
On Loss Differentiation for CSMA-based Dense Wireless Network

*Hui Ma**

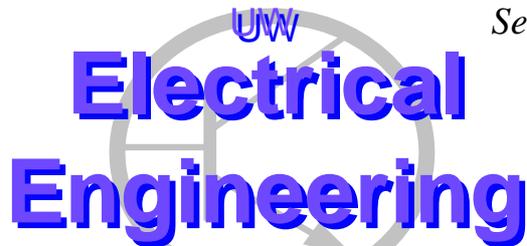
*Dept. of Electrical Engineering
U. Washington Box 352500
Seattle, WA 98195*

Jing Zhu

*Communications Technology Lab, Intel Corpn.
2111 NE 25th St. , JF3-206
Hillsboro, OR 97124*

Sumit Roy

*Dept. of Electrical Engineering
U. Washington Box 352500
Seattle, WA 98195*



UWEE Technical Report
Number UWEETR-2007-0002
April 2007

Department of Electrical Engineering
University of Washington
Box 352500
Seattle, Washington 98195-2500
PHN: (206) 543-2150
FAX: (206) 543-3842
URL: <http://www.ee.washington.edu>

On Loss Differentiation for CSMA-based Dense Wireless Network

Hui Ma*

Dept. of Electrical Engineering
U. Washington Box 352500
Seattle, WA 98195

Jing Zhu

Communications Technology Lab, Intel Corpn.
2111 NE 25th St. , JF3-206
Hillsboro, OR 97124

Sumit Roy

Dept. of Electrical Engineering
U. Washington Box 352500
Seattle, WA 98195

University of Washington, Dept. of EE, UWEETR-2007-0002

April 2007

Abstract

In this paper, we propose a novel method to differentiate packet loss based on interference energy and timing relative to desired signal for a CSMA-based dense wireless network. All measurements are conducted locally at transmitters, and therefore require no additional over-the-air overhead. Our method also separately estimates the PER (packet error rate) due to interference *prior to* or *after* the beginning of the desired signal, which allows for more efficient MAC(media access control) adaptation design.

IEEE 802.11, CSMA, High Density (HD) WLAN, MAC, protocol, loss differentiation

1 Introduction

In *dense* wireless networks based on CSMA MAC protocol such as 802.11 WLANs, one of the primary design issues is how to increase spatial reuse via MAC adaptation (e.g. transmit power control, sensitivity adaptation, rate scaling, etc.), and improve total network throughput. Packet losses due to co-channel interference (asynchronous interference) and collisions (synchronous interference) should be considered separately in the design of MAC adaptation schemes¹. Accordingly, we exploit the timing relations between desired and interference signal to classify the packet losses into three categories below, thereby leading to real-time determination of the causes of packet loss:

1. **Collision (Synchronous Interference):** one or more concurrent packets start at the same time slot leading to corruption of the reference packet. Collision events are denoted by **C**.

*Contact Author: mahui@ee.washington.edu **This work was supported in part by Intel Corp.

¹In this work, we implicitly assume background noise is negligible since the HD WLAN is a interference-limited network.

2. **(Asynchronous) Interference 1:** the received signal strength *prior* to the reference packet arrival is strong enough to cause the reference packet to be corrupted; this event is denoted by **I1** and the interference signal *prior* to the reference packet arrival is called Interference Type 1.
3. **(Asynchronous) Interference 2:** the sum of one or more subsequent arriving packets can cause the reference packet to be corrupted; this event is denoted by **I2** and the interference signal *after* the reference packet arrival is call Interference Type 2.

Note that both I1 and I2 are typical examples of the well-known *hidden terminal problem* in the literature.

Differentiating the type of packet losses allows for the selection of the appropriate counter measure. For C, an appropriate solution would be the tuning of the CW (contention window) size, so that the probability that two transmitters will transmit at the same time is minimized. For I1, if the reference transmission could be successfully decoded in the presence of the interfering signal, an appropriate solution is to adjust the physical carrier sensing (PCS) threshold of the transmitter so as to avoid unnecessary deference [1] as well as minimize I1. Lastly, for I2, transmit power control would provide a potential solution, since it will raise the power of the reference signal to a level that the desired signal either cannot be corrupted by the interfering signal, or can reach the hidden interferer and force its deference. In addition, when transmit power and PCS threshold at each node vary in a general asymmetric network, tuning PCS threshold can solve only I1 but not I2 and thus results in severe link starvation [1], which underscores the necessity of differentiation of I1 and I2.

However, it is difficult to *diagnose the cause of a packet loss* at transmitters because of the binary (success/failure) response to a packet transmission. A transmitter only knows success/failure based on whether an acknowledgement (ACK) is received or not for each transmitted packet, but not the cause of packet loss.

There have been several attempts to distinguish the cause of packet loss in wireless networks. [4] relied on RTS/CTS exchange of IEEE 802.11 protocols for such differentiation; [5] proposed to exchange transmission time information for lost packets; [7] introduced a new MAC frame, NAK, to notify the sender a link error. All above methods require over-the-air exchange of control messages, thereby introducing additional overheads. [2] used large CW size to minimize collisions in the network and then estimated the PER due to interference; [8] estimated the collision probability as the ratio of channel busy times due to transmissions by other stations. However, none of the above addresses how to differentiate I1 and I2, which as mentioned earlier have different implication for MAC performance. The capture effect was explored in [6] for loss differentiation at receivers. Although it could detect I1 and I2 in some cases, it requires significant re-design of the 802.11 receive chain.

2 Novel Method for Loss Differentiation (LD)

We propose a novel method to distinguish and estimate PER due to collision, I1, and I2 respectively using timing relative to desired signal. We seek to estimate PER due to C, I1 and I2 individually, defined as

- p_c : the PER due to C, estimated by ratio of the number of packets lost due to collisions to the total number of transmissions.
- p_1 : the PER due to I1, estimated by ratio of the number of packets lost due to type 1 interference to the total number of transmissions.
- p_2 : the PER due to I2, estimated by ratio of the number of packets lost due to type 2 interference only to the total number of transmissions.

We assume that energy measurement based carrier sensing is implemented. A new metric, TX-RSSI (transmit received signal strength indicator), is introduced to estimate PER due to I1. It is defined as the over-the-air energy observed by a transmitter prior to a transmission. In addition, we define γ_{min} as the

minimum PCS threshold that essentially represents the noise floor. If the TX-RSSI is less than γ_{min} , the node assumes that there is no type-1 interference (i.e. noise only). For convenience, we denote the binary variable $E = \text{TX-RSSI} > \gamma_{min}$, which takes value $E = 1(0)$ if type-1 interference is detected (not detected).

The number of successful transmissions and failures in the presence and absence of type-1 interference are measured. During the measurements, each station counts its number of transmitted data packets and received ACKs within a specific time duration, T , as follows:

- t_1 : number of transmissions with $E=1$
- f_1 : number of failures with $E=1$
- t_2 : number of transmissions with $E=0$
- f_2 : number of failures with with $E=0$

The heuristics behind γ_{min} adaptation can be described as: a) if γ_{min} is too low, weak interference will be unnecessarily considered; b) if γ_{min} is too high, destructive interference might be missed. Here, we adapt γ_{min} to maintain the type-1 interference ratio measured by $t_1/(t_1 + t_2)$ within the range $[dr_l, dr_h]$ dynamically, where the pre-set values of dr_l, dr_h are chosen to be 25% and 75% respectively.

We define the following probabilities:

- p'_1 : the probability of packet loss caused by type-1 interference, given $E=1$
- p : the probability of packet loss, given $E=1$
- \bar{p}_1 : the probability of packet loss caused by non type-1 interference, given $E=1$

Assuming the probability of packet loss caused by non type-1 interference is independent of whether type-1 interference is present², we have

$$1 - p = (1 - p'_1)(1 - \bar{p}_1) \quad (1)$$

where we estimate³ p and \bar{p}_1 via

$$\langle p \rangle = \frac{f_1}{t_1} \text{ and } \langle \bar{p}_1 \rangle = \frac{f_2}{t_2} \quad (2)$$

Note that p'_1 can be estimated when $E = 0$. Now, combine (1) and (2) to get

$$\langle p'_1 \rangle = 1 - \frac{1 - \langle p \rangle}{1 - \langle \bar{p}_1 \rangle} = 1 - \frac{1 - \frac{f_1}{t_1}}{1 - \frac{f_2}{t_2}} \quad (3)$$

Further, since we assume there is no packet loss due to I1 given $E=0$, we have

$$\langle p_1 \rangle = \langle p'_1 \rangle \cdot \frac{t_1}{t_1 + t_2} = \left(1 - \frac{1 - \frac{f_1}{t_1}}{1 - \frac{f_2}{t_2}}\right) \cdot \frac{t_1}{t_1 + t_2} \quad (4)$$

I2 and C may occur in the same transmission. In such case, we will consider collision as the dominant cause. Thus p_2 can be estimated by

$$\langle p_2 \rangle = f_2/t_2 - \langle p_c \rangle \quad (5)$$

²Certainly, this cannot be strictly true, since given the $E=1$ (type-1 interference exists), the contribution of type-2 interference or collisions depends on the amount of type-1 interference present.

³We use $\langle \rangle$ around any quantity to denote it's estimate based on observed data.

Although $\langle p_2 \rangle$ is found using data only over t_2 , the estimate can be used for the whole period (i.e., $t_1 + t_2$), because packet loss due to type-2 interference is independent of the presence of type-1 interference.

Lastly, we propose a simple mechanism to estimate p_c , based on the fact that collision starts at the same time as signal. Define a probability, q , such that **each transmission will delay its transmission by half slot with the probability of q** (say 0.25).⁴ This allows us to estimate p_c with little impact on the network. The nodes that delay their transmissions will then use the first half-slot to measure the on-air energy for collision detection. We measure the following two metrics at a transmitter in each interval:

- n : the number of delayed transmissions at a node;
- $m (< n)$: the number of *failed* transmissions whose energy level measured in the first half slot is higher than PCS threshold, γ_{cs} .

Assume N nodes contend for the channel along with the reference node. Denote the transmission probability for node i as τ_i . The collision probability for the reference node is given by

$$p_c = 1 - \prod_{i=1}^N (1 - \tau_i) \approx \sum_{i=1}^N \tau_i \quad (6)$$

With the proposed delay, a transmission from node i will be detected by the reference node with the probability of $\tau_i (1 - q)$. Hence, the collision probability observed m/n equals

$$\frac{m}{n} = 1 - \prod_{i=1}^N (1 - \tau_i (1 - q)) \approx (1 - q) \sum_{i=1}^N \tau_i \quad (7)$$

Combining (6) and (7), we get

$$\langle p_c \rangle = \left(\frac{m}{n}\right) \left(\frac{1}{1 - q}\right) \quad (8)$$

Insert (8) into (5) to get

$$\langle p_2 \rangle = \frac{f_2}{t_2} - \frac{m}{n} \left(\frac{1}{1 - q}\right) \quad (9)$$

In summary, (6), (3) and (9) give the PER due to C, I1 and I2 respectively.

3 Verification

In this section, we verify the proposed loss differentiation (LD) method by comparing two sets of simulation results⁵. Both sets of simulations are carried out in OPNET using the modified physical carrier sensing module [3]. For the first set (“Direct LD”), the newly developed codes used in [2] count the observed amount of 3-type packet losses at receivers directly. It will serve as the criteria for evaluating the proposed LD method. Here, LD is inserted into the OPNET physical layer model to carefully examine the timing of the receptions of two or more packets. The cause of packets loss is determined by comparing SNIR (Signal to Noise and Interference Ratio) of all segments in a frame to preset SNIR threshold, S_0 ⁶. Meanwhile, the

⁴A slot is 9 μ sec long for .11a or .11g, and 20 μ sec for .11b. Notice that we don’t change the existing WLAN transmission. Even if detecting a collision, the transmission will still proceed. Therefore, the observed collision rate is not the same as the experienced collision rate.

⁵The results of “Direct LD” and “Indirect LD” were collected separately from two rounds of simulations for the same scenario.

⁶The SNIR threshold S_0 is determined from OPNET modulation curves at 10% packet error rate (PER). For 1500 byte frames, S_0 equals 7.54dB.

Table 1: Simulation set-up in a 18 pair ring network with 802.11a

Packet size (bytes)	1500
Link data rate (Mbps)	12
Transmit power (mW)	1
Path loss exponent γ	2
CWmin	15, 31, 63, 127

estimated loss probabilities $\langle p_c \rangle$, $\langle p_1 \rangle$ and $\langle p_2 \rangle$ with proposed method were collected at transmitters, which is called “Indirect LD” in the figures.

For the simulations, a symmetric 18-pair ring network consisting of two concentric rings with 10 m difference in the radii are used. Each sender in the outside ring (Radius = 25m) sends saturated traffic to its dedicated receiver which is located in inner ring with 10m separation distance. The receiver sensitivity was set such that the reception range was 10 m. Different PCS thresholds and CWmins were used in the simulations to evaluate the proposed “Indirect LD” under various conditions. The other parameters are listed in Table 1.

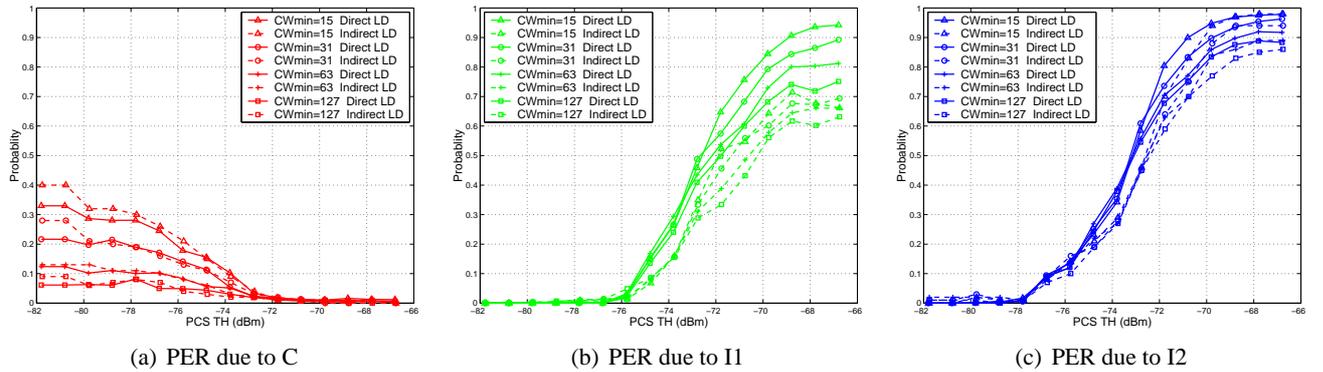


Figure 1: Real and estimated differentiated loss probabilities of individual links as a function of PCS threshold in an 18-pair ring network

Fig. 1 shows “Direct” and “Indirect” differentiated PER of one link as a function of the PCS threshold in the 18-pair ring network. All data points are the average values of 10 runs; each run uses the data with 5 seconds duration. From the figures, we can see that the estimated PER due to C and I2 by “Indirect LD” match the criteria well. The PER due to I1 is a little underestimated because of the assumption in (1). Such underestimation, however, becomes negligible in the low PER region (< 0.1), where an adaptation algorithm is usually designed to be operated.

Key observations are as follows: 1) Fig. 1 (a) shows that smaller the sensing range, the less the collision probability. The proposed solution can provide accurate estimation in a distributed (multi-link) network operating at any PCS threshold, and be used to select proper CWmin. 2) The curves in Fig.1 (b) and (c) for “Direct LD” and “Indirect LD” overlap well particularly for $PER < 0.5$. It means the differentiated PER due to I1 and I2 (asynchronous interference) are insensitive to the CWmin setting, and can be used to adapt other MAC parameters. 3) In the symmetric network, both I1 and I2 could be minimized by adapting the common PCS threshold.

4 Conclusion

Simple yet effective mechanisms were proposed for loss differentiation. Differentiated PER could be used for transmit power control, sensitivity adaptation and collision resolution in the future work.

References

- [1] J. Zhu, B. Metzler, X. Guo and Y. Liu, “ Adaptive CSMA for Scalable Network Capacity in High-Density WLAN: a Hardware Prototyping Approach”, *Proc. IEEE Infocom*, Mar. 2006.
- [2] H. Ma, S. Shin, and S. Roy, “Optimizing Throughput with Carrier Sensing Adaptation for IEEE 802.11 Mesh Networks Based on Loss Differentiation”, *IEEE ICC 2007*.
- [3] H. Ma, E. Alotaibi and S. Roy, “Analysis and Simulation Model of Physical Carrier Sensing in IEEE 802.11 Mesh Networks”, *OPNETWORK Conference 2006*, Aug. 2006, Washington DC
- [4] J. Kim, S. Kim, S. Choi and D. Qiao, “CARA: collision-aware rate adaptation for IEEE 802.11 WLANs”, *IEEE Conference on Computer Communications*, Apr. 2006
- [5] J.H. Yun, S.W. Seo, “Collision Detection based on Transmission Time Information in IEEE 802.11 Wireless LAN”, *Pervasive Computing and Communications Workshops*, 2006. March 2006
- [6] K. Whitehouse, A. Woo, F. Jian, J. Polastre, and D. Culler, “Exploiting The Capture Effect For Collision Detection and Recovery”. In *Proc. of the IEEE Em-NetS-II Workshop*, May 2005.
- [7] Q. Pang, S. C. Liew, V. C.M. Leung, “Design of an effective loss-distinguishable MAC protocol for 802.11 WLAN”, *Communications Letters, IEEE*, September 2005
- [8] D. Malone, P. Clifford, and D. J. Leith, “MAC layer Channel Quality Measurement in 802.11”, *Communications Letters, IEEE*, February 2007