The Effect of Bluetooth Transmission on the Access Point Coverage of IEEE 802.11g

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ABSTRACT

WLANs based on the IEEE 802.11g standard use the same 2.4 GHz ISM frequency band as Bluetooth (BT). In this paper, the effect of BT transmission on the Access Point (AP) coverage of IEEE 802.11g at a data rate of 24 Mb/s is investigated as a function of the separation between the WLAN station and BT device. The use of symbol erasures at the physical layer is investigated as a means of reducing the degradation caused by BT interference. Results for Packet Error Rate (PER) and AP coverage are presented comparing the system performance both with and without symbol erasures. The results show that the use of symbol erasures substantially improves the coverage performance.

1. INTRODUCTION

Wireless LANs have achieved enormous growth because they allow users to gain access to network services without having to be connected by cable to the backbone infrastructure. Two wireless systems that have experienced wide popularity are the IEEE 802.11b standard for wireless local area networks (WLANs) and Bluetooth. Both of these systems operate in the 2.4 GHz Industrial Scientific and Medical (ISM) band which extends from 2.4 to 2.483 GHz. IEEE 802.11b is designed to achieve operating distances between the AP and wireless STA of up to 100m depending on the data rate used. The core elements of an 11b WLAN, referred to as the Basic Service Set (BSS), consist of several wireless STAs and one fixed access point (AP). The AP provides connectivity to the fixed backbone network [1].

Bluetooth (BT) provides wireless interconnection between devices up to a range of 10m. The basic architectural unit of the BT system is the piconet which is composed of a master device and up to seven active slave devices. These slaves are allowed to communicate with the master only. The data rate of BT is equal to 1Mb/s and a frequency hopping spread spectrum (FHSS) modulation scheme is used at the physical layer (PHY). Each master chooses a different hopping sequence so that piconets can operate in the same area without excessive interference. The Time Division Duplex (TDD) technique is used to transmit and receive data in a piconet, where each packet transmitted in a slot corresponds to the minimum dwell time. The master starts its transmission in even numbered slots while a slave starts its transmission in odd numbered slots [1, 2].

The new IEEE 802.11g standard, which will replace 11b, operates at data rates of 6, 9, 12, 18, 24, 36, 48 and 54 Mbps using coded OFDM in the same 2.4 GHz frequency band. The OFDM signal occupies approximately 16 MHz of the 20 MHz channel bandwidth and up to three non-overlapping channels are used simultaneously in the ISM band. BT hops over 79, 1 MHz wide channel across the ISM band with a nominal hop rate of 1600 hops/s. Hence, it is clear that interference between IEEE 802.11g and BT is unavoidable when both technologies transmit simultaneously. In the presence of BT interference, an IEEE 802.11g AP may not be able to achieve sufficient coverage. In this paper, the effect of BT interference on the AP coverage of IEEE 802.11g at a data rate of 24 Mb/s is investigated. Also, the impact of symbol erasures on coverage as a means of improving system performance is investigated

2. OFDM

In this section, the basic principles of coded OFDM as used in the 802.11g standard are explained and discussed briefly. Coded OFDM will be deployed in the 2.4 GHz frequency band as the mandatory portion of the IEEE 802.11g standard. The standard specifies mandatory data rates of 6, 12 and 24 Mb/s and optional data rates of 9, 18, 36, 48 and 54 Mb/s. The OFDM signal consists of a sum of sub-carriers that are modulated either by BPSK, QPSK, 16QAM or 64QAM depending on the data rate used. If d_i denotes the (complex) modulation symbols, N_s the number of sub-carriers, T the symbol duration and f_c the carrier frequency, then equation (1) gives an expression for an OFDM symbol starting at $t = t_s$ [4].

$$\begin{aligned} s(t) &= \mathrm{Re}\left\{ \sum_{i=-\frac{N_s}{2}}^{\frac{N_s}{2}-1} d_{i+N_s/2} \exp\left(j2\pi \left(f_c - \frac{i+0.5}{T} \right)(t - t_s) \right) \right\}, \qquad t_s \le t \le t_s + T \\ s(t) &= 0, \quad t < t_s \text{ and } t > t_s + T \end{aligned} \tag{1}$$

In practice, the OFDM symbols can be generated efficiently using the Inverse Fast Fourier Transform (IFFT), and at the receiver the Fast Fourier Transform (FFT) can be used to convert the received OFDM signal into the frequency domain before demodulation and decoding. The system uses 52 sub-carriers, 48 for data and 4 pilot carriers for synchronisation. The 48 data sub-carriers are modulated using BPSK for data rate of 6 and 9 Mb/s, QPSK for data rates of 12 and 18 Mb/s, 16QAM for 24 and 36 Mb/s and 64QAM for 48 and 54 Mb/s. Forward error correction coding using the rate ½ binary convolution code [133,171] is used. The code is punctured to achieve coding rates of 2/3 and ¾. Code rate ¾ is used with data rates 9, 18, 36 and 54 Mb/s, the code rate 2/3 is used with data rate 48 Mb/s while the code rate ½ is used with the mandatory data rates.

3. SYMBOL ERASURES

When the BT signal hops into the 802.11g signal bandwidth it causes narrow band interference affecting a small number of the OFDM signal sub-carriers. The signal-to-interference ratio (SIR) at a given sub-carrier is determined by taking the ratio of the power of the OFDM symbol to the power of the BT signal within the bandwidth corresponding to the sub-carrier. Data symbols with low SIR values are removed by inserting erasures i.e. setting the complex symbol value to zero. Figure 1 illustrates the process of inserting symbol erasures for the case when the OFDM sub-carriers are modulated using a 16-QAM format. In Figure 1, the carrier frequency of the BT signal is shown located at approximately the 33rd sub-carrier of the OFDM signal.

4. INTERFERENCE SCENARIO AND RESULTS

The proximity of a BT device to a wireless STA substantially affects the amount of interference experienced by the latter. Even though an AP transmits with a higher power than a BT device (20 dBm versus 0 dBm respectively), the AP signal power decreases rapidly with range due to path loss effects. Therefore, at the remote STA the received power from a close BT device can exceed the received power from the AP. Figure 2 shows the geographical layout of the interference scenario investigated. The path loss model used for this scenario is given in equation (2) [5], where λ = 0.1224 m is the free space wavelength at 2.4GHz.

$$L_p(x) = \begin{cases} 20\log(4\pi x/\lambda) & \text{for} \quad x \le 8 \text{ m} \\ 33\log(x/8) + 58.3 & \text{for} \quad x \le 8 \text{ m} \end{cases} \tag{2}$$

The noise floor of the STA receiver is given by equation (3), where B_{OFDM} = 20 MHz is the OFDM channel bandwidth and N_F = 13 dB is the noise figure of the STA receiver.

$$\text{Noise floor} = -174 + 10\log(B_{OFDM}) + N_F = -88.98 \text{ dBm} \tag{3}$$

To evaluate the AP coverage taking into account the BT interference effect, the minimum SIR to achieve a target PER of 1% is required, where 1% PER defines the QoS operating point for non-real time data traffic. The minimum SIR requirement also depends on the number of erasures used to excise the BT interference, as illustrated in Figure 3. The PER curves in Figure 3 also indicate that the target PER of 1% is always achievable if an E_b/N_o > 30 dB is available. Then the AP coverage as a function of distance d (the distance between the STA and BT device) can be calculated as follows:

1. Calculate the BT signal power at the STA with d as parameter, where $L_P(d)$ is given by equation (2);

$$P_{bt} = 0 - L_P(d) \quad \text{dB} \tag{4}$$

2. Based on the minimum SIR requirement from Figure 3, calculate the corresponding received signal power at the STA from the AP;

$$SIR_{\min} = P_{rx} - P_{bt} \quad \text{dB} \tag{5}$$

$$P_{rx} = SIR_{\min} + P_{bt} \quad \text{dBm} \tag{6}$$

3. Determine the distance D from the AP to the STA for received power P_{rx}, then from equation (2) we can write D as shown in equation (8).

$$P_{rx} = 20 - L_P(D) \quad \text{dBm} \tag{7}$$

$$D = \begin{cases} (\lambda / 4\pi) \times 10^{(20-P_{rtx})/20} & for \quad D \le 8 \text{ m} \\ 8 \times 10^{(20-P_{rtx}-58.3)/33} & for \quad D > 8 \text{ m} \end{cases} \tag{8}$$

Figure 4 shows graphs of D vs. d for the data rate 24 Mb/s with the number of erasures as a parameter. Curves are shown for 0, 5 and 9 erasures. When no erasures are used the maximum coverage range of 28 m can only be achieved if the STA-BT distance d is ≥ 20 m. However, the maximum coverage range is achieved for $d \ge 4$ m and $d \ge 2.5$ m when 5 and 9 erasures are used, respectively. The results demonstrate that erasing the BT interference provides an effective means of improving the WLAN coverage performance.

5. CONCLUSION

In this paper a study into the impact of BT interference on the PER and coverage performance of the new IEEE 802.11g WLAN standard has been carried out. The study focused on the 24 Mb/s data rate and used the number of symbol erasures as a parameter. The results showed that 802.11g was inherently sensitive to BT interference for STA-BT separations below 20 m. However, this sensitivity was substantially reduced when symbol erasures are used, making the 802.11g more robust. It was found that using more than 9 erasures did offer further improvements. The coverage performance of 802.11g at other data rates is the subject of further investigation by the authors.

6. REFERNCES

1. Carla F. Chiasserini, Ramesh R. Rao "Performance of IEEE 802.11 WLANs in a Bluetooth Environment" web-based publications at URL: http://www.tlc networks.polito.it/carla/papers/ieee_wcnc00_2.pdf.
2. Andrew S. Tanenbaum "Computer Networks" ,4th ed, Prentice Hall PTR ,USA,2003
3. Bluetooth SIG, "Specification of the Bluetooth System, Ver. 1.1B," **http://www.bluetooth.com**, February 2001
4. R. Van Nee and R. Prasad, *OFDM for wireless multimedia communications*, 1st ed., Artech House, London, UK 2000
5. N. Golmie, "Bluetooth and 802.11 Interference: Simulation Model and System Results," IEEE 802.15-01/195r0, April 2001

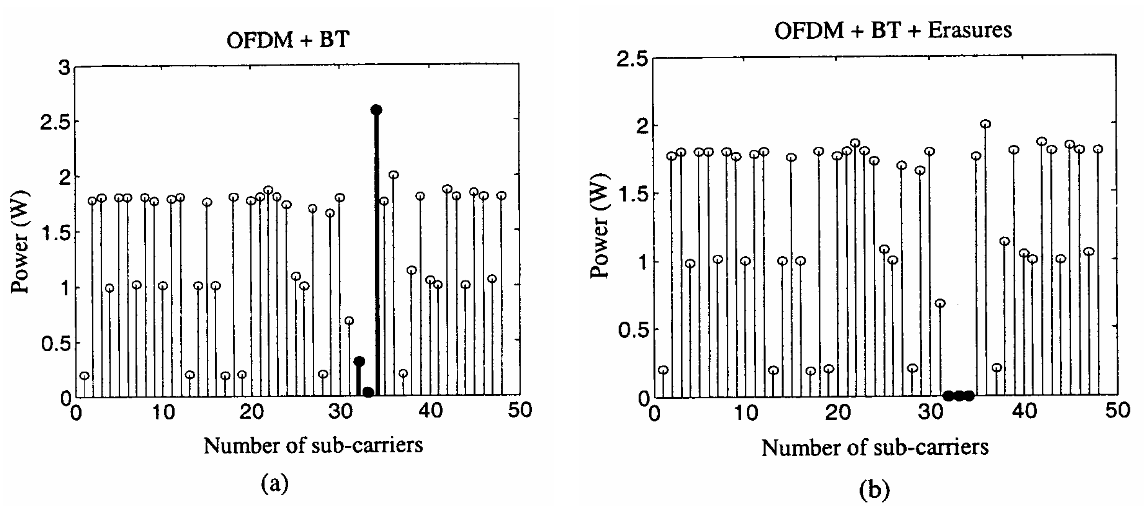

Fig.1 16QAM OFDM + BT: (a) without erasures, (b) with 3 erasures

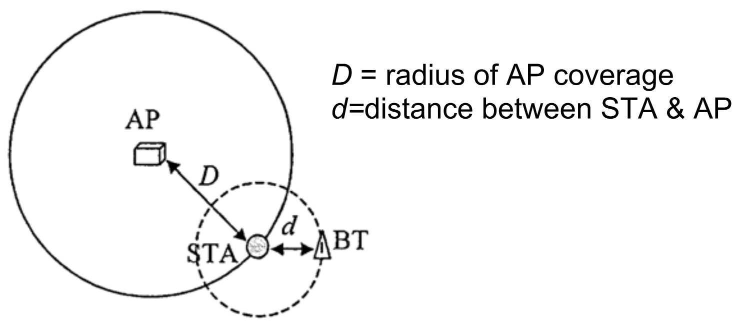

Fig .2 Interference scenario

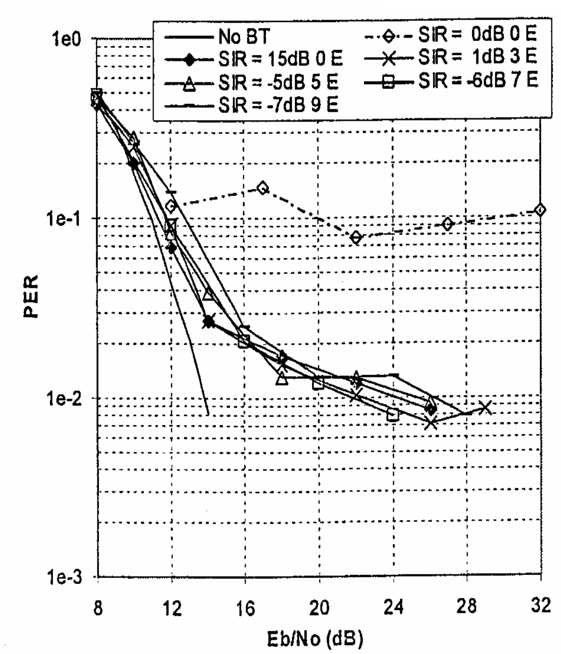

Fig.3: Simulated 802.11g minimum SIR requirements for 1% PER at 24 Mb/s, 100 byte packets, 100 ns *rms* delay spread multipath channel

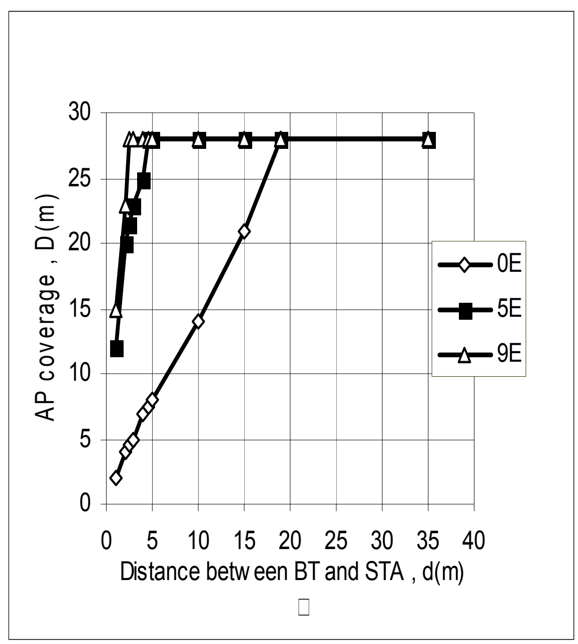

Fig.4: Plots of D vs. d at 24 Mb/s with 0, 5 & 9 Erasures (E)