Co-existence of CSMA/CA and Bluetooth

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***Abstract*— In this paper, we address the issue of co-existence of Bluetooth (BT) and Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA)-based Wireless Local Area Networks (WLANs) in the license free 2.4 GHz band. Specifically, the probabilistic treatment presented in the following investigates the effect of the slotted p-persistent CSMA/CA system on a co-existing BT piconet. A closed-form expression for packet error probability (PEP) in BT as a function of CSMA/CA parameters such as the persistence probability, probability of packet generation and the number of users is derived. The analytical model entails different BT packet types, frequency hopping guard time, and different traffic models in the BT piconet.**

***Index Terms*— WLAN, Bluetooth, Interference, CSMA/CA.**

I. Introduction

The increasingly mobile lifestyle has paved the way for greater utilization of the license-free 2.4 GHz Industrial, Scientific and Medical (ISM) frequency band by a plethora of heterogenous wireless communication devices. Bluetooth (BT) based Wireless Personal Area Networks (WPANs) and IEEE 802.11/802.11b/802.11g Wireless Local Area Networks (WLANs) are two technologies that share the same ISM band, and are being used and deployed together extensively in a large number of countries around the world. Although BT and IEEE 802.11 have a natural partition in the context of services they support, the two technologies can be adopted to provide complementary wireless solutions and services. However, sharing of the ISM band by both systems comes at a price of mutual interference, thereby, the co-existence issue needs to be addressed before the two systems can be efficiently and optimally used together.

The quantification of BT and IEEE 802.11 co-existence in the ISM band is an area of intense research. Several studies have been proposed in the literature, encompassing both the analytical and empirical aspects of the problem. Generally, the research presented in [1]–[9] mostly relies on simulation frameworks or measured experimental results to study the co-existence between the two wireless systems. In [1], simulation results are presented at bit level, highlighting the effect of IEEE 802.11b on BT. The authors present results from a co-existence testbed in [2], [3], where the main aim is to validate the simulation models using the measurements from a real life testbed. The BT packet error probability due to IEEE 802.11b interference is given in [4] using a very simple physical layer analytical model. The work presented in [5] and [6] present a simulation environment for modelling IEEE 802.11 and BT interference based on detailed Physical (PHY) Layer and Medium Access Control (MAC) Layer models. Punnoose *et al.* [8] relies on measurement results to evaluate the performance of an interfered BT link. In [9], the effect of mutual interference on both the BT and IEEE 802.11b links is investigated, and measurements are also taken to validate the simulation results. Other papers, e.g., [10], [11], propose co-existence mechanisms using different traffic scheduling techniques that mitigate interference between BT and IEEE 802.11b WLANs. The work by Howitt [12] examines analytically the impact an 802.11b network will have on BT performance. The approach is based on empirical results to develop the analytical model under varying interference scenarios. In [13], Howitt gives a closed-form solution for the probability of packet collision, using a lognormal shadowing radio propagation model and considering adjacent band interference. An integrated co-existence analytical model is given in [14], entailing PHY and MAC aspects. However, the authors focus on a more combined approach and do not incorporate parameters such as BT frequency hopping guard time, which has a serious effect on the packet error rate.

The aforementioned studies investigate the effect of WLAN and BT co-existence either via analytical models or through simulations. No analytical study has been conducted investigating the co-existence issue integrating the IEEE 802.11's channel access mechanism, i.e., Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA), and its associated parameters. Hence, the aim of this paper is to present a MAC-based analytical methodology studying the impact of IEEE 802.11x-based WLAN on a co-existing BT piconet, by presenting a probabilistic treatment of WLAN's channel access. We consider the slotted p-persistent CSMA/CA channel access protocol and formulate the packet error probability in BT as a function of different CSMA/CA parameters. We take different BT packet types into account, and also include the frequency hopping guard time. We evaluate throughput in the BT piconet under varying traffic load conditions as a function of WLAN parameters such as the number of users, the probability of packet generation and packet transmission, respectively. The analysis presented is highly generic and can easily be tailored for any co-existent CSMA/CA and frequency hopping spread spectrum (FHSS) wireless systems. Furthermore, these results should encourage further investigations on more realistic flavors of CSMA/CA MAC, such as the Distributed Coordination Function (DCF) defined in the IEEE 802.11x standards.

The rest of the paper is organized as follows. BT and IEEE 802.11x systems are described briefly in Section II. In Section III, p-persistent CSMA/CA is explained in detail with analysis of some key parameters. The underlying interference model and co-existence analysis are discussed in Section IV.

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Finally, numerical results are explained and conclusions are drawn in Sections V and VI, respectively.

II. System Descriptions

A. Bluetooth

BT uses short-range, low-power radio links to form a small network among communicating nodes called a *piconet* [15]. The node initiating the formation acts as the master and it can support up to a maximum of seven active slaves in its respective piconet, using Time Division Duplex (TDD) scheme. Frequency hopping spread spectrum (FHSS) is used to transmit packets over the ISM band, which is divided into 79 carriers, each 1 MHz wide. In the time domain, each channel is divided into slots of length 625 μs. The actual data is transmitted in part of the total packet transmission time, e.g. 366 μs out of 625 μs in the case of single-slot packet transmission. The remaining time, known as the frequency hopping guard time, is used to stabilize the electronics for the next frequency hop. Furthermore, packets can be either 1-, 3- or 5-slot in length. For a multi-slot packet, its frequency is determined by the first slot and remains unchanged during the whole packet transmission.

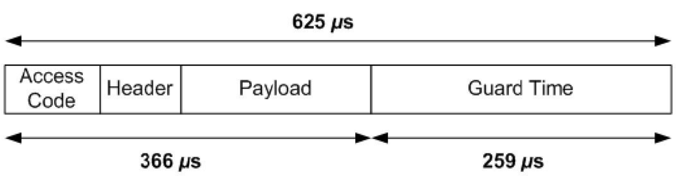

Fig. 1. Frequency hopping guard time illustration for 1-slot packet transmission.

B. IEEE 802.11x

IEEE 802.11, standardized in 1997, defines the PHY and MAC specifications. At the physical layer, IEEE 802.11 defines InfraRed (IR), direct sequence spread spectrum (DSSS) and FHSS transmissions. CSMA/CA is used as the MAC sublayer protocol. The operating frequency for both DSSS and FHSS transmissions is the 2.4 GHz ISM band.

The shortcomings of IEEE 802.11 in terms of low data rates were removed in later released versions of the standard; IEEE 802.11a, IEEE 802.11b, and IEEE 802.11g. IEEE 802.11a operates in the 5 GHz frequency band and can support date rates up to 54 Mbps. Both IEEE 802.11b and IEEE 802.11g operate in the ISM band, but differ in terms of the PHY layer specifications. Apart from the differences in the PHY layer specifications and associated data rates, all the flavors of IEEE 802.11 WLAN standard use the same MAC sublayer, i.e., CSMA/CA. It therefore becomes highly desirable to investigate analytically the co-existence issue between BT and IEEE 802.11/802.11b/802.11g WLANs integrating the CSMA/CA parameters. Although our analytical methodology in this paper is very generic, we focus our attention on IEEE 802.11b's PHY that occupies 22 MHz bandwidth.

III. p-Persistent CSMA/CA

A. Protocol Description

The CSMA protocol was proposed by Kleinrock and Tobagi [16]. In the following, we consider the slotted p-persistent CSMA/CA protocol model, introduced in [17], and shown in Fig. 2.

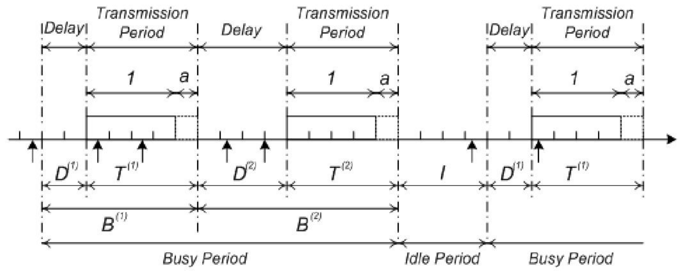

Fig. 2. Channel model for p-persistent CSMA/CA.

We assume that all WLAN terminals are synchronized to start their transmissions at the beginning of a slot. The slot duration, denoted by a, is chosen to be equal to the signal propagation delay. All transmitted packets are considered to have the same length, which for simplicity is set to unity. Each terminal can sense any transmission that occurs within the carrier sensing area and delay its own transmission. For an ongoing packet transmission, the Signal to Interference Ratio is assumed greater than a threshold that allows error-free reception. In each slot, an (empty) terminal generates a new packet with probability g ($0< g <1$), where we assume that g is comprised of both new and rescheduled packets. Since we consider the p-persistent protocol, each ready terminal starts transmitting in the next slot with probability p ($0< p \leq 1$). All terminals make room for new packet arrivals from the beginning of $T^{(j-1)}$ by putting aside the already buffered packets; this is the same assumption as in [16] and [17].

In the CSMA/CA channel model used, the system state consists of a sequence of regeneration cycles, composed of consecutive busy and idle periods. The periods are independent and geometrically distributed. We call *idle period* (I) the time in which the channel is idle and all the terminals in the area are empty. We call *busy period* (B) the time in which there is a transmission (successful or not) or at least one of the M terminals has a packet ready to be transmitted. A busy period ends if no packets have accumulated at the end of transmission.

B. CSMA/CA Analysis

Our derivation of key CSMA/CA parameters follows the approach in [17] for a finite number of transmitters and a single receiver in line-of-sight of all transmitters. A further assumption is that the destination node does not generate any new packets during the transmission period.

As shown in Fig. 2, the channel busy period is divided into several sub-busy periods such that the jth sub-period, denoted by $B^{(j)}$, comprises a transmission delay, denoted by $D^{(j)}$, followed by a transmission time, denoted by $T^{(j)}$. The $D^{(1)}$ occurs when one or more packets arrive in the last slot of the idle period. Similarly, $D^{(j)}$ ($j \geq 2$) occurs when one or more

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packets arrive in the previous transmission time $T^{(j-1)}$. The transmission period is $T^{(j)} = 1 + a$, whether the transmission is successful or not. Thus, $B^{(j)} = D^{(j)} + 1 + a$. Let J denote the number of sub-busy periods in a busy period B. Since the busy periods continue as long as there is at least one arrival amongst the M terminals during the last transmission time, the expectation of J as derived in [17], is given by $\overline{J} = 1/(1-g)^{(1+1/a)M}$, and the average duration of the idle period is shown as $\overline{I} = a/(1-(1-g)^M)$. Also, $B^{(j)}; j = 1, 2, \ldots, J$ are independent and $B^{(j)}; j = 2, 3, \ldots, J$ are identically distributed. Thus

$$\overline{B} = \overline{B^{(1)}} + (\overline{J} - 1)\overline{B^{(2)}}. \tag{1}$$

Let $Pr[N_0^{(j)} = n, X]$ be the probability that n packets arrive among M terminals during X slots, given that $n \geq 1$. Using the geometric arrival rate g for each of the M terminals in a slot, we have

$$\Pr[N_0^{(j)} = n, X] = \frac{1}{1-(1-g)^{XM}} \cdot \binom{M}{n} \cdot \left[1-(1-g)^X\right]^n \cdot (1-g)^{X(M-n)}, n = 0, 1, \ldots, M \tag{2}$$

where $X = 1$ slot for $j = 1$, and $X = (1 + 1/a)$ slots for $j \geq 2$. This essentially gives us the distribution of the number of packets awaiting transmission at the beginning of $B^{(j)}$. The distribution of $D^{(j)}$, given $N_0^{(j)} = n$, $n \geq 1$, is derived in [17] and is given by

$$\begin{aligned}\Pr[D^{(j)} \geq ka, N_k^{(j)} = n + m \mid N_0^{(j)} = n] &= (1-p)^{kn}(1-g)^{k(M-n)}\binom{M-n}{m} \cdot \left(\frac{g}{p-g}\right)^m \\ &\cdot \left[1 - \left(\frac{1-p}{1-g}\right)\right]^m, \quad m = 0, 1, 2, ..., M-n\end{aligned} \tag{3}$$

where m is the number of new arrivals during the transmission delay $D^{(j)}$. Simplifying

$$\begin{aligned}Pr[D^{(j)} \geq ka \mid N_0^{(j)} = n] &= \sum_{m=0}^{M-n} Pr[D^{(j)} \geq ka, N_k^{(j)} = n + m \mid N_0^{(j)} = n] \\ &= (1-p)^{kn}\left[\frac{p(1-g)^k - g(1-p)^k}{p-g}\right]^{M-n},\end{aligned} \tag{4}$$

Unconditioning (4) by using (2), we get

$$\begin{aligned}\Pr\left[D^{(j)} \geq ka\right] &= \frac{1}{1-(1-g)^{MX}}\Bigg\{(1-p)^k - p(1-g)^X\left[\frac{(1-p)^k - (1-g)^k}{p-g}\right]\Bigg\}^M \\ &- \frac{(1-g)^{MX}}{1-(1-g)^{MX}}\left[\frac{p(1-g)^k - g(1-p)^k}{p-g}\right]^M,\end{aligned} \tag{5}$$

The expected value of $D^{(j)}$ is

$$\begin{aligned}\overline{D^{(j)}} &= \frac{a}{1-(1-g)^{XM}}\sum_{k=1}^{\infty}\Bigg\{(1-p)^k - p(1-g)^X \cdot \left[\frac{(1-p)^k - (1-g)^k}{p-g}\right]\Bigg\}^M - \frac{a(1-g)^{XM}}{1-(1-g)^{XM}} \\ &\cdot \sum_{k=1}^{\infty}\left[\frac{p(1-g)^k - g(1-p)^k}{p-g}\right]^M.\end{aligned} \tag{6}$$

The total time is finally given as follows

$$\begin{aligned}\overline{B} + \overline{I} &= \overline{D^{(1)}} + 1 + a + [(1-g)^{-(1+(1/a))M} - 1] \cdot (\overline{D^{(2)}} + 1 + a) + \overline{I} \\ &= \frac{1+a}{(1-g)^{(1+(1/a))M}} + \frac{a}{(1-g)^{(1+(1/a))M}} \cdot \sum_{k=1}^{\infty}\Bigg\{(1-p)^k - p(1-g)^{1+(1/a)} \cdot \left[\frac{(1-p)^k - (1-g)^k}{p-g}\right]\Bigg\}^M.\end{aligned} \tag{7}$$

IV. INTERFERENCE MODEL & ANALYSIS

The performance of the BT piconet is evaluated using quantitative metrics such as the packet error probability (PEP) and the piconet throughput (Θ). The respective equations for the PEP and Θ are derived using a probabilistic treatment entailing different BT baseband parameters.

We consider a CSMA/CA-based WLAN with a finite population model (M terminals), co-existing with a BT piconet in a certain closed physical environment. We assume that the co-located BT piconet uses a frequency hopping range of 79 frequency channels. Also, the two systems are co-located close enough such that if the BT packet transmission hops on to the 22 MHz frequency used by a WLAN packet transmission, the BT packet is considered corrupted and lost. The two wireless systems operate independently and no coordination is assumed.

In the following, we derive the PEP in the BT piconet, as a function of CSMA parameters such as persistence probability, probability of packet generation and number of users M. The BT piconet can transmit a 1-, 3- or 5-slot (DH1, DH3 or DH5)[1] packet with associated arrival probability denoted by ρ_1, ρ_3 or ρ_5, respectively. We focus, in particular, on DH1/3/5 type packets as these packets do not use forward error correction (FEC) and are more susceptible to channel impairments and interference. Here, ρ_i, $i = 1, 3$ or 5, accounts for both new and retransmitted packets, therefore, we do not model the ARQ mechanism of the BT's link layer. We characterize the idle time in the piconet by assuming a single-slot empty or dummy packet that does not carry any traffic but occurs with a certain probability ρ_0, such that $\rho_0 = 1 - (\rho_1 + \rho_3 + \rho_5)$. Same approach has been used in [18].

As we consider three different BT packet lengths, for ease of notation we denote PEP by $P_e(i)$, representing the error

[1] We use the terms 1-slot/3-slot/5-slot and DH1/DH3/DH5 interchangeably

probability of an i-slot BT packet, i=1, 3, 5, in the presence of interference from WLAN. As assumed in the analysis presented in Section III-B, the WLAN packets are of the same length T_W, which is normalized to 1. The normalized packet length of an i-slot BT packet of length $T_{BT,i}$ is thus given as $T_{BT,i,N} = \frac{T_{BT,i}}{T_W}$. As an example, the packet length of a 1-slot BT packet is $T_{BT,1} = 625\mu s$, whereas T_W can be upto 1210 μs for a high-rate packet transmission of 1500 bytes in IEEE 802.11b [13]. Given the slot duration a, the number of slots occupied by a WLAN packet is calculated as $S_W = 1/a$, and by an i-slot BT packet as $S_{BT,i} = \lceil \frac{T_{BT,i,N}}{a} \rceil$, where $\lceil x \rceil$ represents the ceil function.

We introduce the *data occupancy ratio*, denoted by ξ_i, i=1, 3 and 5, to incorporate the BT frequency hopping guard time into our analytical framework. For each of the three 1-, 3- and 5-slot packet types, the values are $\xi_1 = \frac{366}{625}$, $\xi_3 = \frac{1622}{1875}$ and $\xi_5 = \frac{2870}{3125}$, respectively [15]. The number of slots occupied by the data-filled period of an i-slot BT packet is thus given as $r_i = \lceil \frac{T_{BT,i,N}}{a} \cdot \xi_i \rceil$. We denote the probability that a transmitted BT packet resides on the 22 MHz frequency range used by the WLAN by $P_f = \frac{22}{79}$. For the case of IEEE 802.11g PHY specifications, the value of P_f needs to be changed according to the occupied bandwidth i.e., 16.6 MHz.

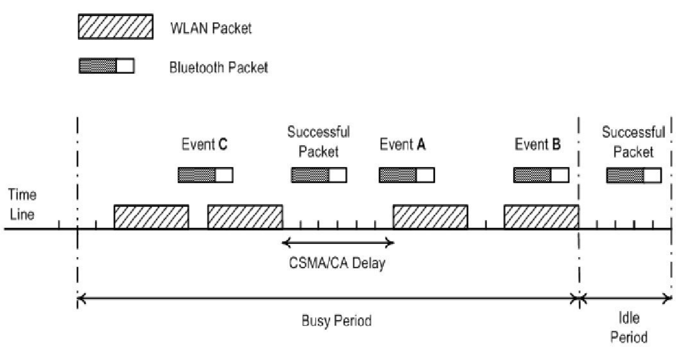

Fig. 3. Packet collisions between BT and CSMA/CA.

Consider a time line which exhibits the packet transmissions from the WLAN network (Fig. 3). We observe an alternate sequence of busy and idle periods on this time line, which is completely determined by the traffic rate ($G = gM/a$) of the WLAN. The average busy and idle periods are derived in Section III-B. Our tagged i-slot BT packet overlaps in time with a WLAN packet if either of the following two events happen (Fig. 3).

- **A**: The start of transmission of a WLAN packet occurs during the data-filled period of the tagged BT packet.
- **B**: The start of transmission of the tagged BT packet occurs during a WLAN transmission period.

The events **A** and **B** are not mutually exclusive events. The intersection of these two events gives rise to another event **C**, i.e., **C** =**A** $\cap$ **B**. Representing the probability of time overlapping of the tagged BT packet with an ongoing WLAN transmission by P_t, we have $P_t = \text{Pr}[\mathbf{A}] + \text{Pr}[\mathbf{B}] - \text{Pr}[\mathbf{C}]$.

Finally, $P_e(i)$ is established as follows

$$P_e(i) = P_t \times P_f. \tag{8}$$

We next derive each of the probabilities Pr[**A**], Pr[**B**] and Pr[**C**]. The probability that the tagged packet starts transmission during a slot on the WLAN's time line is $\frac{a}{(\overline{B}+\overline{I})}$. The event **A** occurs when the start of a WLAN packet occurs at any instant of the data-filled period of the tagged BT packet. Since the tagged BT packet's occurrence is uniformly distributed over the WLAN time line, and by taking into account all the sub-busy periods, we get

$$\text{Pr}[\mathbf{A}] = \frac{\overline{J} \cdot r_i}{(\overline{B}+\overline{I})/a}, \tag{9}$$

Similarly

$$\text{Pr}[\mathbf{B}] = \frac{\overline{J} \cdot S_W}{(\overline{B}+\overline{I})/a}, \tag{10}$$

and

$$\text{Pr}[\mathbf{C}] = \frac{1}{\overline{J}} \cdot \text{Pr}[\mathbf{C}]^{(1)} + \frac{(\overline{J}-1)}{\overline{J}} \cdot \text{Pr}[\mathbf{C}]^{(2)}, \tag{11}$$

Since **A** and **B** are not mutually exclusive events

$$\text{Pr}[\mathbf{C}]^{(j)} = \text{Pr}[\mathbf{B}|\mathbf{A}]^{(j)} \cdot \text{Pr}[\mathbf{A}], \tag{12}$$

where

$$\text{Pr}[\mathbf{B}|\mathbf{A}]^{(1)} = \sum_{l=1}^{(r_i-2)} \frac{1}{r_i} \sum_{z=0}^{(r_i-l-2)} \text{Pr}\left[D^{(1)} = za\right] \cdot \text{Pr}\left[I < (r_i - l - z)a\right], \tag{13}$$

and

$$\text{Pr}[\mathbf{B}|\mathbf{A}]^{(j)} = \sum_{l=1}^{(r_i-1)} \frac{1}{r_i} \cdot \text{Pr}\left[D^{(j)} < (r_i - l)a\right] \qquad j = 2, 3, \ldots \tag{14}$$

Also, $\text{Pr}\left[D^{(j)} = \beta a\right]$ and $\text{Pr}\left[I < \beta a\right]$ are calculated as

$$\text{Pr}\left[D^{(j)} = \beta a\right] = \text{Pr}\left[D^{(j)} \geq \beta a\right] - \text{Pr}\left[D^{(j)} \geq (\beta+1)a\right], \tag{15}$$

$$\text{Pr}\left[I < \beta a\right] = \begin{cases} 1-(1-g)^{M(\beta-1)} & \beta > 1, \\ 0 & \text{otherwise} \end{cases} \tag{16}$$

The success probability $P_s(i)$ of an i-slot BT piconet is simply formulated as $P_s(i) = 1 - P_e(i)$, and the piconet throughput in terms of kilo bits per seconds (Kbps) is finally obtained as

$$\Theta = \rho_1 \cdot P_s(1) \cdot R_1 + \rho_3 \cdot P_s(3) \cdot R_3 + \rho_5 \cdot P_s(5) \cdot R_5, \tag{17}$$

where $R_1(345.6)$, $R_3(780.8)$ and $R_5(867.9)$ are the data rates (Kbps) for 1 (DH1), 3 (DH3), and 5-slot (DH5) packets, respectively (for example, 1464 data bits are contained in a DH3 packet of time duration 1875 μs, therefore $R_3 = \frac{1464}{1875} =$ 780.8 Kbps).

V. Numerical Results

Numerical results for the derived performance metrics are given in this section, where the accuracy of the results has been validated by means of simulations. For CSMA/CA, the

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transmission probability is set to $p = 0.03$, and the slot duration is set to $a = 0.01$.

Fig. 4 reports PEPs for individual packet types as a function of probability of packet arrival per slot per user (g) and the number of users (M) in the co-existent WLAN. PEP for DH1 type packets is lesser with respect to their longer counterparts as they are shorter in duration and can be transmitted successfully during delay periods of WLAN. Also, higher values of M lead to greater utilization of the ISM band by the WLAN causing more packet collisions in BT. The simulation results match with our analytical results, which justifies the correctness of our approach.

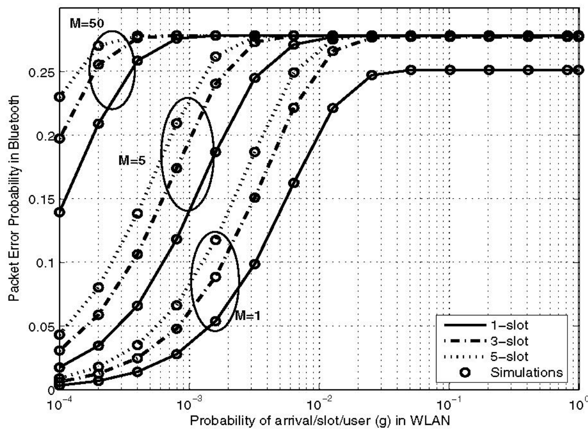

Fig. 4. BT PEP in the presence of p-persistent CSMA/CA.

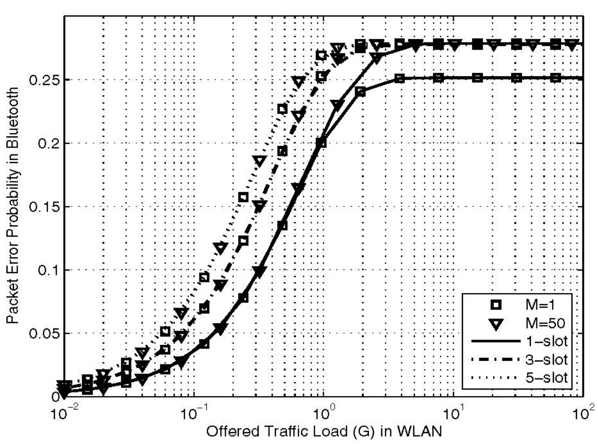

Fig. 5. PEPs for DH1/3/5 packets in the presence of lightly (M=1) and densely (M=50) populated WLAN.

The offered traffic load G of WLAN provides a good measure of it's associated delays between packet transmissions. Increased values of M substantially reduce the delays (alternatively increase the ISM band utilization), and consequently BT packets may always overlap in time with the WLAN packets. Fig. 5 accentuates the effect of higher number of users in WLAN on the PEP of different packet types in BT. An important observation here is that for longer packets (3-slot and 5-slot), higher number of WLAN users does not produce any substantial change as PEPs exhibit similar values. However, 1-slot packets experience higher PEP for higher values of M, for $G > 1$. We can conclude that the PEP in a BT piconet is primarily a function of WLAN offered traffic load G and does not rely heavily on it's number of users.

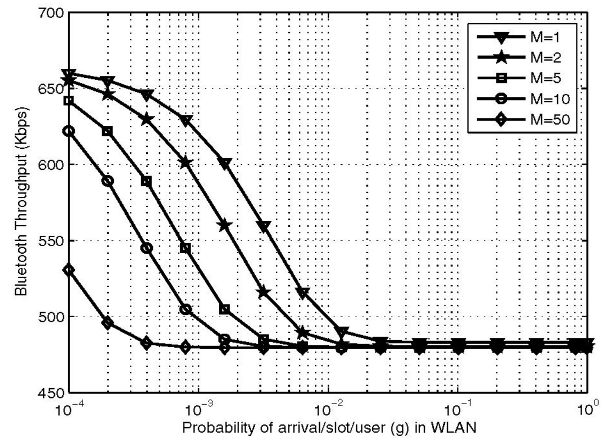

Fig. 6. BT throughput as a function of WLAN users, 100% piconet traffic and Equal Arrivals of DH1/3/5.

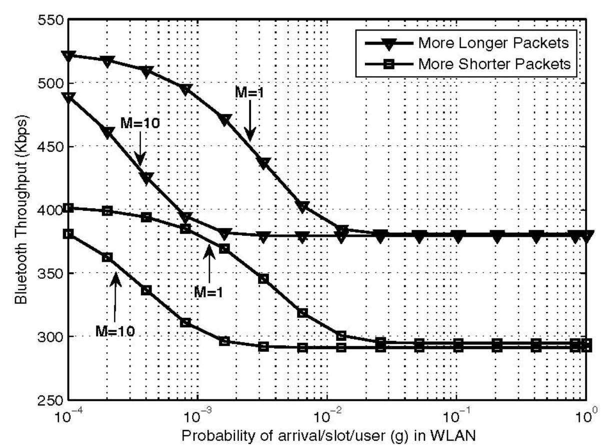

Fig. 7. BT throughput with different arrival probabilities of DH1/3/5 packets and 70% piconet traffic.

Fig. 6 depicts the throughput performance of BT in dependency of WLAN's parameters M and g. DH1/3/5 packets with equal arrival probabilities ($\rho_1 = \rho_3 = \rho_5$), and 100% ($\rho_0 = 0$) piconet traffic is considered. For a fixed value of g, ISM band's utilization is increased by increasing number of WLAN users, which subsequently causes more packet collisions in BT and hence low throughput. The throughput saturates after a certain value of g(≈0.01). This is because the channel occupancy of WLAN also saturates at this point and hence has no effect on the BT throughput.

In Fig. 7, we evaluate BT throughput with 70% ($\rho_0 = 0.3$) piconet traffic, and under varying arrival models for DH1/3/5 packets. We consider two different packet arrival probabilities: one with more longer packets ($\rho_1 : \rho_3 : \rho_5 = 1 : 2 : 3$), and one with more shorter packets ($\rho_1 : \rho_3 : \rho_5 = 3 : 2 : 1$).

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The result indicates that although longer packets are more vulnerable to collisions (Fig. 4) from WLAN, they are more preferable in terms of achieving higher throughput. Even for higher WLAN interference ($M = 10$), longer packets produce more throughput as compared to lesser WLAN interference ($M = 1$). This is justified because the difference in PEPs between DH5 and DH1 packets is not significant as compared to a substantial difference in the number of data bits/slot. Transmitting longer packets in the presence of WLAN may prove beneficial for achieving higher throughputs, however it may pose a different problem for optimizing the piconet's latency profile. Since a lost packet is retransmitted in BT, longer packets will cause larger delays.

VI. Conclusions

We derive a closed-form expression for PEP in a BT piconet as a function of co-existing CSMA/CA based WLAN's parameters such as the offered traffic load, the transmission probability and the number of terminals. Our analytical methodology takes different BT packet types into account, and also incorporates frequency hopping guard time. The co-existence framework is highly generic in nature and can easily be tailored for any co-existent CSMA/CA and FHSS based wireless systems.

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