EDCA Delay Analysis of Spatial Multiplexing in IEEE 802.11-Based Wireless Sensor and Actuator Networks

Mohsen Maadani, *Member, IACSIT*, Seyed Ahmad Motamedi, and Mohammadreza Soltani

***Abstract*—Low packet delay and packet loss probability are the two most contradicting requirements of wireless sensor and actuator networks (WSAN). In this paper, saturation delay characteristics of Multiple Input Multiple Output (MIMO)-enabled IEEE 802.11 technology utilizing Enhanced Distributed Channel Access (EDCA) at Medium Access Control (MAC) and a simple spatial-multiplexing scheme in PHYsical (PHY) layer has been thoroughly analyzed. Results show that due to the low Signal to Noise Ratio (SNR) in WSAN environment, simple modulation schemes with low spectral efficiency have better delay and reliability performance. Otherwise, the delay will be highly sensitive to SNR, packet payload, number of competing nodes.**

***Index Terms*—IEEE 802.11, maximum likelihood receiver, packet delay, spatial multiplexing.**

I. Introduction

Due to the numerous advantages of wireless technology, it has been used in various consumer devices. Recently, there has been much attention in making some parts of wireless sensor and actuator networks (WSAN), wireless. Being reliable and real-time are the two most challenging requirements of these networks, which contradict with the nature of wireless communication medium. Enhancing current wireless technologies and standards towards industrial needs, and if not possible, designing new protocols is a developing research field [1].

Wireless Local Area Network (WLAN) based on IEEE 802.11 standard [2] is one the most common and popular technologies which has been used as the dominant technology in local wireless networks. One of the problems of using this standard for industrial applications is the non-deterministic behavior of Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) mechanism used in its Medium Access Control (MAC) layer. The MAC amendment IEEE 802.11e was introduced to improve the packet delay for certain applications through traffic prioritization. It defines 4 Access Categories (AC), which in the order of priority are: Voice, Video, Best Effort and Background. Voice applications can tolerate latency of about 150 ms and packet loss of up to 1%, whereas latency in some WSAN's must be as low as 10 ms, and much higher reliability is required. Analysis and enhancement of IEEE 802.11e delay property for real-time applications has been studied in the literature since the release of this amendment [4]-[9]. Final version of IEEE 802.11n amendment [2] has recently been released, aiming to increase the throughput by utilizing Multiple Input Multiple Output (MIMO) technology and some other modifications. Using a feedback from receiver to the transmitter, the Space-Time Code (STC) and pre-coder are adopted to the channel situations with the target of maximizing data-rate while maintaining an acceptable packet error rate (PER). Ref. [4] has studied saturation delay performance of EDCA mechanism in Single Input Single Output (SISO) configuration and compared it with a simple Spatial Multiplexing (SM) MIMO scheme. It is shown that SM outperforms SISO in both packet delay and PER. In this paper, delay and reliability performance behavior of utilizing SM in MIMO-enabled WLAN stations for WSAN's has been thoroughly studied. Due to random nature of packet transmission initiations, which is highly dependent on the network topology and application, carrying out a theoretical analysis without making several simplifying assumptions is not an easy task [5]. As an alternative, our choice has been trying to assess SM scheme through simulation. This approach sometimes provides better results than some oversimplified analytical approaches.

This paper is organized as follows: Section II reviews the related work in IEEE 802.11 assessment. Section III presents the simulation scenario and results. The paper is concluded in section IV.

II. Related Work

Ref. [4] has compared SISO and SM MIMO schemes from average and maximum packet delay perspective for 1Mbps data rate. It shows that SM outperforms SISO from delay, PER and Bit Error Rate (BER) aspects, at the cost of 2 transceivers per node and a little decoding complication. Ref. [5] has analyzed statistical distribution of response time in IEEE 802.11g/e configuration. It presents a computational model for transmission delays when low-to-medium concurrent traffic is taken into account. It is shown that for low network load (below 20%), response times are generally bounded. For higher traffic load (up to 40%), quasi-deterministic and bounded latencies are achieved for selected high-priority messages using EDCA mechanism. Ref. [6] using simulation, has analyzed the EDCA behavior for real-time industrial communication. A Markov chain complicated analytical model for the throughput and access delay of IEEE 802.11 EDCA mechanism under saturation condition has been proposed in [7]. References [4] and [8] have studied the effect of traffic prioritization in IEEE802.11e for real-time applications using simulation. To

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the author's knowledge, no other analysis has been done regarding the packet delay and reliability of using spatial multiplexing in wireless sensor and actuator networks based on MIMO-Enabled WLAN stations.

TABLE I: IEEE802.11E SIMULATION SCENARIO

Parameter	Value
Data Rate	1 & 2 Mbps (DBPSK and DQPSK Modulations)
Control Rate	1 Mbps (DBPSK Modulation)
PHY Header	24 Bytes
MAC Header	28 Bytes
ACK Packet size	14 Bytes
Slot Time	20 µs
SIFS	10 µs
AIFSN	2
CWmin [0 1]	7 15
CWmax [0 1]	15 31
TXop	Disabled
Retry Limit	Disabled (Unlimited)

III. SIMULATION RESULTS

A. Simulation Scenario

IEEE 802.11b with default EDCA parameters listed in Table I [2] has been chosen as PHY and MAC layers, except for AIFSN (Arbitration Interframe Space for access category N) which is considered the same for all AC's; i.e. its differentiation effect is not in the scope of this paper. SIFS stands for Short Interframe Space, CWmin and CWmax are minimum Contention Window and maximum Contention Window respectively. TXop is the Transmission Opportunity [1].

PHY layer preamble and header and packet acknowledgement (ACK) are sent with control rate (1Mbps). MAC layer header and payload are sent with data rate.

Retransmission limit is assumed infinity; each packet is sent as much as needed to get to the destination. The standard default value is 7 [2], but loosening this limitations helps to enhance reliability of the network to maximum (100%). Reliability is defined as the percentage of packets reaching to the destination.

Packet data payload for monitoring and control applications is typically short; 8, 32, 128 and 256 bytes are simulated and compared.

Quasi-static flat fading multipath Rayleigh channel model is used; channel condition doesn't change during each packet transmission time, and changes for the next.

Saturated traffic mode is considered: all 4 access categories in all nodes always have a packet waiting to be sent. It is a good indicator of network performance under heavy traffic load and shows the upper bound to delay, Packet Error Rate (PER) and Bit Error Rate (BER) [4], [5].

Both causes of packet loss are considered: collision and channel error. Each of them initiates the backoff process in IEEE 802.11e CSMA/CA [1].

Transceivers have 2 Receive (Rx) and Transmit (Tx) antennas (2×2 MIMO). Maximum Likelihood (ML) spatial multiplexing (SM) receiver, with 2 spatial paths SM order of 2) has been simulated, which results in Spatial Diversity (SD) gain of 2, improving the error rate [10].

Real-Time traffic is mapped to highest priority (AC0) and its characteristics have been analyzed.

Mesh topology with single-hop transmissions has been chosen; each node can send packet to all other nodes. Such configuration is typical in sensors and actuators connected to the same instrument in a factory (e.g. control loops etc.)

Simulation has been done using MATLAB communications toolbox.

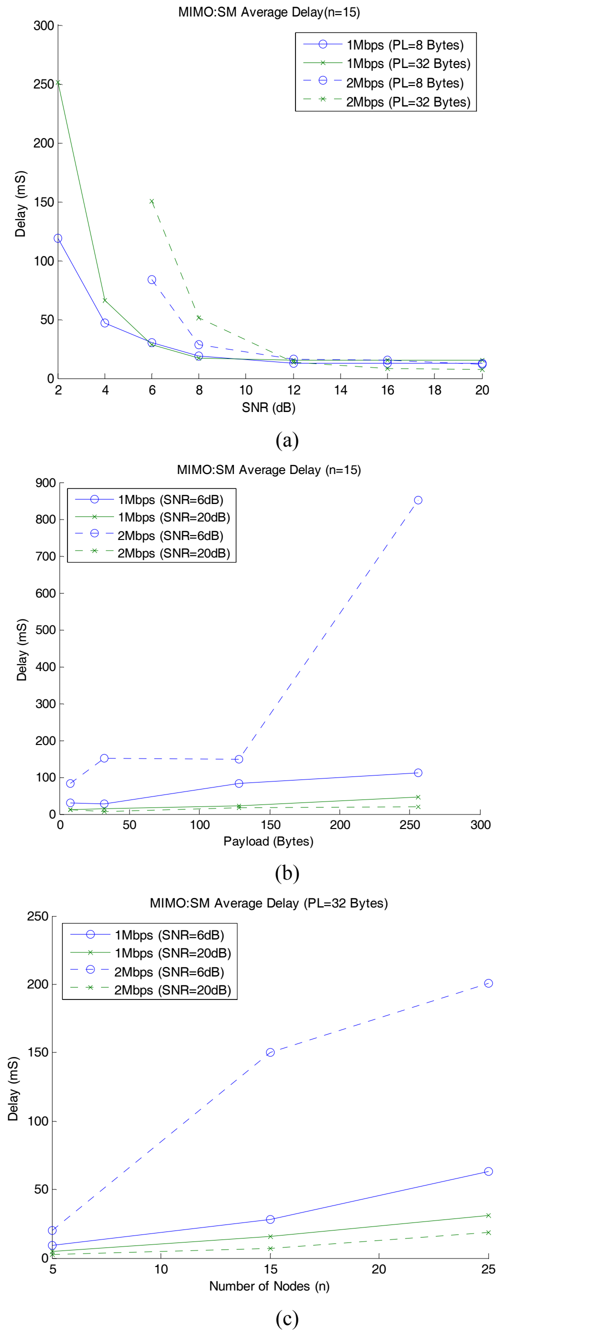
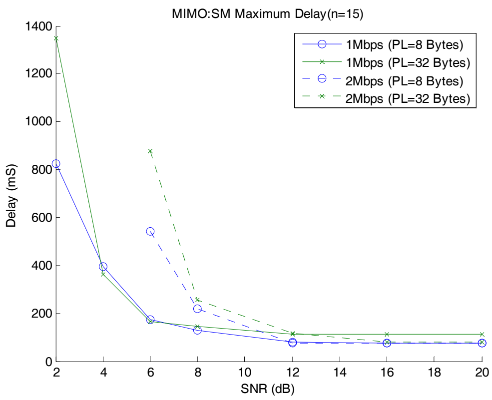


Fig. 1. MIMO Spatial multiplexing (MIMO:SM) average EDCA AC0 saturation delay for 1/2Mbps data rate and in (a) different SNR's, (b) diffrenent packet payload, (c) different number of competting nodes

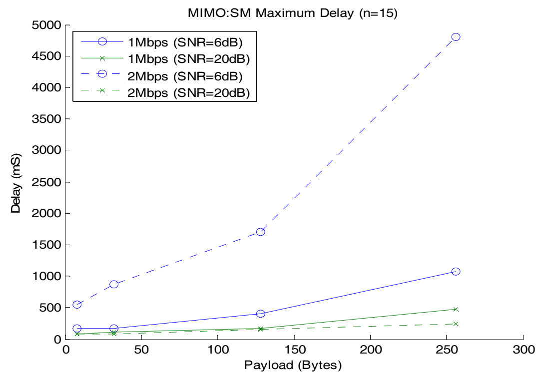
B. EDCA Delay

Fig. 1 compares the packet delay for different configurations. It can be seen in fig. 1a that at high Signal to Noise Ratios (SNR) (above 12dB), 2Mbps data rate has lower packet delay, but at medium (6-12dB) and low (below 6dB) SNR's delay is worse than 1Mbps data rate, and increases exponentially. At low SNR's, the packet payload impacts the delay and it is increased exponentially. Fig.1b studies the effect of packet payload. It is seen that at high SNR's, as expected, high data rate outperforms the low one. But at medium and low SNR's, 1Mbps delay increases linearly with packet payload, whereas 2Mbps delay increases exponentially. It can be noticed in fig. 1c that the slope of delay increase with respect to node density (n) at low SNR's is much higher for 2Mbps data rate. Fig. 2 compares different configurations from maximum packet delay perspective. As can be seen, the slope of increase is higher with respect to Fig. 1.

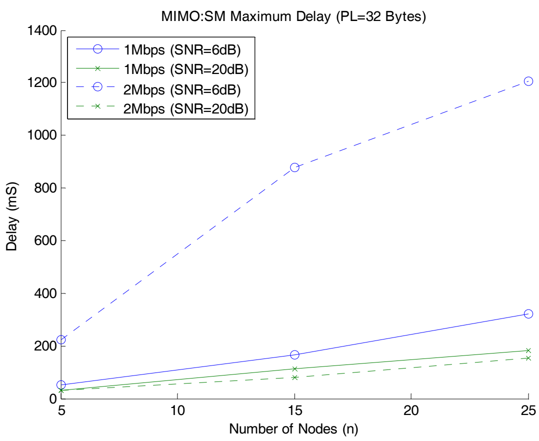
C. EDCA Retransmission Count



(a)



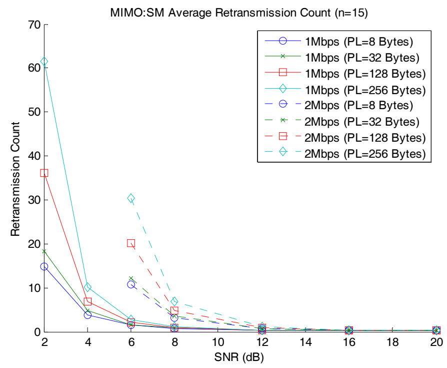
(b)



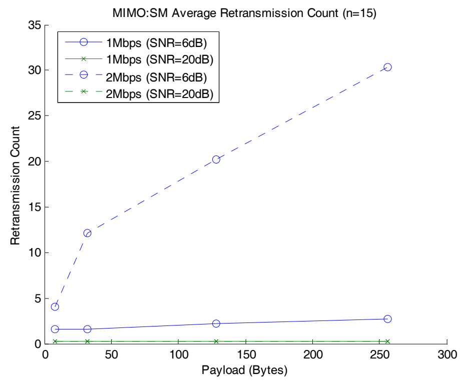
(c)

Fig. 2. MIMO Spatial multiplexing maximum EDCA AC0 saturation delay for 1/2Mbps data rate and in (a) different SNR's, (b) diffrenent packet payload, (c) different number of competing nodes

Fig. 3 compares the average number of retransmissions needed to have 100% reliability in different configurations. As expected, retransmission counts at high SNR's are generally bounded. Fig. 3a shows that at medium and low SNR's, retransmission count increases exponentially with increasing packet payload and data rate. Fig. 3b and c show that at high SNR's or low data rate, packet payload and number of competing nodes have negligible effect on retransmission count. 2Mbps data-rate delay at low SNR's increases exponentially with payload and/or node density. Fig. 4 compares the maximum retransmission counts for different configurations and has similar results as fig. 5. It can be inferred from theses simulations that, fixing retransmission limit to its default value (7) has destructive effects on system reliability in sensor and actuator applications due to low SNR environment. Hence, it should be disabled, or for better performance, dynamically adapted to the network load, SNR and node density. Fig. 5 and 6 compare retransmission probability density for 8-byte and 32-byte payload respectively. Fig.7 compares BER and PER for different configurations. The higher the data-rate and packet payload, the higher is the error rate.



(a)



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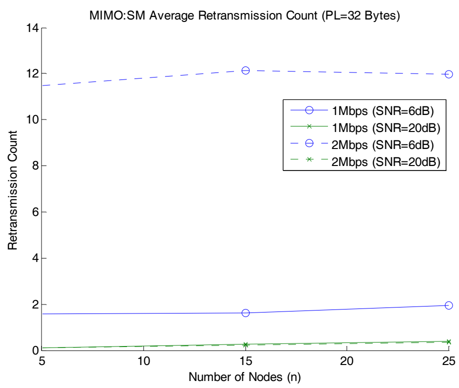

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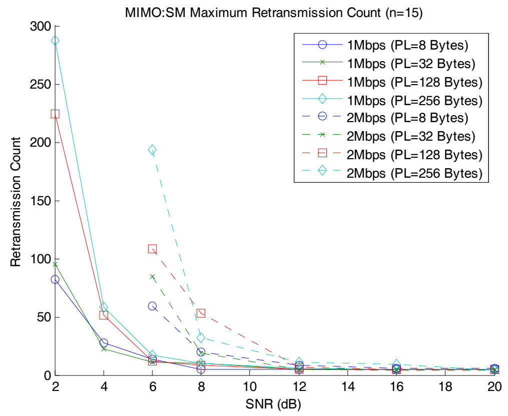
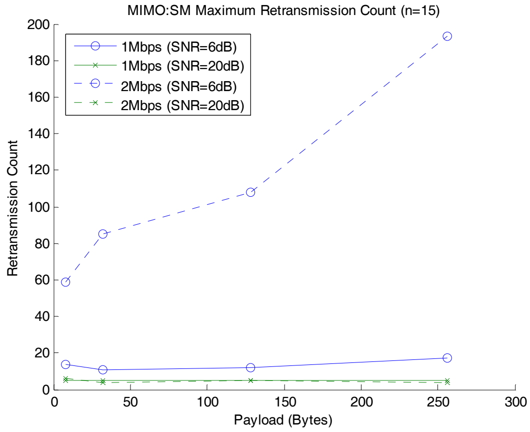
Fig. 3. MIMO Spatial multiplexing average number of AC0 retransmissions for 1/2Mbps data rate and in (a) different SNR's, (b) diffrenent packet payload, (c) different number of competing nodes



(a)



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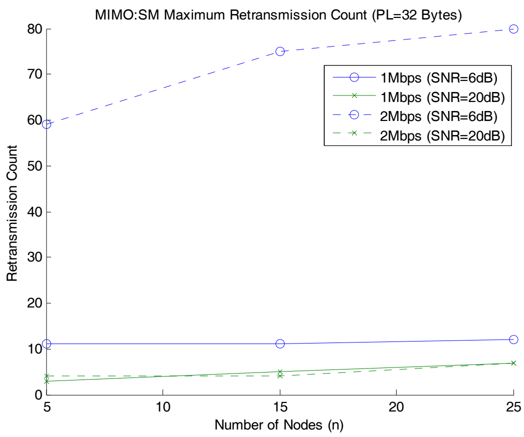

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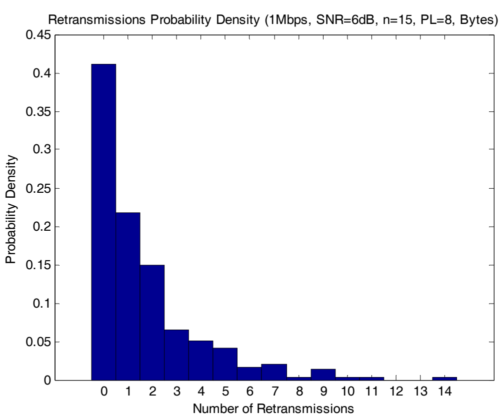
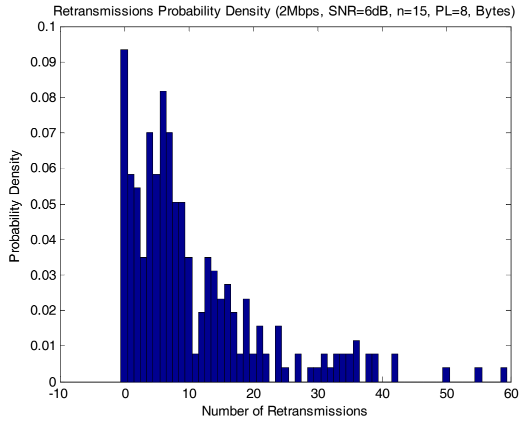
Fig. 4. MIMO Spatial multiplexing maximum number of AC0 retransmissions for 1/2mbps data rate and in (a) different SNR's, (b) diffrenent packet payload, (c) different number of competting nodes

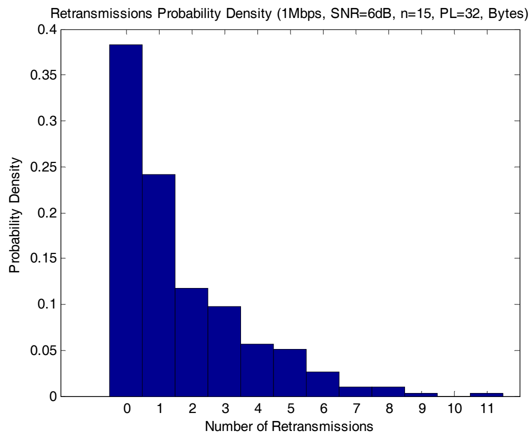


(a)

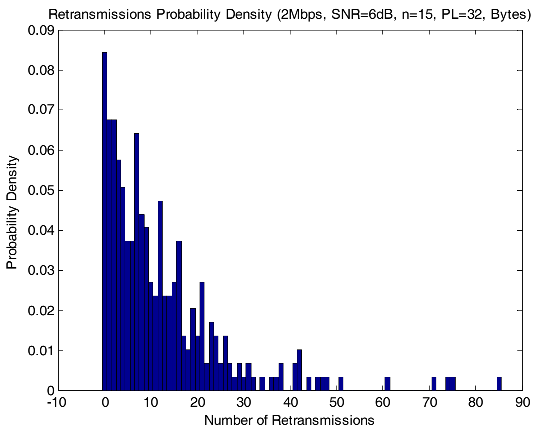


(b)

Fig. 5. MIMO Spatial multiplexing retransmission-count probability density for 8-byte packet payload (a) 1mbps data rate (b) 2mbps data rate

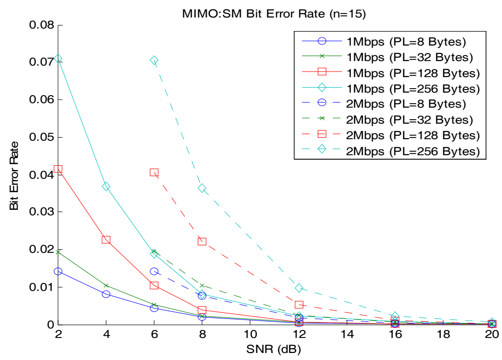


(a)



(b)

Fig. 6. MIMO Spatial multiplexing retransmission-count probability density for 32-byte packet payload (a) 1Mbps data rate (b) 2mbps data rate



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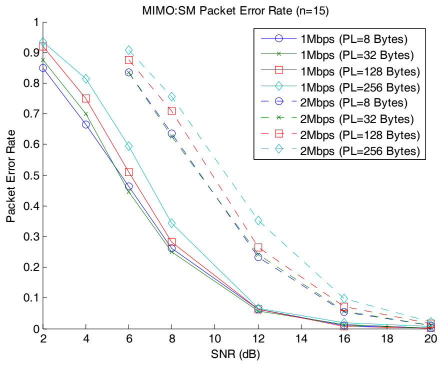

(b)

Fig. 7. MIMO Spatial multiplexing error performance for 1/2mbps data rate (a) bit error rate (BER) (b) packet error rate (PER)

IV. Conclusion and Future Work

In this paper, saturation delay and reliability of EDCA mechanism for SM-enabled IEEE 802.11 based wireless sensor and actuator networks has been analyzed. Simulation results show that simple modulation schemes with spectral efficiency of 1 usually outperform high-rate ones, due to the noisy and short packet payload nature of industrial networks. Also for reliable applications, retransmission limit must be canceled, loosened or dynamically adopted to the network condition. Otherwise, packet loss ratio will increase beyond acceptable limit. Our future work is to assess using more sophisticated spatial multiplexing codes, and adaptive schemes.

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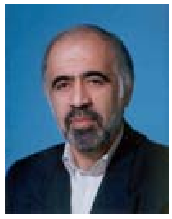

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