On Loss Differentiation for CSMA-Based Dense Wireless Network

H. Ma, J. Zhu, and S. Roy

***Abstract*— In this paper, we propose a novel method to differentiate packet loss based on interference energy and timing relative to desired signal in CSMA-based dense wireless networks. All measurements are conducted locally at transmitters without any additional over-the-air overhead. Our method can estimate PER (packet error rate) due to interference *prior to* or *after* the beginning of the desired signal separately, allowing for more efficient MAC(media access control) adaptation design.**

***Index Terms*— IEEE 802.11, CSMA, WLAN, MAC, protocol, loss differentiation.**

I. Introduction

CSMA-BASED (e.g. IEEE 802.11 standard compliant) dense wireless networks are being increasingly deployed on university campuses and in enterprizes due to the increased demand of network capacity. In such environments, aggregate network throughput is interference limited. It is critical to the design of an effective interference mitigation scheme that packet losses due to various types of interference can be differentiated. There are mainly three categories of interference based on the timing relation between desired and interference signals, which are illustrated in Fig. 1:

1) **Collision (Synchronous Interference)**: the interference signal that starts at the same slot as the desired signal.
2) **Type-1 Interference**: the interference signal that arrives *prior* to the desired signal.
3) **Type-2 Interference**: the interference signal that arrives *after* the arrival of the desired signal.

Note that packet losses caused by both type-1 interference and type-2 interference are typically known as *hidden terminal problem* in the literature.

The major benefit of differentiating the type of packet loss lies in selecting an appropriate counter measure. Combatting collisions is done by tuning of the CW (contention window) size, so that the probability that stations transmit at the same time is minimized. For type-1 interference, our strategy is to decrease the PCS threshold of the transmitter so as to detect strong type-1 interference and therefore avoid unnecessary transmission attempts. Lastly, for type-2 interference, transmit power control is a potential solution, since sufficient increase of the power of the reference signal implies it cannot be corrupted by the interfering signal, or can reach the hidden interferer and force its deference. When both transmit power and PCS thresholds at each node vary, tuning only the PCS threshold can solve only type-1 interference but not type-2 interference, resulting in severe link starvation [1], which underscores the necessity for differentiating and counteracting *both* type-1 and type-2 interference.

Manuscript received July 11, 2007. The associate editor coordinating the review of this letter and approving it for publication was Prof. Tracey Ho. This work was supported in part by Intel Corp.

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Digital Object Identifier 10.1109/LCOMM.2007.071154.

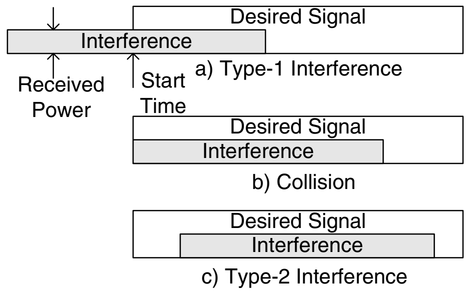


Fig. 1. Illustration of three types of interference

It is difficult to *diagnose the cause of a packet loss* because of the coarse 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 actual 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; [6] introduced a new MAC frame, NAK, to notify the sender a link error. All the 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; [7] estimated the collision probability as the ratio of channel busy times due to transmissions by other stations. *However, none of the above can effectively differentiate PER due to type-1 interference and type-2 interference, which is critical for improving MAC Layer throughput in dense WLANs.*

II. Novel Method for Loss Differentiation (LD)

We propose a novel method to distinguish and estimate PER due to different types of interference exploiting *timing of arrival* relative to desired signal. For convenience, the events that collision, type-1 interference and type-2 interference arrive, will be denoted by **C**, **I1** and **I2** respectively. We seek to estimate PER due to C, I1 and I2 individually, defined as

- p_c: the packet loss rate due to C.
- p_1: the packet loss rate due to I1.
- p_2: the packet loss rate due to I2.

We invoke the following key assumption: **the packet loss due to C, I1, and I2 are independent**[1], which will be used in estimating p_1 and p_2.

We assume that energy detection based carrier sensing is implemented. We introduce s, defined as the over-the-air energy observed by a node *prior* to a transmission. We denote γ_{min} as the *minimum* PCS threshold that essentially represents the noise floor [2]. If $s < \gamma_{min}$, the node assumes that there is no type-1 interference (i.e. noise only) and thus the PER due to I1 is assumed negligible. For convenience, we denote the binary variable E $=\{s > \gamma_{min}\}$, which takes value E = 1(0) if type-1 interference is detected (not detected). Thus packet losses for $E = 1$ may be ascribed to either I1 or I2 or C; whereas packet losses given $E = 0$ are only due to I2 or C.

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 choice of γ_{min} can be described as follows. A low γ_{min} ensures that only collisions or type-2 interference contribute to f_2; however, small γ_{min} will also lead to a lower T2-ratio (measured by $t_2/(t_1+t_2)$) and therefore require longer observation duration T to generate enough samples for reliable estimation, yielding the familiar trade-off between estimation accuracy and time. Thus, we set γ_{min} such that T_{2th} (T2-ratio threshold) fraction of transmissions satisfy $s \leq \gamma_{min}$ to achieve a desired operating point.

We define the following probabilities:

- p_1': the probability of packet loss due to I1, given E=1
- p : the probability of packet loss, given E=1
- $\bar{p_1}$: the probability of packet loss due to C or I2, given E=1

Using the independence assumption, we have

$$1 - p = (1 - p_1')\,(1 - \bar{p_1}) \tag{1}$$

where we estimate [3] p and $\bar{p_1}$ via

$$\langle p \rangle = \frac{f_1}{t_1} \text{ and } \langle \bar{p_1} \rangle = \frac{f_2}{t_2} \tag{2}$$

Note that we estimate the probability of packet loss due to C or I2 at E=0 using the assumption that such loss are independent of whether type-1 interference is present. Now, combine (1) and (2) to get

$$\langle p_1' \rangle = 1 - \frac{1 - \langle p \rangle}{1 - \langle \bar{p_1} \rangle} = 1 - \frac{1 - \frac{f_1}{t_1}}{1 - \frac{f_2}{t_2}} \tag{3}$$

[1]Certainly, this cannot be strictly true, since given the type-1 interference exists, the contribution of type-2 interference or collisions depends on the amount of type-1 interference present.

[2]The actual PCS threshold γ_{cs} always exceeds γ_{min}.

[3]We use $< >$ around any quantity to denote its estimate based on observed data.

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

$$\langle p_1 \rangle = \langle p_1' \rangle \cdot \frac{t_1}{t_1 + t_2} = (1 - \frac{1 - \frac{f_1}{t_1}}{1 - \frac{f_2}{t_2}}) \cdot \frac{t_1}{t_1 + t_2} \tag{4}$$

Using the assumption that the probabilities of packet loss due to C and I2 are independent, we estimate p_2 as

$$\langle p_2 \rangle = 1 - \frac{1 - f_2/t_2}{1 - \langle p_c \rangle} = \frac{f_2/t_2 - \langle p_c \rangle}{1 - \langle p_c \rangle} \tag{5}$$

Note that (5) gives the estimate of p_2 regardless of the value of E.

Finally, we propose a simple mechanism to estimate p_c based on the fact that collisions are synchronous with the reference signal. Define a probability, q, such that **each node will delay its transmission by half slot with probability of** q. [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 the PCS threshold, γ_{cs}.

Assume that N other 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

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

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 observed collision probability measured by m/n equals

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

Combining (6) and (7), we get

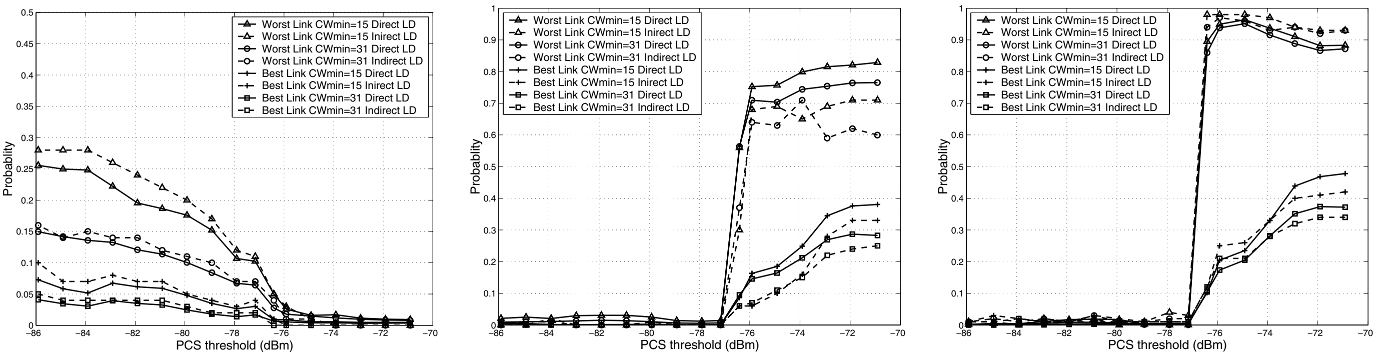
$$\langle p_c \rangle = (\frac{m}{n})(\frac{1}{1 - q}) \tag{8}$$

Inserting (8) into (5)

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

In summary, (8), (4) and (9) give the PER due to C, I1 and I2 respectively.

[4]A slot is 9 μs for .11a or .11g, and 20 μs for .11b. Notice even if a collision is detected, the transmission will still proceed.



(a) PER due to C (b) PER due to I1 (c) PER due to I2

Fig. 2. Differentiated loss probabilities of individual links as a function of PCS threshold in a dense WLAN

TABLE I
SIMULATION SET-UP IN A DENSE WLAN WITH 802.11A

Path loss exponent γ	3	Packet size(byte)	1500
Link data rate(Mbps)	36	T_{2th}	0.25
Transmit power(mW)	25	q	0.25

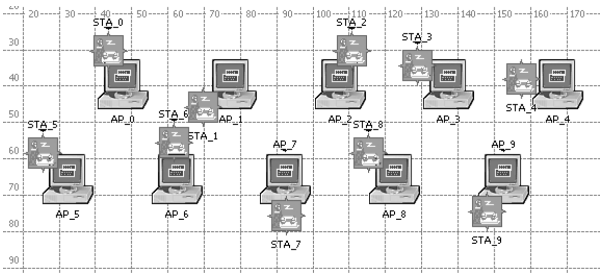


Fig. 3. A 10-cell dense WLAN

III. VERIFICATION

In this section, we verify the proposed loss differentiation (LD) method by comparing two sets of simulation results[5]. Both sets of simulations are carried out in OPNET using the modified physical carrier sensing module [3]. For the first set ("Direct LD"), the code developed in [2] is used to count the three types of packet losses at receivers. The "Direct LD" module (which is inserted into the OPNET physical layer) uses known timing of all packet arrivals (both reference and interference), to compute the SNIR (Signal to Noise and Interference Ratio) on a segment basis and determine packet accept/reject by comparing SNIR to preset SNIR threshold, S_0[6]. In summary, "Direct LD" essentially acts like a 'genie' and serves as a useful baseline reference for comparing performance of our "Indirect LD" method. Meanwhile, the estimated loss probabilities $\langle p_c \rangle$, $\langle p_1 \rangle$ and $\langle p_1 \rangle$ with proposed method were collected at transmitters, which is called "Indirect LD" in the figures.

For the simulations, a realistic dense WLAN scenario is used, which comprises 10 co-channel cells with cell radius of 10 meters and AP-to-AP distance of 30 meters. Each cell has one AP and one client (STA), and AP are transmitting saturated UDP traffic, i.e. a total of 10 links in the network.

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 I.

Fig. 2 shows "Direct" and "Indirect" differentiated PER estimation of the worst link (AP_6 - STA_6) and best link (AP_9 - STA_9) (in terms of PER) as a function of the PCS threshold and the CWmin in the dense WLAN. All data points are the average values of 10 runs; each run uses the data with 5 seconds duration. The figures show that the "Indirect LD" curves match the "Direct LD" curves well. Furthermore, as expected, the differentiated PER estimation for I1 and I2 is insensitive to the CWmin setting.

IV. CONCLUSION

We proposed a simple yet effective method to differentiate PER estimation for collision, type-1, and type 2 interferences. We showed preliminary simulation results with a typical cellular deployment to validate the method. Future work will consider more detailed simulation scenarios and address pragmatic issues concerning algorithm implementation.

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

[6]The SNIR threshold S_0 is determined from OPNET modulation curves at 10% packet error rate (PER). For 1500 byte frames with 36Mbps, S_0 equals 16.8dB.

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