International Journal of Mechatronics, Electrical and Computer Technology

Vol. 2(3), Apr, 2012, pp 44-57, **ISSN**: 2305-0543
Available online at: http://www.aeuso.org

Packet Retransmission and Delay Assessment of Spatial Diversity-Enabled Reliable Wireless Industrial Networks

Arthur M. Blake

Department of Engineering, Gold-Smith University, London, UK

*Corresponding author's E-mail: *Ablake.university@yahoo.com.uk*

Abstract

Most important parameters in Industrial Communication Networks are packet delay and reliability. In this paper, packet delay and retransmission characteristics of Multiple Input Multiple Output (MIMO)-enabled wireless industrial networks using a simple Spatial-Diversity (SD) scheme in physical layer has been analyzed. Results show that due to the low Signal to Noise Ratio (SNR) in factory environment, simple modulation schemes with lower spectral efficiency have better delay performance and the default retry-limit parameter of 7 will satisfy the reliability of about 100%. Otherwise, the delay will be highly sensitive to SNR, packet payload, number of competing nodes and other parameters.

Keywords: Wireless Industrial Network; Spatial Diversity; Packet Delay; Packet Reliability, IEEE 802.11.

1. Introduction

Due to the numerous advantages of wireless technology, it has been used in various consumer devices. Being reliable and real-time are the two most challenging requirements of Wireless Industrial Networks, which contradict with the error-prone nature of wireless communication medium. Improving current wireless technologies towards industrial needs is a developing research field [3]. Wireless Local Area Network (WLAN) based on IEEE 802.11 standard is one the most common and popular technologies which has been used as the dominant technology in local wireless networks. Non-deterministic behavior of Carrier Sense Multiple Access/Collision Avoidance

(CSMA/CA) mechanism used in WLAN Medium Access Control (MAC) layer, limits its usage in industrial applications. The MAC amendment IEEE 802.11e bounds the packet delay for real-time traffics using 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. Delay analysis of this amendment ant introducing methods for its enhancement has been studied [4]-[9].

Final version of IEEE 802.11n amendment [2] was released in 2009, aiming to increase the throughput by utilizing Spatial Multiplexing (SM) scheme of 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). In [4] we have studied saturation delay performance of EDCA mechanism in a simple Spatial Multiplexing (SM) MIMO scheme. In this paper, delay and reliability performance behavior of utilizing Spatial Diversity (SD) 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 [6].

As an alternative, our choice has been trying to assess SM scheme through simulation. This approach provides better insights than some oversimplified analytical approaches. This paper is organized as follows: Section 2 reviews the related work in IEEE 802.11 assessment. Section 3 presents the simulation scenario and results. The paper is concluded in section 4.

2. Related Work

Ref. [5] 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. [4] has studied delay performance of SM MIMO scheme. It is shown 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. Ref. [7] 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. [8] using simulation, has analyzed the EDCA behavior for real-time industrial communication.

A Markov chain based and rather complicated analytical model for the throughput and access delay of IEEE 802.11 EDCA mechanism under saturation condition has been proposed in [9]. References [6] and [9] have studied the effect of traffic prioritization in IEEE802.11e for real-time applications using simulation. To the author's knowledge, except [4], no other analysis has been done regarding the packet delay and reliability of wireless industrial networks based on MIMO-Enabled WLAN stations using spatial diversity.

3. Simulation Results

3.1. Simulation Scenario

- IEEE 802.11b with default EDCA parameters listed in Table I [1] 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.

Table1. IEEE802.11 Simulation parameters

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
Payload	40 Bytes
Slot Time	20 µs
SIFS	10 µs
AIFSN	2
CWmin [0 1 2 3]	7 15 31 31
CWmax [0 1 2 3]	15 31 1023 1023
TXop	Disabled
Retransmission Limit	Disabled (Unlimited)

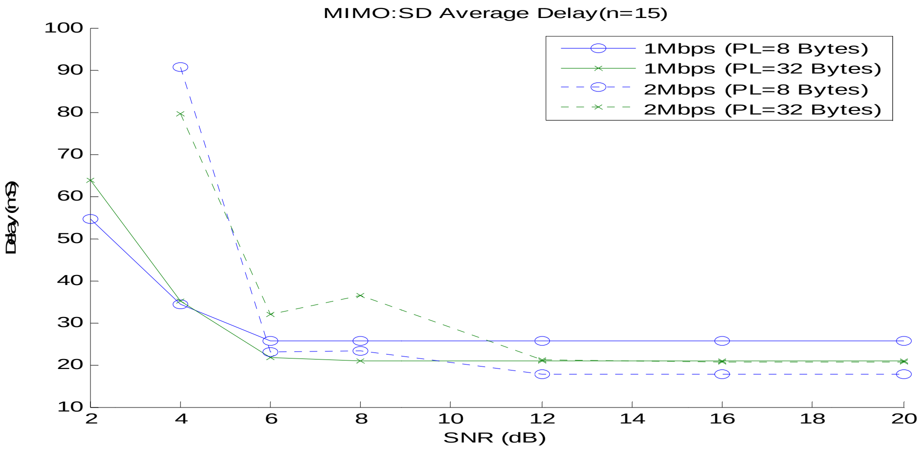
- Retransmission limit is assumed infinity; each packet is sent as much as needed to get to the destination. The standard default value is 7 [1], but loosening this limitations helps to enhance reliability of the network to maximum (100%). Reliability is defined as the percentage of packets reaching 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 Rayleigh multipath channel model is used; channel condition doesn’t change during each packet transmission time, and changes for the next.

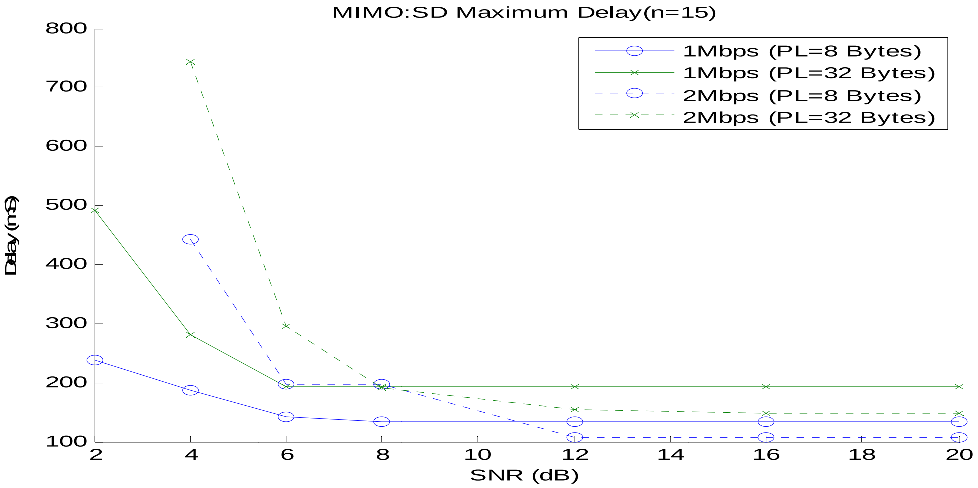
- Saturated traffic mode is considered: all 4 access categories in all nodes always have a packet waiting to be sent. It is a good indicator of network performance under heavy traffic load and shows the upper bound to delay, Packet Error Rate (PER) and Bit Error Rate (BER) [4], [5].
- Both causes of 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). Spatial Diversity (SD) receiver, with Alamuti Space-Time code and no channel state information (CSI) at transmitter is used [11].
- 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.

3.2. Packet Delay

Fig. 1 compares the packet delay with respect to Signal to Noise Ratio (SNR) for different configurations. It can be seen that at high SNRs (above 12dB), 2Mbps data rate has lower packet delay for 8-byte packet payload (PL), while its' the same for 32-byte payload. At medium (6-12dB) and low (below 6dB) SNR's 2Mbps the delay is worse than 1Mbps data rate, due to channel error. Fig.2 studies the effect of packet payload. It is seen that at high SNR's, as expected, high data rate outperforms the low one in most node densities. But at medium and low SNR's, 1Mbps delay increases linearly with packet payload, whereas 2Mbps delay increases exponentially [10]. It can be noticed in fig. 3 that the slope of delay increase with respect to node density (n) at low SNR's is much higher for 2Mbps data rate. Comparing fig.2 and fig.3 shows that increasing node density and packet payload have similar effect on packet delay.

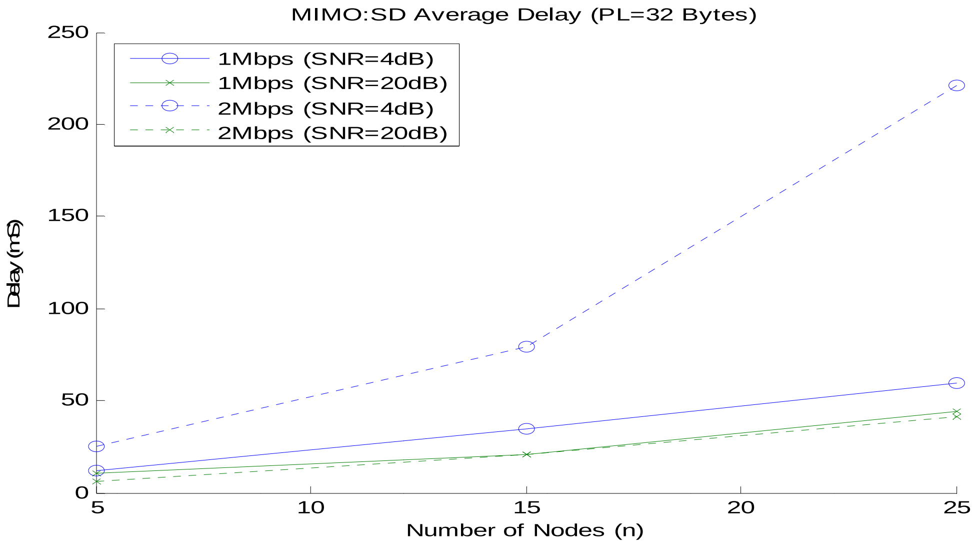


(a)

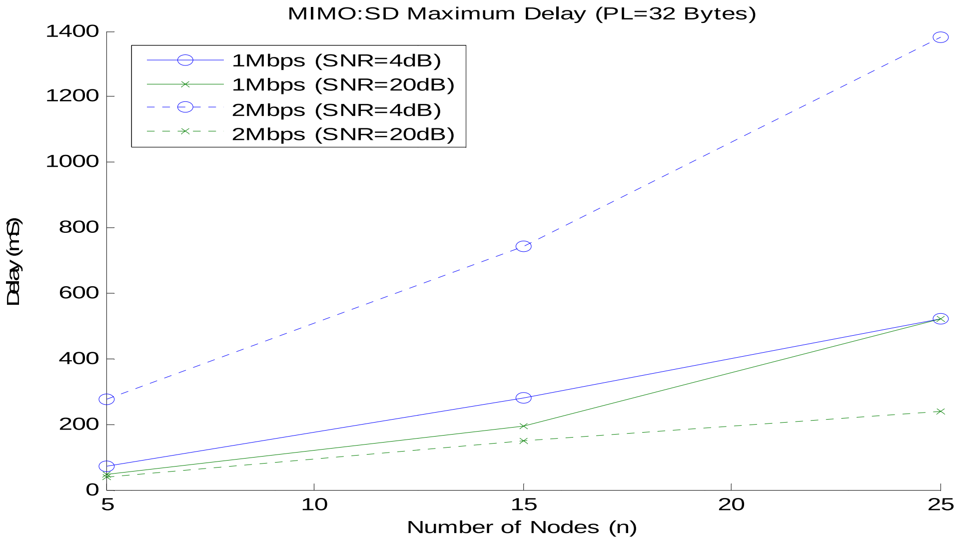


(b)

Fig. 1: MIMO Spatial Diversity saturation delay with respect to SNR for 1/2Mbps data rate (a) average, (b) maximum

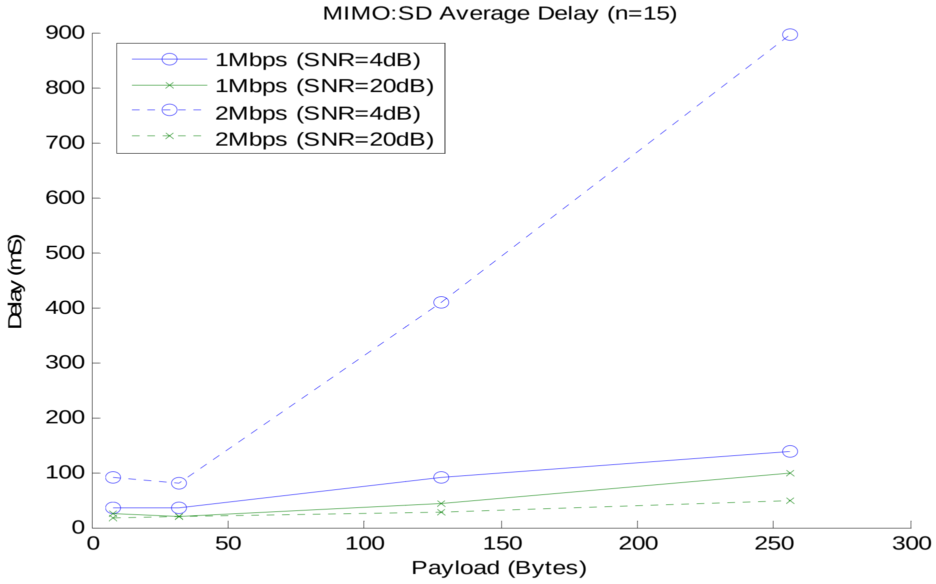


(a)

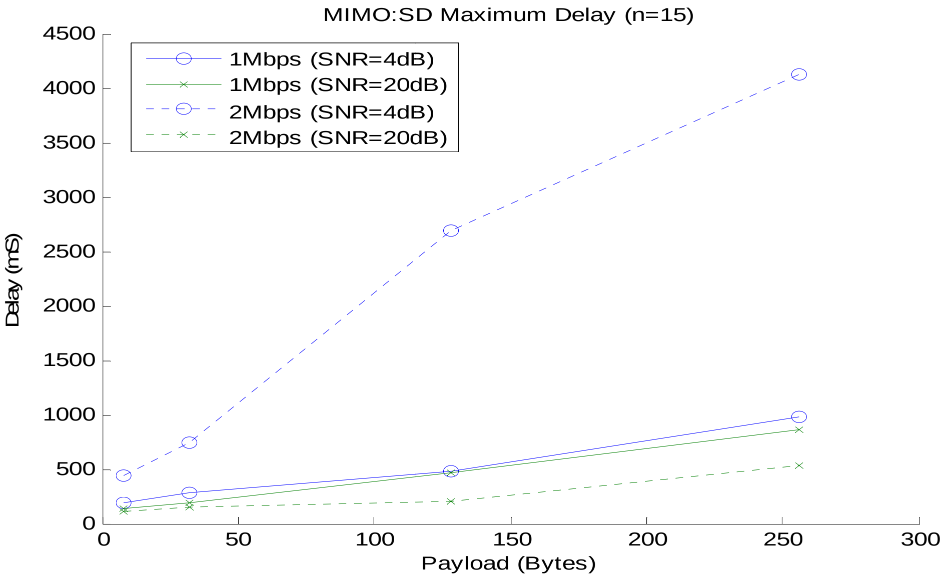


(b)

Figure2. MIMO Spatial Diversity saturation delay with respect to number of competting nodes for 1/2Mbps data rate (a) average, (b) maximum



(a)

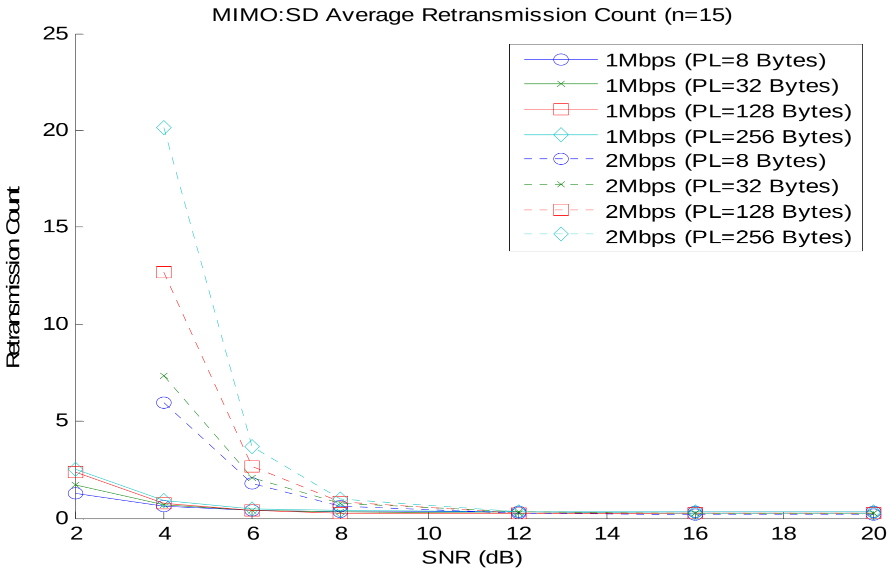


(b)

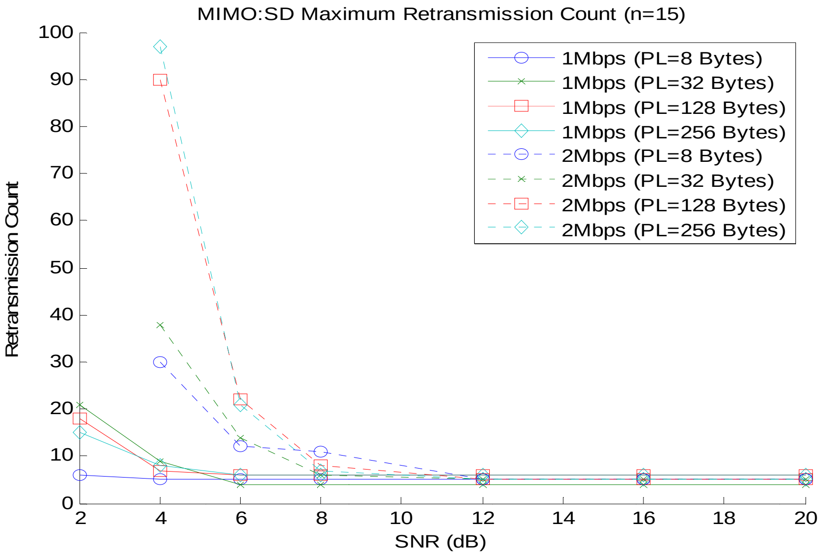
Figure3. MIMO Spatial Diversity saturation delay with respect to data length (payload) for 1/2Mbps data rate (a) average, (b) maximum

3.3. Packet Retry Count

Fig. 4 compares the number of retransmissions needed to have 100% reliability in different configurations. As expected, retransmission counts at high SNR's are generally bounded. It can be seen that at medium and low SNR's, retransmission count increases exponentially with increasing packet payload and data rate. Fig. 5 and 6 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. 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. 7 compares retransmission probability density at SNR=4dB for 32-byte payload. As noticed in previous results, high data rates have lower reliability at low SNR's.

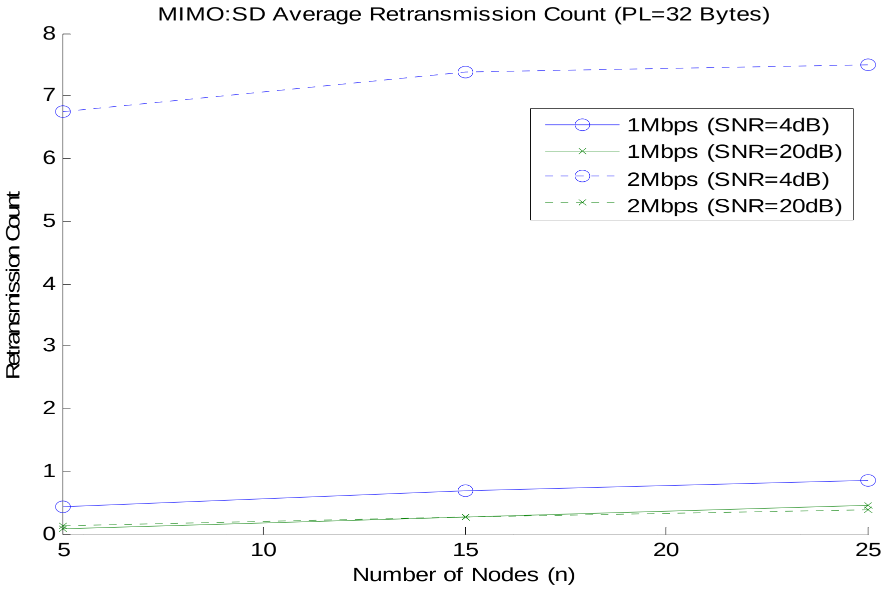


(a)

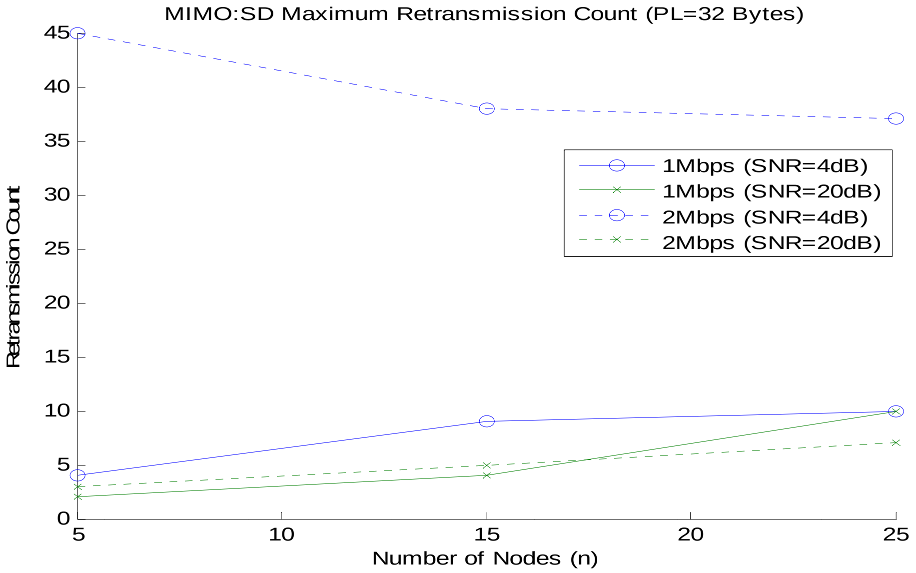


(b)

Figure4. MIMO Spatial Diversity number of retratnsmissions for 100% reliability with respect to SNR for 1/2Mbps data rate (a) average, (b) maximum

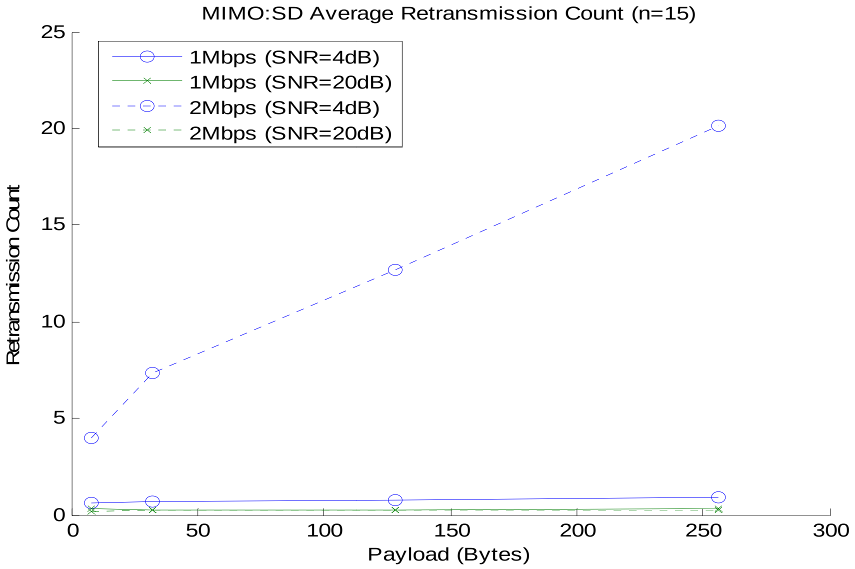


(a)

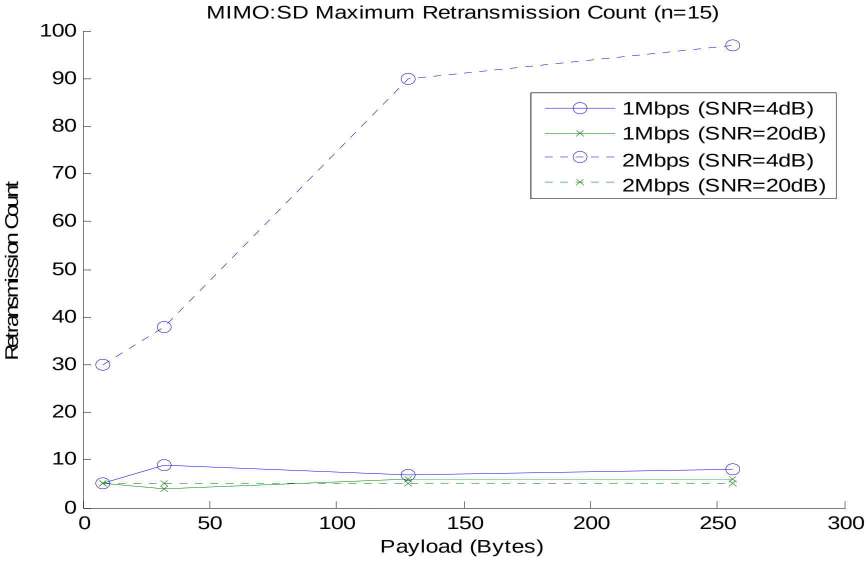


(b)

Figure5. MIMO Spatial Diversity number of retratnsmissions for 100% reliability with respect to nubmer of competting nodes for 1/2Mbps data rate (a) average, (b) maximum

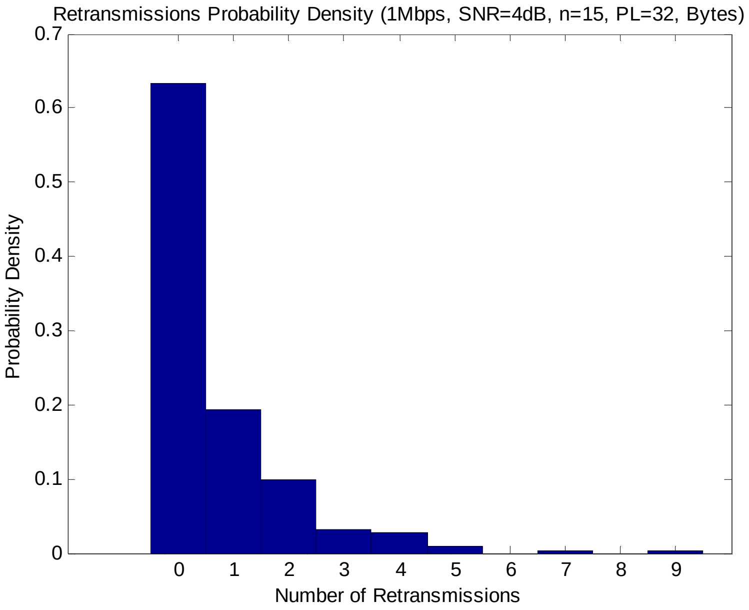


(a)

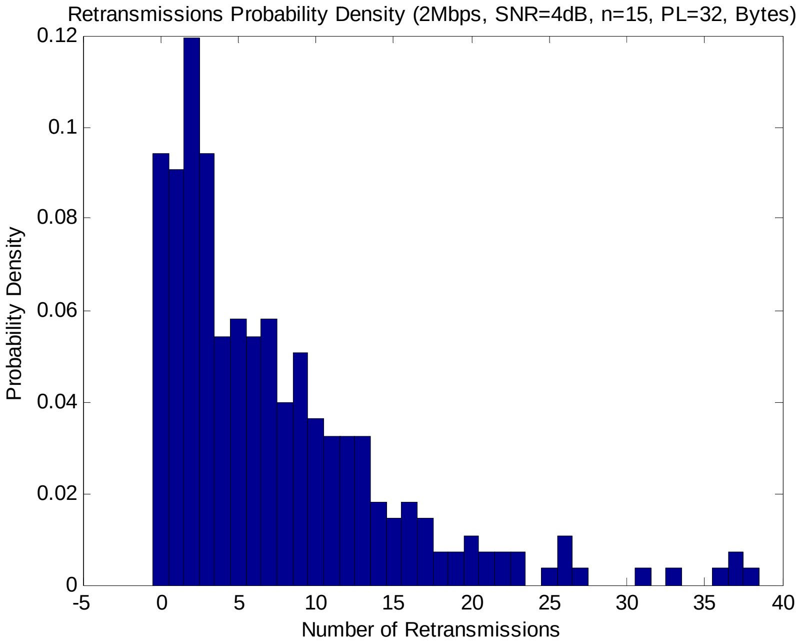


(b)

Figure6. MIMO Spatial Diversity average number of retratnsmissions for 100% reliability with respect to SNR for 1/2Mbps data rate (a) average, (b) maximum



(a)



(b)

Figure7. MIMO Spatial Diversity retransmission-count probability density for 32-byte packet payload (a) 1Mbps data rate (b) 2Mbps Data rate

Conclusion

In this paper, packet delay and reliability of SD-enabled IEEE 802.11 based wireless industrial 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 default value (7) satisfies almost 100% reliability in 1Mbps data rate. For 2Mbps, 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 of more sophisticated spatial diversity codes, and adaptive schemes.

References

[1] IEEE 802.11-2007 Standard, “Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications,” Jun 2007.

[2] IEEE 802.11n, “Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications Amendment 5: Enhancements for Higher Throughput,” 2009.

[3] Andreas Willig, “Recent and Emerging Topics in Wireless Industrial Communications: A Selection,” IEEE Transactions On Industrial Informatics, Vol. 4, No. 2, May 2008.

[4] M. Maadani, S. A. Motamedi, and M. R. Soltani, "Delay Analysis of MIMO-Enabled IEEE 802.11-Based Soft-Real-Time Wireless Sensor and Actuator Networks," 2011 International Conference on Intelligent Information Networks (ICIIN 2011), Mar 2011.

[5] M. Maadani, S. A. Motamedi, M. Mohammadi Noshari, "Delay Analysis and Improvement of IEEE 802.11e-Based Soft-Real-Time Wireless Industrial Networks using an Open-Loop Spatial diversity Scheme," 2011 IEEE International Symposium on Computer Networks and Distributed Systems (CNDS 2011), Feb 2011.

[6] G. Cena, Lucia Seno, Adriano Valenzano, and Claudio Zunino, “On the performance of IEEE 802.11e wireless infrastructures for soft-real-time industrial applications,” IEEE Transactions On Industrial Informatics, Vol. 6, No. 3, Aug 2010.

[7] G. Cena, Ivan Cibrario Bertolotti, Adriano Valenzano, and Claudio Zunino, “Evaluation of response times in industrial WLANs,” IEEE Transactions On Industrial Informatics, Vol. 3, No. 3, Aug 2007.

[8] Nada Chendeb Taher, Yacine Ghamri Doudane, Bachar El Hassan, “A complete and accurate analytical model for 802.11e EDCA under saturation conditions, ” IEEE Conf. 2009.

[9] G. Cena, L. Seno, A. Valenzano, and C. Zunino, “Evaluation of real-time communication performance in QoS-enabled infrastructure WLANs,” IEEE ETFA 2009 Conf., 2009.

[10] E. Pourmand and E. S. Parizi**,** “Transient Over Voltage Effect Consideration of Using a Resistive Type Superconductive Fault Current Limiter on Power Transformers”, International Journal of Mechatronic, Electrical and Computer Technology (IJMEC**)**, Vol. 1, No. 1, pp. 12-22, Oct, 2011.

[11] Tolga M. Duman and Ali Ghrayeb, Coding for MIMO Communication Systems, John Wiley & Sons Ltd, 2007.