# BLMon: A Loss Differentiation Scheme for 802.11n

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*Abstract*— **An important problem in 802.11 wireless networks is to accurately differentiate between losses while incurring low overhead. Lack of loss differentiation can result in throughput degradation, which becomes increasingly severe as data rates scale up. This paper presents BLMon, a loss differentiation scheme for 802.11n networks that leverages loss patterns in aggregate frames and frame retries to distinguish between losses. BLMon achieves high accuracy, incurs low overhead and does not require any protocol changes or customized hardware support.**

(a) Example     (b) Testbed Results

Fig. 1. Loss patterns within an A-MPDU.

## I. INTRODUCTION

Packet losses in 802.11 wireless networks can occur due to a variety of reasons. These include noisy channel conditions (e.g., signal attenuation and channel fading), collisions (when two or more nodes, that can carrier sense each other, transmit at the same time) or hidden nodes (when two or more nodes, that *cannot* carrier sense each other, have overlapping transmissions) [1], [2], [3]. Determining the cause of a packet loss is important because it dictates the corresponding action to be taken at the link layer. For instance, in case of collisions, exponential backoff is invoked, under noisy channel conditions, rate adaptation algorithm is used, and for hidden collisions, RTS/CTS may be enabled [1].

Several schemes have been proposed in the past for loss differentiation. *SoftRate* [1] uses BER estimates from the physical layer to differentiate losses but requires customized hardware support. *COLLIE* [3] uses error patterns within a physical-layer symbol to isolate collisions from a weak signal. However, to do this, a *COLLIE* receiver relays the entire packet to the sender for pattern analysis, incurring significant overhead. In [2] and [4], authors use RTS/CTS or fragmentation for loss differentiation but it is well-known that using them can result in signficant overhead [1]. In addition, [2] also uses PIFS; a non-standard inter-frame spacing for 802.11 DCF. In RRAA [5], RTS/CTS is adaptively enabled to differentiate between losses. However, it also incurs the overhead of RTS/CTS. In [6], authors propose the use of sub-frame loss patterns but do not distinguish between losses due to collisions and hidden nodes. In summary, prior schemes either require customized hardware support, protocol changes, incur large overhead, or differentiate between only two kinds of losses.

In this work, we present the *Burst Loss Monitor* (BLMon); a loss differentiation scheme for 802.11n wireless networks. The 802.11n standard allows frame aggregation whereby multiple frames (or MPDUs) are packed into an aggregate frame (called A-MPDU) and sent as a single transmission. BLMon leverages the differences in loss patterns within A-MPDUs as well as A-MPDU retries to isolate losses. BLMon accurately distinguishes losses due to noise, collisions, and hidden nodes
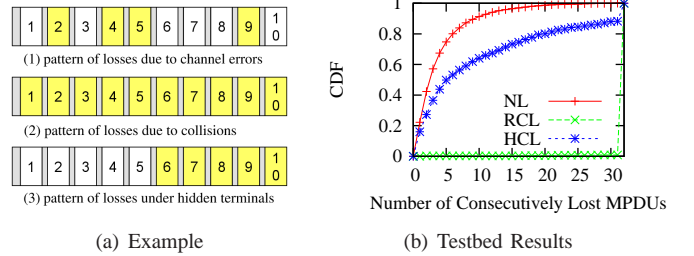
without requiring any protocol changes or customized hardware support and incurs low overhead.

Figure 1(a) shows an example of the kind of loss patterns that may occur within an A-MPDU. In particular, losses due to channel noise tend to be scattered whereas all MPDUs within an A-MPDU may be lost in case of collisions. In case of hidden nodes, bursty losses may occur starting from anywhere within an A-MPDU. Results from real testbed experiments show that pattern of consecutive losses along with parameters, such as number of A-MPDU retries, can be used to accurately differentiate losses. All these parameters are available at the sender. We make three main contributions in this work: (1) We conduct experiments to highlight the differences in loss patterns and A-MPDU retries under different kinds of losses, (2) we propose metrics for capturing differences in loss patterns, and (3) we design BLMon, which uses these metrics to perform accurate loss differentiation.

## II. EXPERIMENTAL STUDY

**Experimental Platform**: We use Ubiquiti Litestation as the AP, which uses Atheros AR9160 chipset. The client stations use PCI based TP-Link 802.11n cards with Atheros AR5416 chipset. Both AP and clients are of $3 \times 3$ antenna configuration and have 2 spatial streams. The A-MPDU length is 32 frames.

**Noise Analysis**: To obtain loss patterns only due to noise (termed as Noise Loss or NL), we use a single transmitter-receiver pair. With background channel noise, MPDU losses are mostly isolated or occur in small bursts across a range of Packet Error Rates (PER). Figure 1(b) shows the CDF of the number of consecutively lost MPDUs on a link with a PER of ∼30%. Observe that in ∼80% of A-MPDUs, less than 5 consecutive MPDU losses were observed. In addition, A-MPDU retries tend to be rare under NL (as shown by the occasional blue bars in Figure 2(a)) unless the PER is very high (e.g., ≫ 50%). This is because the PHY Header/Preamble is sent at the basic rate which tends to be much lower compared to the rates at which A-MPDUs are transmitted.

**Collision Analysis**: To obtain collision patterns (termed as Regular Collision Loss or RCL), we use two transmitters and
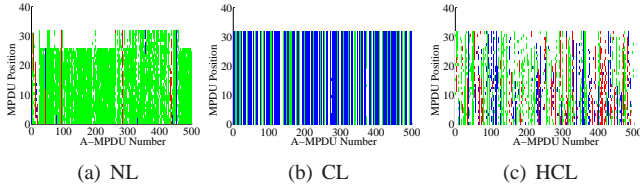
Fig. 2. MPDU losses and A-MPDU retries under different kinds of losses. Vertical white bars indicate lost frames, green bars indicate successful frames, blue bars indicate A-MPDUs that are retried once, and the red bars indicate A-MPDUs retried more than once. Link PER was 13% under NL.

| Metric | DA/FP | NL | RCL | HCL |
|--------|-------|------|------|------|
| BII | DA | 95.4 | 95.3 | 80.2 |
|     | FP | 1.9 | 16.5 | 8.3 |
| PER | DA | 81.3 | 100 | 25 |
|     | FP | 0 | 25 | 0 |
| ARET | DA | 72.9 | 100 | 74.9 |
|      | FP | 0 | 33.4 | 6.2 |

TABLE I
INDIVIDUAL METRICS (PER=33%)

| PER | DA/FP | NL | RCL | HCL |
|-----|-------|-----|------|-----|
| 5% | DA | 96 | 100 | 95 |
|    | FP | 0.1 | 1.5 | 1.3 |
| 33% | DA | 95 | 100 | 95 |
|     | FP | 0.1 | 2.8 | 0 |
| 60% | DA | 83 | 97 | 96 |
|     | FP | 0.8 | 16 | 0 |

TABLE II
BLMON

a common receiver and set distances between them so as to ensure that no losses occur due to noise or hidden nodes. In case of RCL, either (1) an A-MPDU is received with zero or more MPDUs in error, which happens when a signal from one transmitter dominates the other, thus winning in physical layer capture or (2) no A-MPDU is received, this happens when the PHY header/preamble gets corrupted, which causes the entire A-MPDU to be lost. Figure 1(b) shows results for the scenario in which the transmitters are placed at the same distance from the common receiver. Observe that 99.9% of A-MPDUs, that were part of a collision, had all MPDUs corrupted (These results include only those A-MPDUs for which a blockACK was received). In addition, A-MPDUs are generally retried once under RCL (see Figure 2(b)). This happens because the randomized exponential backoff mechanism of 802.11 desynchronizes channel access. Consequently, if a blockACK is not received, A-MPDU retries can reveal information about A-MPDU collision.

**Hidden Node Analysis**: To obtain loss patterns under hidden nodes (termed as Hidden Collision Loss or HCL), we use two transmitters and a common receiver and ensure that no losses occur due to noise or collisions. We observed that under HCL, senders either experience isolated losses or very large number of consecutive losses as shown in Figure 1(b). For instance, more than 55% of A-MPDUs had more than 5 consecutively lost MPDUs compared to 20% under NL. Moreover, a large number of A-MPDUs were retried more than once. Since nodes are unable to carrier sense, successive collisions are more likely under HCL.

## III. METRICS FOR LOSS DIFFERENTIATION

To capture the observed differences in loss patterns, we propose the use of following metrics.

*Burst Isolation Index (BII)*: BII is used for quantifying the *degree* of isolation or spread in MPDU losses. $BII=L_T/L$, where $L$ is the number of MPDUs received in error and $L_T$ is the number of "01" and "10" transitions within an A-MPDU, where 1 and 0 correspond to successful and unsuccessful MPDUs, respectively. The maximum value of BII is two (when the blockACK bitmap contains only alternating 1s and 0s and the sequence starts and ends with a 1) and the minimum value is zero (when we get all 0s). The more isolated losses we have in an A-MPDU, the greater the value of BII ($> 1$).

*A-MPDU Retries (ARET)*: This is the number of times an A-MPDU is retransmitted.

*Packet Error Rate (PER)*: It is the ratio of MPDUs received in error to the total number of MPDUs in an A-MPDU.

## IV. BURST LOSS MONITOR (BLMON)

To differentiate between NL, RCL, and HCL, we propose BLMon. BLMon computes the metrics discussed in the previous section for each A-MPDU having at least one MPDU in error. It then uses the *joint distribution* of these metrics to conclude whether an A-MPDU experienced NL, RCL, or HCL. For evaluation, we first run each metric individually on a real trace containing losses due to noise, collisions, and hidden nodes. We then perform comparison with BLMon. The evaluation is based on two measures: (a) Detection Accuracy (DA), and (b) False Positive rate (FP). DA is the percentage of A-MPDUs that are correctly detected to have experienced a certain kind of a loss whereas FP is the percentage of A-MPDUs concluded to have experienced a certain kind of a loss when in reality they did not.

Tables I and II show the performance results for individual metrics and BLMon, respectively. BII results in the highest average DA (90.3%) across all metrics. However, FP with BII can be high under RCL and HCL. This happens because BII can term bursty noise losses as being RCL or HCL. PER has poor DA for HCL and results in a high FP for RCL. ARET can be a useful metric for HCL as it has high DA and low FP. BLMon, on the other hand, outperforms all individual metrics both in terms of DA and FP. It has high average DA ($\geq 96.7\%$) and low FP ($\leq 0.97$) when link PER is 33%. When link PER is 60%, FP is high under RCL due to increase in bursty losses.

## V. CONCLUSION AND FUTURE WORK

In this work, we proposed BLMon; a loss differentiation scheme which leverages loss patterns within 802.11n aggregate frames and frame retries to isolate losses due to noise, collision and hidden nodes. BLMon only uses information that is already available to the sender. In the future, we plan to explore history based metrics to further improve the performance of BLMon. Moroever, we plan to evaluate BLMon's performance when it is used by rate adaptation and exponential backoff algorithms.

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