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Performance Evaluation Of Multiband CSMA/CA With RTS/CTS For M2M Communication With Finite Retransmission Strategy

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Abstract

M2M communication is information exchange between machines and machines without any human interaction. M2M communication based on cellular network suffers from the extremely large number of devices in service coverage. In cellular network case, the large number of devices lead to communication problem caused by collisions between the senders. In this work we study the collision probability, saturation throughput and packet error rate for the carrier sense multiple access collision avoidance (CSMA/CA) protocol with request to send and clear to send (RTS/CTS) mechanism in the case of frequency band division. We propose in this paper a modified version of CSMA/CA-RTS/CTS to be compatible with the band repartition technique and we prove that an important gain is introduced in terms of system performance especially for loaded networks. Different backoff stage numbers with different finite retransmission limit values are investigated. Simulations highlight that dividing the RTS band into independent channels reduces drastically the RTS collision probability and in particular the packet error rate. A gain in terms of saturation throughput is also demonstrated especially in charged networks mode.

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Keywords: M2M; Carrier sense multiple access/collision avoidance (CSMA/CA); Frequency band division; RTS/CTS; MAC protocol.

1. Introduction

M2M (Machine-to-Machine) communication is information exchange between machines and machines without any human interaction. The fast development of wireless communication technologies made the M2M a very remarkable market. The huge demand on M2M market caused by much applicability of M2M communication in various fields such as tracking, tracing and recovery, public safety, sensor, vehicular telematics, healthcare monitoring of bio-sensors, secured access and surveillance, remote maintenance and control, smart metering, automated services on

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consumer devices, enlarge digital signage management[1]. As mentioned above, a variety of great potential application services based on M2M communication are being supported in combination with many wireless networks. Nowadays, this concept is deployed everywhere for indoor and outdoor services and shared by many users. A robust medium access control (MAC) based on random-access, called carrier-sense multiple access/collision avoidance (CSMA/CA)[2,3] may be employed in M2M communication. When CSMA/CA is used a high loss in terms of system performance is noticed especially in loaded networks[4,5]. To avoid wasting the limited radio resources, many researchers proposed to split, in frequency, the single shared channel to several channels (multichannel)[6,7].

A multichannel CSMA/CA MAC protocol for multihop wireless networks is proposed[8]. The authors describe a new CSMA/CA protocol for multihop wireless networks. The protocol divides the available bandwidth into several channels and selects an idle channel randomly for packet transmission. It has been demonstrated via simulations that this multichannel CSMA/CA protocol provides a higher throughput compared to its single channel counterpart by reducing the packet loss due to collisions.

All the cited works apply a basic CSMA/CA for each channel part in order to improve the throughput performance and to reduce the packet collision probability between users. Eventually, they obtained simultaneous transmission on different channels (bands). However since packet duration is multiplied by the number of bands, the system performance is penalized in terms of transmission delay. Also the results are illustrated only for advantaged scenario where network is very loaded (225 nodes[8]). On the other hand they didn't explain in which limit there is interest to use this kind of strategy.

Moreover, the RTS/CTS mechanism for CSMA/CA protocol was adopted in the IEEE 802.11 to reduce the collision probability caused by hidden nodes terminals[9]. So applying the CSMA/CA - RTS/CTS to each channel part should improve the performance in terms of throughput and collision probability. We propose to assess a better tradeoff by using the frequency division strategy only for RTS messages, while keeping the whole band as a single channel for the purpose of data transmission. The exact protocol is described below, and simulation results highlight the interest of this approach.

The paper study the proposed protocol in the case of finite retransmission limits[10,11] and is outlined as follows. We explain and describe in section II the proposed protocol and we give the system model. In section III we present the simulation results and the protocol analysis. Finally, section IV is reserved for conclusion.

2. System Model

We consider a scenario where many users would transmit some packets to a base station (uplink communication mode). Actually the system performance is closely related to the collision between simultaneous transmitted packets[12]. Considering a symmetrical and ideal channel with RTS/CTS mechanism, collisions may occur only during RTSs transmissions. Sending RTS on different bands may help to reduce drastically this collision probability.

In this paper, orthogonal frequency multiplexing for these RTS is considered. Hence a single channel is divided into N bands during RTS transmission. Due to RTS channel decomposition, the transmission duration (T^{new}) of the new RTS message is equal to the time needed for original RTS (T) multiplied by the number of bands (N). Hence, $T^{new} = N \times T$. We assume that both transmitter (TX) and receiver (RX) have the knowledge of the band size and central frequency. The proposed protocol is based on a CSMA/CA protocol with RTS/CTS techniques. The proposed scheme is used to avoid collisions between multiple users (source nodes) which are willing to access at the same time to a common access point (destination node). A state machine of the proposed protocol is depicted in Figure 1. According to this protocol, a source node wishing to transmit data should first sense the communication channel. Note that the receiver listens to all RTS bands simultaneously. If a signal is detected on at least one RTS band, the communication channel between the source and the destination is declared busy. Then, a period (expressed in number of time slots) of a waiting counter (known as "backoff counter") is chosen randomly in the interval [0, CW-1], where CW is a contention window. The backoff counter is decremented by one each time the channel is detected to be available for a DIFS duration ("Distributed Inter-Frame Space"). The wait counter freezes when the channel is busy, and resumes when the channel is available again.

When the backoff counter attempts zero, the source (STA) randomly chooses one band over the N available bands to send a request permission message (RTS "Request To Send") to the destination node. It waits for receiving an authorization message (CTS "Clear To Send") from the destination node (access point) before transmitting data. The

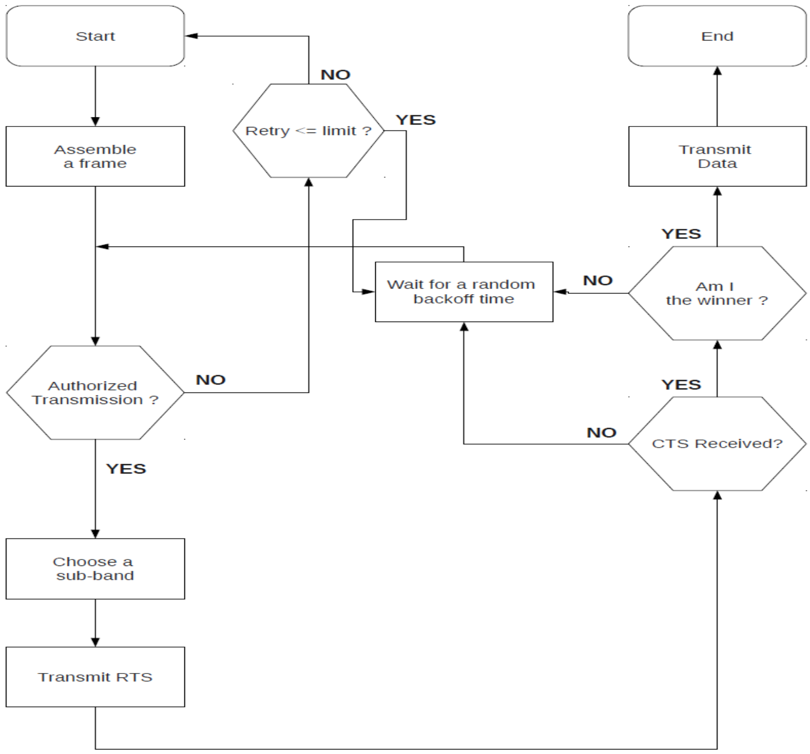

Fig. 1. Flow chart of the proposed protocol.

access point (AP) listens simultaneously to all RTS bands. If one or more RTS is detected, the AP broadcasts CTS over all the bands indicating the authorized station to communicate. How the AP selects the authorized STA in case of decoding several RTS messages depends on the scheduler and on some priorities that can be easily implemented. This question is kept out of the scope of this paper. The chosen STA sends its data and waits for Acknowledge (ACK) from the AP. Both data and ACK messages are sent over all the bands. Upon receipt of all transmitted data (successful transmission), and immediately, after a SIFS duration ("Short Inter-Frame Space"), the destination node sends an ACK (for "Acknowledgment"). Contention window (CW) is an integer between CWmin and CWmax. The CW is initially set to the minimum value; CW=CWmin. Whenever a source node is involved in a RTS collision, it increases the waiting time of transmission by doubling the CW, up to the maximum value CWmax=2^m. Where m is the number of backoff stages. Conversely, in case of a successful RTS transmission, the source node reduces the CW to CWmin. When the number of retransmission limit of packet is finite, a retry counter per station is incremented after each collision happened at the last backoff state (CW=CWmax). After each collision this counter is compared to a define limit in order to decide if the packet should be rejected or not. A packet is rejected when the counter value passes the limit (allowed retry transmission at the last backoff stage).

We illustrate in Figure 2 both standard and proposed protocols for the case of two bands where RTS duration is doubled respect to the standard. In the proposed protocol (see Figure 2.c), we consider that 2 stations are ready to transmit (Backoff=0) with one AP. STA0 (resp. STA1) chooses randomly band 1 (resp. 2). At the receiver side, the AP detects both RTS from STA0 and STA1. The AP chooses randomly the STA0 and sends CTS over all present bands indicating that STA0 has gained the channel access. All the STAs receive and decode the CTS and only STA0 tries to send its packets during a defined amount of time (many time slots). Successful communication takes place when the AP responds with ACK over all the bands. However, the case of many RTS transmission was considered as a collision in the classical CSMA/CA-RTS/CTS (see Figure 2.b). The proposed scheme provides the collision avoidance aspect in the shared medium context.

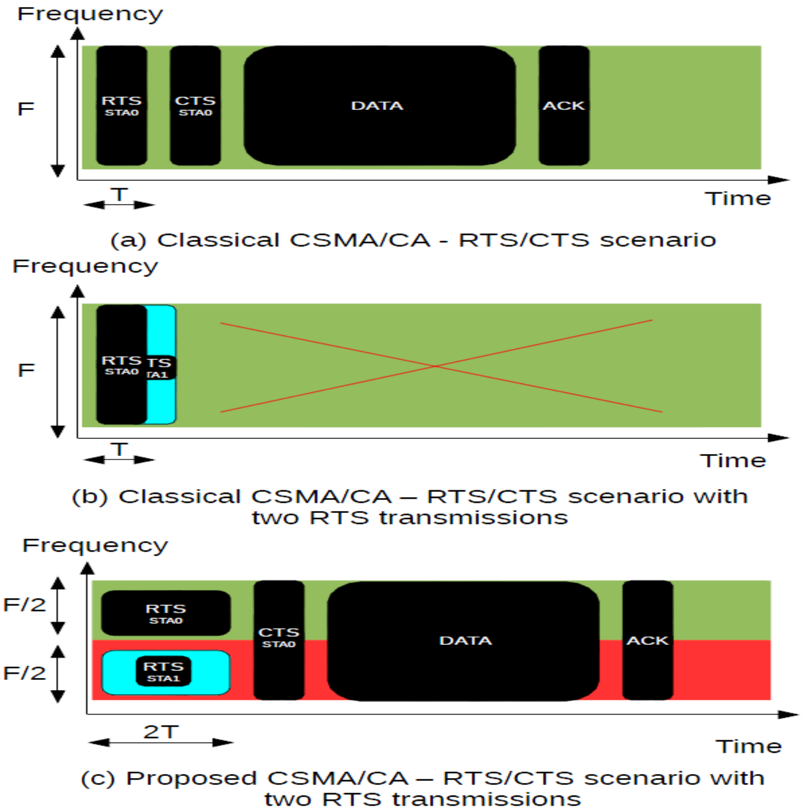

Fig. 2. Illustration of CSMA/CA - RTS/CTS for standard and proposed protocols in the case of two RTS messages, $T^{new} = N \times T$.

The implementation for such protocol would not need strong changes at the PHY layer. It is sufficient that each node is able to receive on the whole band, and then to detect RTS message on bands, which can be easily implemented on a multicarrier based PHY (e.g OFDM).

3. Simulation Results

In this Section, we study the collision probability, saturation throughput and packet error rate for the proposed protocol in the case of finite packet retransmission limits. The scenario of one AP and many mobile stations is considered for simulation. Home-made event-driven simulator was used to model the protocol behavior. The protocol and channel parameters adopted are those specified in Table 1 which correspond to 802.11n standard. The minimal contention window (CWmin) has been chosen constant and equal to 16. A high bit rate configuration is considered to minimize the duration of a packet. This feature is particularly adapted to dense M2M networks. It should be mentioned that in order to study the proposed protocol we consider a MAC layer integrating this protocol and an ideal physical layer (no path loss, no fading, no shadowing, ...).

3.1. Collision Probability

Since the MAC performance depends on the RTS collision probability, it is necessary to study the impact of the proposed protocol on this factor. We assume a plurality of sources trying to access a destination. Figure 3 depicts the collision probability between RTS messages in function of the number of mobile stations present in the network for different RTS bands values with three backoff stages (m=3) and for packet retransmission limit equals to 3.

It shows that the collision probability increases with users number and proportionally inverse to the number of RTS bands. For a single band CSMA/CA with 50 users, the probability of collision is around 55%. For a two bands protocol

Table 1. PHY layer parameters for 802.11n.

Parameter	Value
Packet payload	8184 bits
MAC header	272 bits
PHY header	128 bits
ACK length	112 bits + PHY header
RTS length	160 bits + PHY header
CTS length	112 bits + PHY header
Channel Bit Rate	72.2 Mbit/s
Propagation Delay	1 μs
SIFS	10 μs
Slot Time	9 μs
DIFS	28 μs

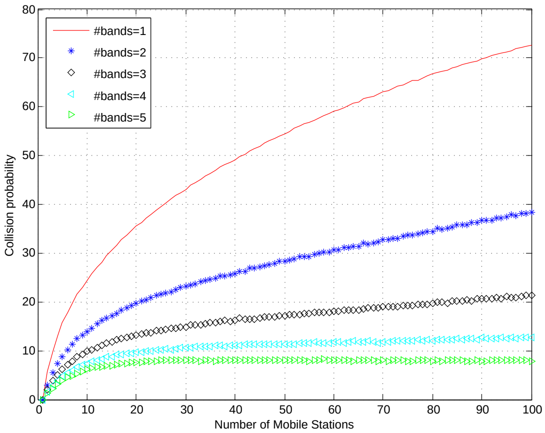

Fig. 3. Collision probability (%) vs. number of users with m=3 for various number of RTS bands.

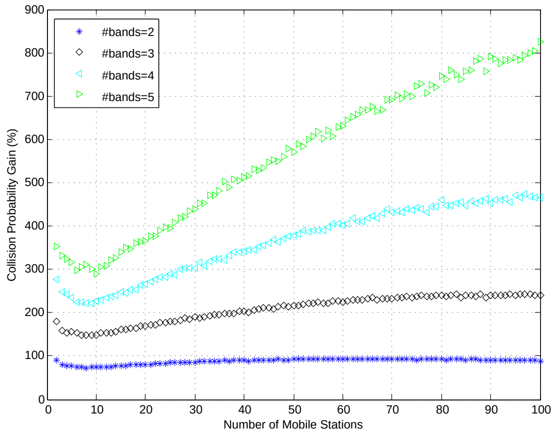

Fig. 4. Collision probability gain (%) vs. number of users with m=3 for various number of RTS bands.

the probability of collision is reduced to 30%. When 5 bands are considered the probability of collision is less than 10%. As we discussed before, the proposed protocol reduces drastically the RTS collision probability. As collisions happened only during RTS transmissions, the proposed MAC should improve the global system performance in terms of throughput and packet error rate.

Figures 4, 5 and 6 depict the collision probability gain introduced by the proposed protocol respect to the single band in function of the number of users presents in the network for $m = 3$, $m = 4$ and $m = 5$ with maximum retransmission limit equals 3. We can notice that the gain is inversely proportional to the number of backoff stages (m). With high m values the stations have more chance to transmit without collision due to the sufficient degree of freedom in the backoff machine. The band division technique leads always to the reduction of collision probability but it is highlighted with low m values. Since collision probability is drastically reduced, we would to see the outcome in terms of saturation throughput. This study will be the object of the next sub-Section.

3.2. Saturation Throughput

The throughput is the average information payload over the average duration needed to send the useful information. In this Section we study the throughput in saturation mode, so we assume that the stations have always something to transmit (there is always at least one packet in the buffer of each node). Figure 7 depicts the saturation throughput in function of the number of mobile stations present in the network for the proposed protocol with different number of RTS bands and for retransmission limit equals to 3.

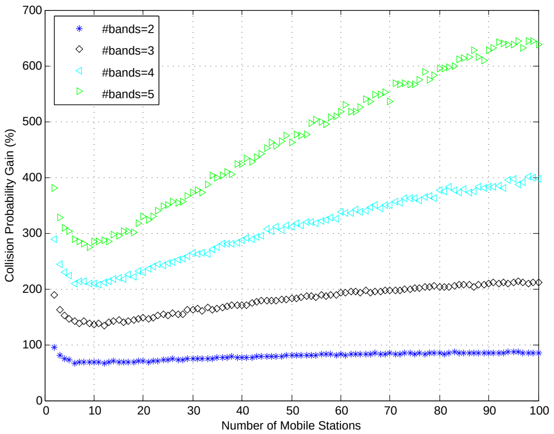

Fig. 5. Collision probability gain (%) vs. number of users with m=4 for various number of RTS bands.

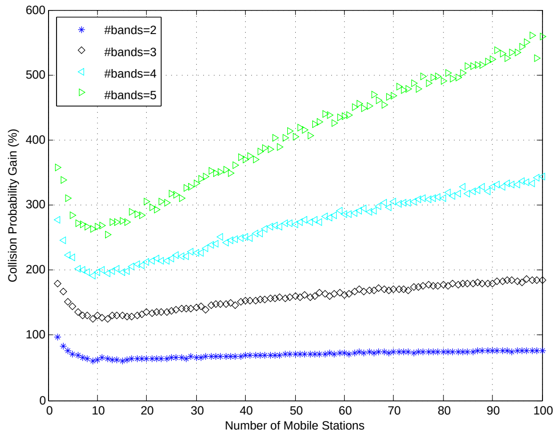

Fig. 6. Collision probability gain (%) vs. number of users with m=5 for various number of RTS bands.

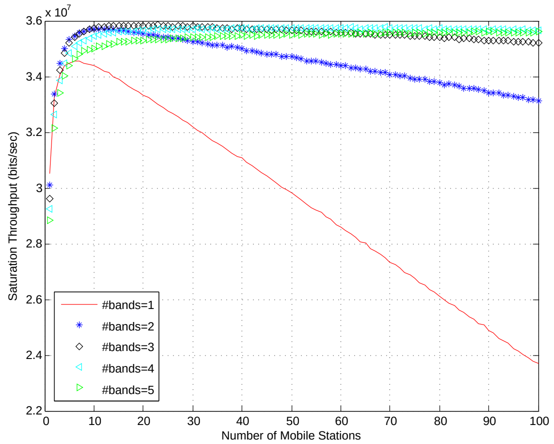

Fig. 7. Saturation throughput with retransmission limit=3 vs. number of mobile stations for different RTS bands with m=3.

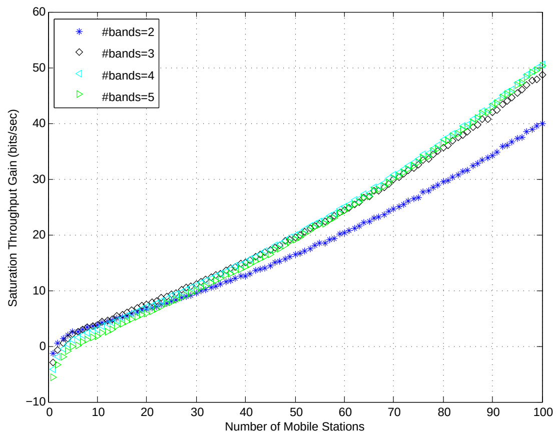

Fig. 8. Saturation throughput gain (%) vs. number of users with m=3 for various number of RTS bands.

The saturation throughput for single band degrades rapidly when the number of mobile stations increases. This protocol which is adopted by the 802.11 standard presents weak performance in loaded mode.

Figures 8, 9 and 10 depict the saturation throughput gain in function of the number of users presents in the network for $m = 3$, $m = 4$ and $m = 5$ with limited retransmission times equals 3. The saturation throughput is improved using the proposed protocol. We can remark from Figures 4, 5 and 6 that we have interest to shrink the RTS band into two bands or more when the number of users is upper than 10. In fact, this amelioration is due to the reduction of the RTS collision probability which becomes significant when the number of users becomes high. Based on simulation results of very loaded networks, we remarked that we have interest to enhance the RTS band division when the networks become denser (very loaded). We can notice that the gain is inversely proportional to the number of backoff stages (m). Indeed with high m values the stations have more chance to transmit without collision due to the sufficient degree of freedom in the backoff machine. Hence we can predict that the packet error rate (PER) will be higher in the case of low m values and may be reduced thanks to the proposed protocol. A detailed study related to PER will be addressed during the last sub-Section.

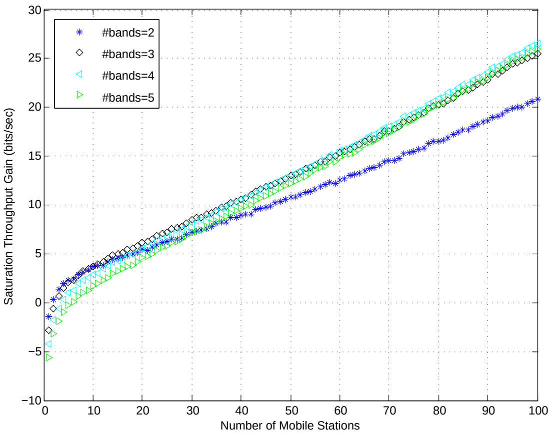

Fig. 9. Saturation throughput gain (%) vs. number of users with m=4 for various number of RTS bands.

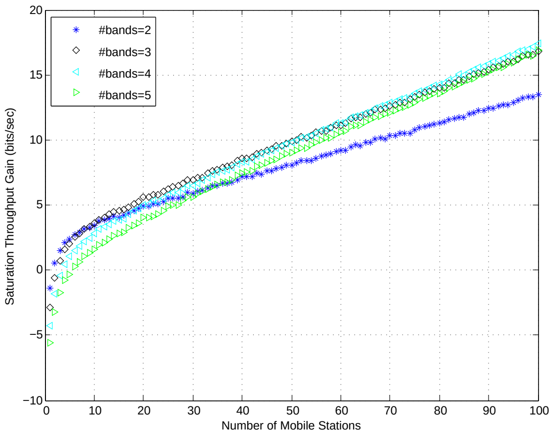

Fig. 10. Saturation throughput gain (%) vs. number of users with m=5 for various number of RTS bands.

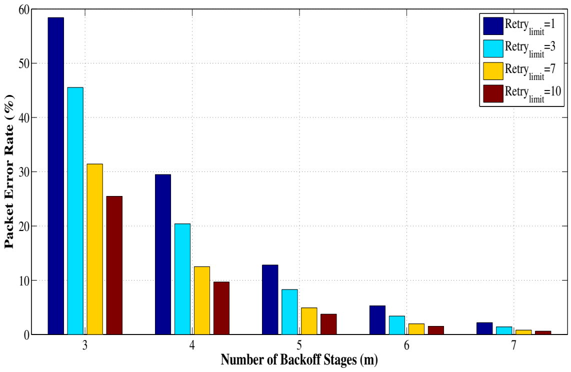

Fig. 11. Packet error rate for single band vs. number of backoff stages for various retransmission limits.

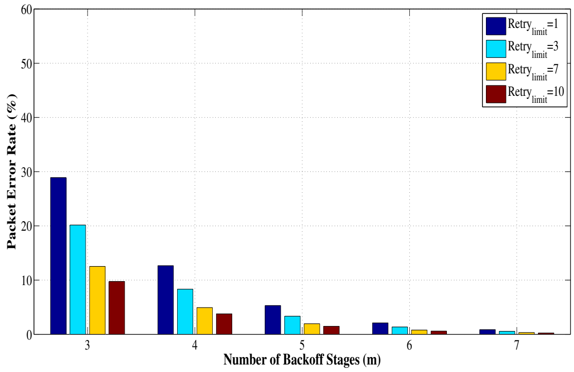

Fig. 12. Packet error rate for #band=2 vs. number of backoff stages for various retransmission limits.

3.3. Packet Error Rate

In this Section we study the packet error rate (PER) due to packets rejection. The PER which is the ratio between the rejected packets and the total amount of packets to be transmitted (succeed+rejected) is expressed as follow:

$$PER = \frac{R}{S + R} \tag{1}$$

where R and S stand for the rejected and succeed packets.

Figures 11, 12 and 13 depict the simulated packet error rate for single and multiband protocols with 100 users stations present in the network. Figure 11 (12 and 13) represents the packet error rate for single band (two bands and four bands) as a function of the number of backoff stages for various maximum retry limits. We define, the maximum retry limit by the maximum allowed times to stay in the last backoff stage (CW=CW_{max}).

Figures 11, 12 and 13 highlight that the number of rejected packets decreases when the number of backoff stages and the maximum retry limit increase. This is due to the fact, that the transmitters have more chance to stay in the system when m becomes high. The PER is approximately reduced by a factor of 2 (4) when the number of RTS bands is equal to 2 (4). Since the proposed multiband protocol reduces collisions between transmitters (RTS collisions), the stations have more chance to have success transmissions and hence the number of stations with (CW=CW_{max}) is reduced. When the number of RTS bands increases, the number of collisions decreases which allows to achieve lower PERs.

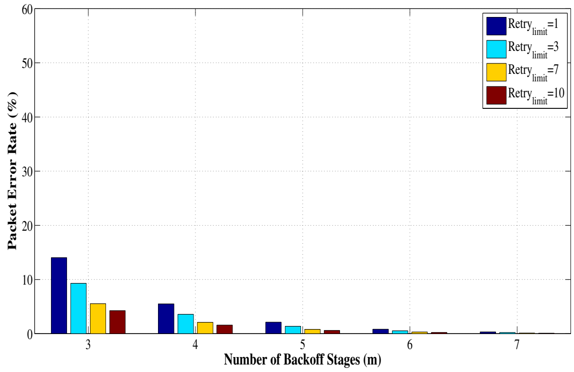

Fig. 13. Packet error rate for #band=4 vs. number of backoff stages for various retransmission limits.

4. Conclusion

In this work, we proposed a novel strategy based on CSMA/CA - RTS/CTS which is characterized by shrinking a channel into many bands of known size. We prove that the proposed technique will be very interesting for M2M applications since the system performance is improved especially in crowded networks. Dividing the RTS band into many parts reduces significantly the RTS collision probability which leads to improvement in terms of saturation throughput and packet error rate. For instance, using 4 RTS bands with 3 backoff stages and maximum retry limit equals to 3, a gain of 50% (480%) in terms of saturation throughput (collision probability) is shown. The *PER* is reduced by four as well. Moreover, it should mentioned that a full study for packets transmission delay (time needed to transmit a packet) is done in the case of infinite maximum retransmission limit (in order to be sure that all packets will be transmitted without rejection). As we mentioned in the introduction the delay is not very affected since the RTS size is negligeable regarding the packet size. To conclude, in this contribution we proposed a new protocol to enhance the MAC layer, but still as future works to focus on optimal scheduling policies that the AP can adopt when several RTS are received simultaneously. Another interesting question relies on evaluating the performance in distributed scenarios with multiple destinations.

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