Performance Enhancement of Wireless LANs Through Packet Combining

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Abstract

Wireless Local Area Networks (WLANs) are faced with the presence of hidden terminals and the possibility of capture when operating in multipath radio channels. These phenomena complicate both their design and performance analysis. In this paper we consider a WLAN with CSMA/CA MAC protocol over mobile radio channels and evaluate its performance in terms of average throughput and average packet delay. In order to improve the system performance, we propose the use of different packet combining methods where the receiver keeps wrongly detected packets, combine them with their retransmitted versions and then makes a decision. Such a simple technique is well suited for wireless LANs since it provides a diversity gain to the system that can reduce interference problem (hidden terminal situation) and improve the capture effect. Simulation results show that both Maximum Ratio Packet Combining (MRPC) and hard decision can achive a considerable gain in system throughput.

1. Introduction

Since the last decade Wireless Local Area Networks (WLANs) have rent some considerable interest in today's wireless world and several new standards have been employed [1],[2]. WLANs give the possibility for devices to be connected to the fixed network while moving freely from area to area. This devices may require rapid deployment and may be portable, handheld, or mounted on moving vehicles. In this paper we use the IEEE 802.11 WLAN standard, which has been developed to provide high bandwidth to mobile users. Apart from mobility, it should allow a certain sets of services and Quality of Services (QoS) requirements which are commonly provided by its wired counterparts. The radio spectrum is limited and the radio channel introduces several parameters that decreases the performance of the WLAN. Phenomena such as additive noise, multipath fading, shadowing and co-channel interference. These interference sources put limits on the performance of the transceiver system, coverage area of the Access Points (APs), and the density of mobile stations within the system. When stations sharing an AP, all using the same channel, will interfere with each other.

The IEEE 802.11 adopt *Carrier Sense Multiple Access with Collision Avoidance* (CSMA/CA) as media access protocol. This scheme, unlike CSMA/CD, does not detect and prevent collisons, but rather attempts to reduce likelihood of collisions. However, collisions can still occur. In radio channels, the link quality varies over time and space in unpredictable ways so that full connectivity can not be assumed. It also creates the *hidden terminal* problem where a mobile station may be shadowed by some structure, or be further away from another station. The effect of hidden terminals on the performance of WLANs have been treated in several papers [3],[4]. These studies did however use simple models that did not catch the real interference situation within the system. In [5] a simple model that naturally models the hidden terminal problem was proposed and used to study the performance of wireless LANs in radio channels.

In this paper, we investigate possible techniques for improving the performance of these WLAN systems under fading conditions. For that, we consider a simple packet combining method at the receiver. In many error control protocols, the receiver discards the erroneous packets and requests the transmitter for a retransmission. However, an erroneous packet may contain both erroneous bits and correct bits and hence it may still contain useful information. The receiver may be able to combine this information from multiple erroneous copies to recover the packet.

The paper is organized as follows: The WLAN model including all the assumptions and the different parameters is introduced in Section 2. Section 3 introduces the radio channel model between the AP and the mobile terminal, and also between the two mobile terminals. Section 4 introduces packet combining and in Section 5 we look at the system performance and finally in Section 6 we conclude the work.

2. System Model

In this paper we consider a multiple-access communication system with one *Access Point* (AP) and N independent *Mobile Stations* (STAs). We assume that all information traffic destinated for a mobile station is delivered via the AP. A station is called active if it has data to transmit; otherwise it is idle. The fundamental access method we use is called *Distributed Coordination Function* (DCF) and is the random access protocol based on *Carrier Sense Multiple Access with Collision Avoidance* (CSMA/CA). The DCF descibes two techniques to employ for packet transmission. In CSMA/CA, all stations listen to the medium as in CSMA/CD. A station that is ready to transmit a frame senses the medium, and if the medium is busy, the STA will wait until the end of the current transmission. The station will then wait for a predetermined time period, denoted as the DCF Inter-Frame Space (DIFS), and select a random time slot within a contention window to transmit its frame. If there are no other transmissions before the selected time slot arrives, the station starts transmitting its frame when the time slot arrives. However, if there are transmissions by other stations during this time period, known as the back-off time, the station freezes its counter and then resumes the count where it left off, after the other station has completed its frame transmission and after a DIFS. Thus, collisions can occur only when two or more stations select the same slot in which they transmit their data frames. In the event of a collision, the source detects the collision based on the abscence of a positive acknowledgement (ACK) from the destination or the receipt of an explicit negative acknowledgement (NAK) from the destination. The station then increases its contention window to reduce the possibility of another collision and the back-off process continues as before. The process continues until the collided packet has been succesfully transmitted or the transmission is aborted. As mentioned before the collision avoidance of the MAC protocol is performed through a random backoff procedure, known also as *Contention Window* (CW). Each station computes a random backoff time, an integer of slots. In the initial phase a small backoff time is selected (assumed in the range of 0-7 in this paper) and then increases exponentially after each retransmission attemt as

$$Backoff = Random() \times T_{slot} \tag{1}$$

where Random() is a pseudorandom integer drawn from a uniform distribution over the interval $[0, CW]$ and CW is an integer with $CW_{min} \leq CW \leq CW_{min}$, with $CW_{max} = 255$. This access scheme promotes fairness among stations by giving each station the chance of gaining access to the channel. However, under fading conditions, stations in the border of the *Basic Service Set* (BSS) may have problems to accessing the channel. This is due to the fact that fading channels create fading dips into the received signal and thus increasing the occurrence of hidden terminal situations.

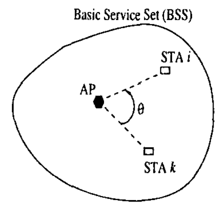

Figure 1. A basic service set with one AP and two STA's

3. Channel Model

As the size of the cell in a wireless LAN is in general quite small and if the position of the AP is properly chosen, a clear Line-Of-Sight (LOS) should exist between a given station (STA) within the cell and its AP. Here we model such radio channel as Rician fading with constant LOS component characterized by Rician factor $K = 10\,dB$. For indoor propagation, the path loss is more accurately modeled using ray tracing [6]. However, in this paper we will use distance dependent expression for simplicity. Thus, denoting by $s_i(t)$ the equivalent lowpass transmitted signal of station i, the corresponding equivalent lowpass of the received signal at the AP can be written as follows:

$$r_{i,p}(t) = a_i \sqrt{P_i D_{i,p}^{-\alpha}} s_i(t) + n(t) \tag{2}$$

where P_i, is the transmitted power of station i, $d_{i,p}$ is the distance between the STA i and the AP, the α is the propagation coefficient which is assumed here equal to 3. The additive term $n(t)$ is total interference which includes background noise, possible interference from other active stations, and external interference. The multiplicative fading coefficient a_i is a complex Gaussian random variable with constant mean $A = \sqrt{K/(K+1)}$ and variance $\sigma^2 = 1/[2(K+1)]$. Thus, the fading amplitude is Rician distributed with Rice factor K and probability density function

$$p_{|a_i|}(x) = \frac{x}{\sigma^2} e^{-(x^2+A^2)/2\sigma^2} I_0\left(\frac{xA}{\sigma^2}\right), \quad x \geq 0. \tag{3}$$

Concerning the radio channel between the different stations within the service area the situation could be much different and the channel behaviour is in general dependent on their positions with respect to each other. Here we propose a simple model that tries to account for such behaviour. Let us consider the situation of Figure 1 where two stations are placed within the service area of the AP. If one STA is in transmission mode, its signal strength at the other

STA is a function of the distance between the two STAs and should also in principle be a function of the angle θ. This angle θ can be used to define the degree of shadowing of the medium between the two stations. Shadowing can be the result of people moving around within the service area and/or the presence of different objects such as furniture. To include the dependecy on θ, we model such a channel as Rician fading with a LOS component, denoted $A(\theta)$, which in this case is not constant but rather a function of the angle between the direction of two stations toward the AP.

Again denoting by $s_i(t)$ the transmitted signal of station i, the corresponding received signal at station k takes the following form

$$r_{i,k}(t) = a_i(\theta)\sqrt{P_i d_{i,k}^{-\alpha}}\, s_i(t) + n(t) \tag{4}$$

where

$$a_i(\theta) = A(\theta) + n_{c,\theta} + j n_{s,\theta} \tag{5}$$

with

$$A(\theta) = \sqrt{\frac{1+\cos(\theta)}{2}} \tag{6}$$

and $n_{c,\theta}$, $n_{s,\theta}$ are independent identically Gaussian random variables with zero mean and variance

$$\sigma_a^2 = \frac{1-\cos(\theta)}{4}. \tag{7}$$

With relation to Figure 1, this channel model indicates that as the two terminals, i and k, get close to each other, the shadowing effect gets smaller and the probability that one station detects the presence of the other station improves. As the distance between the two mobile stations approaches zero, the channel converges to an ideal channel where a clear LOS exists between them. However, when the two terminals are in opposite sides with respect to the access point the LOS component goes to zero and the fast fading channel becomes Rayleigh fading. In such situation, the probability of one station detecting the other decreases, which causes more collisions. This simple stochastic model gives a more realistic description of the terminal situation. With this model one does not need to assume a predefined probability of the occurrence of hidden terminal to evaluate the performance of wireless LAN systems. Infact, this probability is dictated by the position of the different stations with respect to each other. Therefore, for mobile stations the probability of a given station being under the influence of hidden terminal will change in time and is also different from one station to the other.

4. Packet Combining

In order to increase the system performance in the WLAN system we try to use different methods of packet combining. In this case we consider the situation where mobiles transmitting to the AP, then assume that the AP has a buffer for each STA that can take one packet. A mobile transmits its packet to the AP. The AP checks if this packet is successfully decoded, then a positive acknowledgement (ACK) is transmitted back to the STA, otherwise it stores it in the corresponding buffer and waits for retransmission of the same packet (here we assume that each mobile keep transmitting the same packet until it successfully transmitted). Once the packet is received, the AP combines it with the old version and makes a decoding attempt. If the decoding attemt succeeds, a positive ACK is transmitted to the STA, otherwise the combined packet is stored. This procedure is repeated until the packet is correctly decoded or ignored if a decoding failure is declared after the time limit of packet transmission. Notice that this combining technique is well suited for IEEE 802.11 WLAN since it does not require negative acknowledgement from the receiver to the transmitter.

In analyzing the system performance we consider different types of packet combining methods such as *Maximum Ratio Packet Combining* (MRPC) and hard decision combining. In MRPC, the received samples of every symbol is weighted by their corresponding channel coefficients and then combined. Such a method requires storing the received samples of the packet as well as the channel coefficients of that packet. With hard decision combining only hard values of the packet need to be stored which is much simpler but could also be less reliable.

5. Performance Evaluation

In this paper we have implemented the different packet combining methods and compared them with a system without any combining method [5]. We studied their performance in a WLAN environment based on the channel models described in Section 3.

5.1 Performance Measurements

5.1.1 Throughput

The throughput is generally defined as the amount of data that is transmitted over the channel during a unit time. For a single BSS the throughput is the fraction of a packet transmitted during a time packet length (T_{packet}). Consider an observation time $T_0 = MT_{packet}$ and let S_M be the total number of successfully transmitted packets from all mobile stations of the BSS to the AP during this observation time. Then we can approximate the throughput of the system by

$$U = \lim_{M\to+\infty} \frac{S_M}{T_0}, \tag{8}$$

which is a number smaller or equal to one.

5.1.2 Packet Delay

The average MAC delay is defined as the time it takes to transmit a packet from a mobile station to the access port. In this paper the average packet delay is evaluated by means of computer simulation for a given number of users under different channel environments as a function of offered traffic. We obtain average packet delay by adding the average MAC delay with the average queuing delay. In our paper we consider that the mobile station i has a packet ready for transmission in the physical layer and let t_0 be the time instant at which the station starts sensing the channel attempting to transmit such a packet. Let t_e be the time at which this packet is received correctly at the access port. Since we neglect the acknowledgment time of the packet, we define the packet delay as the number of slots between t_0 and t_e divided by number of slots per packet. Thus, if T_{slot} is the slot duration and $T_{packet} = LT_s$ is the packet duration then the packet delay is obtained as

$$D_i = \frac{t_e - t_0}{LT_s} \quad i = 0, 1, ..., N-1, \tag{9}$$

which is conditioned on the number of stations N, their positions within the service area, and the load of the system. The average delay is defined as

$$E\{D\} = \frac{1}{N} \sum_{i=0}^{N-1} E\{D_i\} \tag{10}$$

The computation of the above expression requires the knowledge of the probability density function of $t_e - t_0$ which is not easy to derive. The average packet delay is obtained by adding the average MAC delay and the average queuing delay [7].

5.1.3 Fairness

To try to evaluate the fairness in the system, we looked at the performance of a given station as a function of its distance with respect to the AP. Here, the mobile under study is still at a given position and all the other mobiles are moving with the constant speed v_s. In order to use the fairness we must know the efficiency in the system. In this paper we define the efficiency as the number of successfully transmitted packets divided by the total number of transmitted packets (all packets including retransmissions). The total number of transmitted packets from the mobile stations to the AP within the observation time T_0 is denoted by W_M. So then we can define the system efficency as

$$\mu = \lim_{M \to +\infty} \frac{S_M}{W_M}, \tag{11}$$

which is always smaller or equal to one.

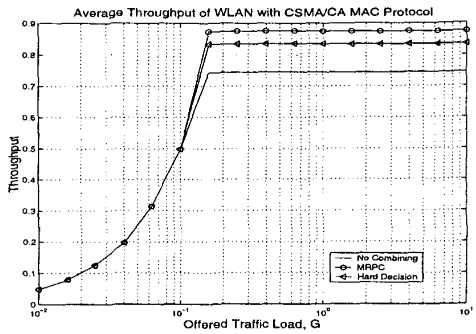

Figure 2. Average throughput for different types of packet combining.

5.2 Simulation Model

The simulation model uses the DCF as the access scheme with one single circular Basic Service Set (BSS) with radius R having the AP placed in the middle. We assume that there are N independent mobile stations, uniformly distributed over the service area, synchronized to a global clock at the AP. All stations are moving with very low speed, v_s, which corresponds to a speed of 3 m/s for a time slot of 10 μsec. The moving direction of the STA's is changing randomly at every time slot but without leaving the service area. Furthermore we assume that we have messages of different types (e.g. voice, data and voice) which are subdivided into fixed lengths packet (each packet requires $T_p = 100T_{slot}$). All packets arrive to the MAC of each user according to a Poisson distribution with intensity $G\ packet/T_{slot}$ and are stored in a buffer of size 200, until they are transmitted. When the buffer is ful, newly arrived packets are ignored. A packet is successfully received if and only if all of its time slots are successfully captured. The Signal-to-Noise Ratio (SNR) at the border of the cell is assumed to $\gamma_0 = 19\ dB$. The capture threshold is set to 10 dB and the threshold for detecting the presence of an active mobile terminal is set to 6 dB.

Propagation delay has not been considered in the simulation model and immediate acknowledgement to the source station is assumed. Therefore, collisons can occur because of presence of hidden terminals created by the radio channel.

5.3 Simulation Results

The throughput is illustrated in Figure 2 as a function of the offered load. Maximum achievable throughput of the shared channel for the case without packet combining is

75% and remains unchanged for relatively high loads, this is due the fact that the queueing delay is not included. Then we introduce packet combining in the system and maximum achievable throughput increases to 85% for MRPC and in the case where we use hard decision we get a throughput of nearly 82%. In Figure 3 the average packet delay in number of packet unit length as a function of the intensity G is shown for a system with five mobiles and the packet length is set to 100. The obtained results clearly show that both cases of packet combining decreases the packet delay of the system compared to the system without packet combining. MRPC performance is slightly better than hard decision. The fairness is illustrated in Figure 4 where we observe that near the AP all the packets transmitted by the mobile are successfully transmitted without any retransmission, while near the border of the cell an average of two retransmissions are needed for successful transfer of a packet from the mobile station to the AP in the case when the system does not use packet combining. When MRPC or hard decision is used we notice that the fairness of the system is better, i.e., fewer retransmissions are required.

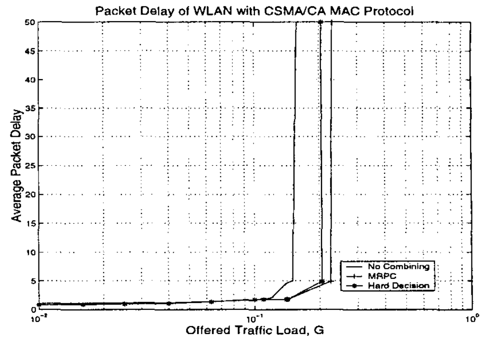

Figure 3. Average access delay for different types of packet combining

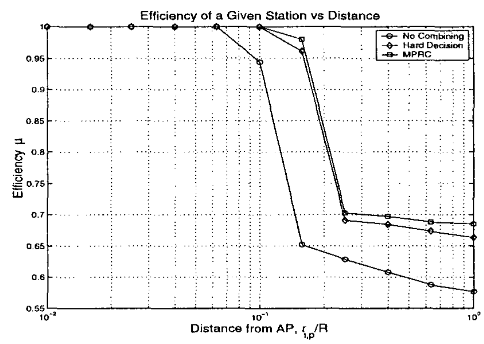

Figure 4. Efficiency of a given station as a function of its distance to the AP.

6. Conclusions

In this paper we have treated the performance of Wireless LANs with CSMA/CA MAC protocol over fading channels taking into account the distributed nature of communication between the access point and the mobile stations. By modeling the radio channel between the mobile stations, the hidden terminal was naturaly modeled. We propose to use packet combining to increase the system performance of the WLANs. Simulation results show that both MRPC and hard decision improve the system performance. That is, throughput increases and average packet delay decreases. Among the proposed packet combining methods, it is observed that MRPC performs better than hard decision, but then one must take into consideration that MRPC is far more complex to implement than hard decision.

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