS option is not used. Products two different vendors' are used as a receiver; Buffalo's WLI-PCI-G54 PCI-card (IEEE 802.11b/g), and Proxim's Orinoco Classic Gold PC Card (IEEE 802.11b). Another Buffalo's WLI-PCI-G54 PCI-card is used as the transmitter. Buffalo cards are run in Windows 2000, and Orinoco card in Linux.

MEASUREMENT RESULTS

The measurements are conducted over all transfer modes of IEEE 802.11b; bit rates of 1 Mbit/s (BPSK modulation), 2 Mbit/s (QPSK), 5.5 Mbit/s (CCK) and 11 Mbit/s (CCK).

Receiver: Buffalo WLI-PCI-G54

The results of the measurements when the Buffalo WLI-PCI-G54 card was used as a receiver for different bit rates are shown in Figure 2 to Figure 5. In general, the results show that throughput decreases and PER increases as the excess delay of the channel increases, as expected. As the excess delay of the channel approaches the symbol duration (727 ns or 1 µs), the system capacity and performance decreases substantially, and eventually as the excess delay increases to more than the symbol duration, the system cannot operate anymore.

Receiver: Orinoco Classic Gold PC Card

The results of the measurements when the Orinoco Classic Gold PC Card was used as a receiver for different bit rates are shown in Figure 6 to Figure 9. In general, the results show also in this case that throughput decreases and PER increases as the excess delay of the channel increases. However, the system capacity and performance degradation is more straightforward compared to the preceding case. Even a slight increase of excess delay decreases the system capacity and performance substantially, and at the latest as the excess delay of the channel approaches the symbol duration (727 ns or 1 µs), the PER increases to 100 %, and the system cannot operate anymore. However, as can be seen from Figure 9, at the bit rate of 1 Mbit/s the system starts to operate again as the excess delay is increased to more than 1 µs. This behavior was observed only in a few measurements.

DISCUSSION OF THE RESULTS

In general the measurement results follow the interpretations made in part II. As the excess delay increases the system performance and capacity decreases, and as the excess delay of the channel approaches the symbol duration the system operation becomes very difficult or even impossible.

From the measurements it can be seen that the Buffalo WLAN terminal is clearly more tolerant to large excess delays than the Orinoco WLAN terminal at higher bit rates. For bit rates of 5.5 and 11 Mbit/s, the Buffalo WLAN terminal remains operational while the excess delays remain smaller than 600 ns, if a boundary of 1 % PER is used. For the Orinoco WLAN terminal the system can only operate as the excess delay is less than 100 ns for 11 Mbit/s bit rate, and approximately 400 ns for 5.5 Mbit/s bit rate.

At lower bit rates the Orinoco WLAN terminal is more tolerant, but the difference between the terminals is much smaller. For a bit rate of 2 Mbit/s the operation limit is at an excess delay of 700 ns for the Buffalo WLAN terminal, and at 800 ns for the Orinoco WLAN terminal. For the 1 Mbit/s bit rate, the limit is as at 800 ns, and 775 ns, respectively.

A few interesting observations can be made from the measurements. Both terminals have serious problems with delay components of 800 ns for every bit rate. At the 1 Mbit/s bit rate the performance increases back to normal level as the excess delay increases even further.

The behavior of the Orinoco WLAN terminal at a bit rate of 1 Mbit/s with an excess delay of over 1 µs can be explained as follows. The correlation result of the Barker code in that situation is such that the receiver is once again able to lock on to the main propagation component. This result indicates that the receiver implementation cannot be based on the RAKE processing, since the second finger of the RAKE receiver would lock on to the preceding symbol and is thus incapable of tolerating such large delay components. As the receiver locks on to another symbol, the combining of the fingers would result in high error ratio. This behavior at excess delays of over 1 µs could not be repeated with any other bit rate or with the Buffalo WLAN terminal.

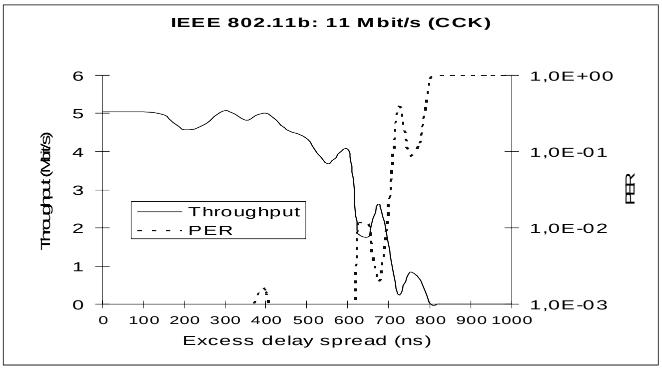

Figure 2 Results of Buffalo receiver, 11 Mbit/s bit rate

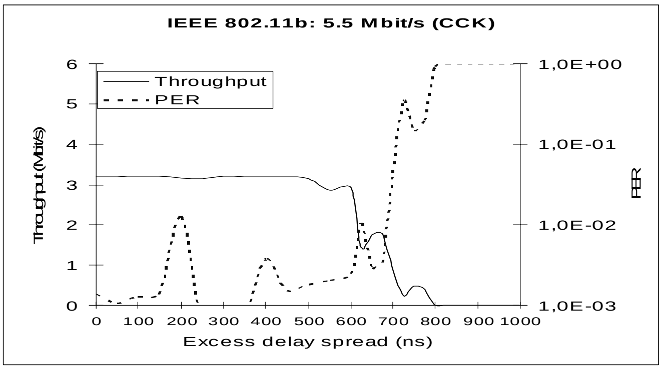

Figure 3 Results of Buffalo receiver, 5.5 Mbit/s bit rate

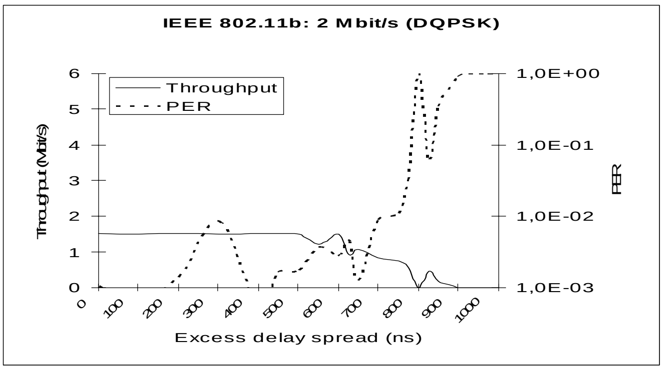

Figure 4 Results of Buffalo receiver, 2 Mbit/s bit rate

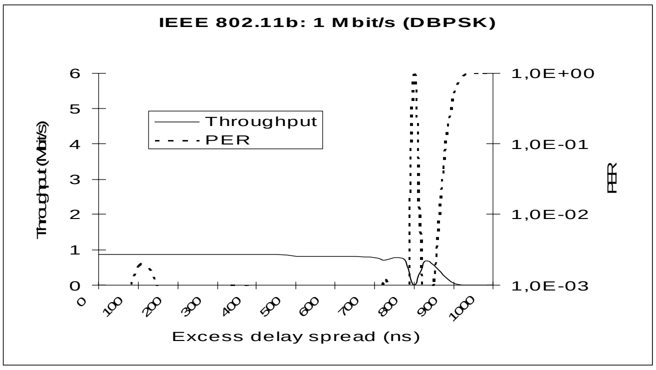

Figure 5 Results of Buffalo receiver, 1 Mbit/s bit rate

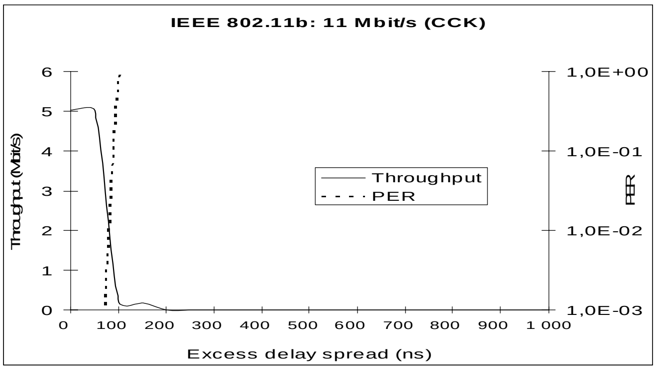

Figure 6 Results of Orinoco receiver, 11 Mbit/s bit rate

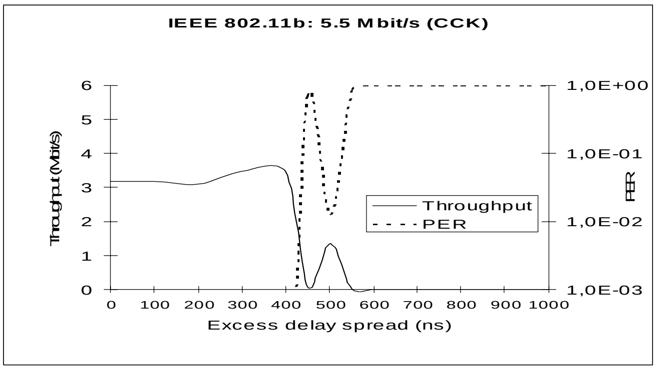

Figure 7 Results of Orinoco receiver, 5.5 Mbit/s bit rate

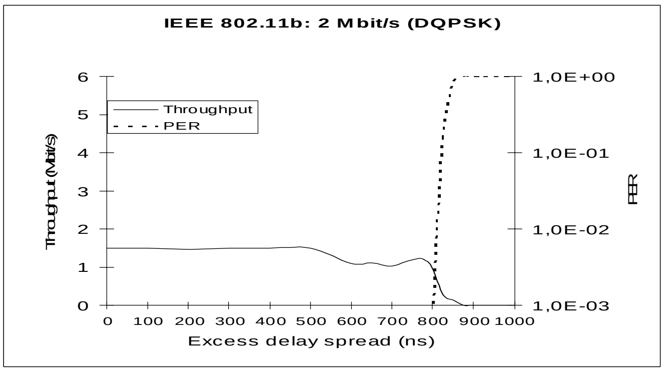

Figure 8 Results of Orinoco receiver, 2 Mbit/s bit rate

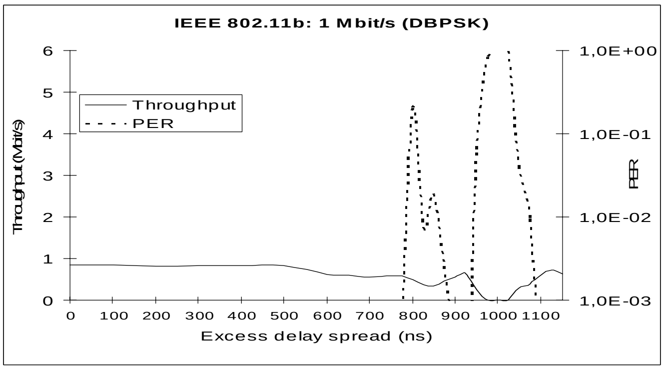

Figure 9 Results of Orinoco receiver, 1 Mbit/s bit rate

A delay component of 600 ns corresponds to a radio wave propagation of 180 m, i.e. a reflection from 90 m away, and a delay component of 800 ns correspond a reflection from 120 m away, respectively. Such a reflection can easily exist in outdoor environments, especially in suburban or rural environments. On the other hand, components with much larger delays can also exist in such an environment. For example, the excess delay of the UMTS vehicular model is 2.51 µs for the small delay spread model or 20 µs for the large delay spread model [3].

Summarizing the results of the measurements: the IEEE 802.11b WLAN system capacity and performance decreases as the excess delay of the radio channel increases and this indicates that systems cannot efficiently operate in channels where the excess delays are larger than the symbol duration. This result also raises question, whether this IEEE 802.11b systems can be effectively used in suburban and rural environments.

CONCLUSIONS

In this paper we studied the capacity and performance of a IEEE 802.11b WLAN system based on measurements of two different vendors' WLAN terminals in channels with large delay spreads. The measurements were conducted using a PropSim+ radio channel simulator.

The measurements indicate that the IEEE 802.11b WLAN system capacity and performance decreases as the excess delay of the radio channel increases and the system cannot efficiently operate in channels where the excess delays are larger than the symbol duration.

REFERENCES

[1] IEEE 802.11 Std, "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications", ISO/IEC 8802-11, IEEE, 512 pp., 1999

[2] IEEE 802.11b Std, "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Higher-Speed Physical Layer Extension in the 2.4 GHz Band" ISO/IEC 7498-1, IEEE, 96 pp. 1999

[3] ITU-R Recommendation M.1225, "Guidelines for valuation of radio transmission technologies for IMT-2000", ITU-R, 60 pp., 1997

HOMEWORK

Calculate attenuator and isolator values (in dB) in the measurement setup (Figure 1) to achieve a proper setup. RX power levels should approximately -60 dBm. TX power of the WLAN terminal is -5 dBm. The circulator attenuation is 10 dB in the conducting direction and 40 dB in the blocking direction. PropSim+ powerlevels are -15 dBm (in) and -30 dBm (out). Ensure that circling is prevented. RX sensitivity is approximately -90 dBm.