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***Abstract*—Machine to machine communication (M2M) or machine type communication (MTC) facilitates communication without any human intervention. These applications will support an enormous number of stations (STAs). To mitigate degradation of the throughput and delay performance in wireless local area networks (WLAN) that employ carrier sense multiple access collision avoidance (CSMA/CA) protocol with request to send and clear to send (RTS/CTS) mechanism, we propose to reduce the overhead introduced by the hand shake mechanism. The medium access control (MAC) overhead caused by the RTS and CTS messages is high comparing to the total duration of successful transmission. In order to reduce the MAC overhead we propose in this work a new strategy to serve many users successively. This strategy consists on sending many RTS in parallel by different stations on different frequency sub-bands. Once the RTS messages do not collide with each other, there will be no need to resend the RTS and wait for a CTS to gain the channel access. In this paper, this proposed strategy is investigated and we demonstrate that it reaches better saturation throughput and delay especially in loaded networks.**

***Index Terms*—Carrier sense multiple access/collision avoidance (CSMA/CA), multiband, throughput, MAC protocol, scheduling, M2M, overhead reduction.**

I. INTRODUCTION

Machine to machine (M2M) communication [1] which are composed of smart meters (power, gas, water), smart vehicles (road tolling, real time traffic info to vehicles), vending machines, payment (gas meters), security alerting/reporting, people tracking is an emerging communication concept where all devices can communicate without human intervention. Actually, the M2M applications are based on coordinated and centralized communication. Let's consider a sensor that is in an idle state requiring to transmit its data (temperature message, a picture...) on a cellular network such as LTE. The node should wakes up and initialize a synchronization procedure with the base station. Signaling messages (RACH) [2] are exchanged to synchronize and allocate resource to the node. Only at the end of this procedure the node can transmit its data. A significant overhead is introduced resulting in the decreasing of the network efficiency [3]. Moreover, according to the researchers [4] 20 billion devices will be part of M2M communication by the end of 2020. The huge amount of devices shall work opportunistically and without need to be synchronized with a predefined device (i.e. access point (AP) or base station (BS)). To fulfill these requirements random access protocols are a possible choice. The CSMA/CA - RTS/CTS could be adopted for many reasons: it allows to operate in an environment with an unknown number of devices with the entire available bandwidth [5], operates in distributed manner [6] and leads to a cheaper deployment since it doesn't require much planning, interoperability and management complexity [7]. As the number of active STAs increases (dense networks), the throughput and delay performances of the system are significantly degraded when CSMA/CA is exploited. CSMA/CA - RTS/CTS is widely used in many random access wireless networks especially to combat hidden node problem [8] as it can reduce potential collisions and improves the overall network performance. CSMA/CA is an opportunistic random access protocol which allows transmitters to access equally the wireless channel, which incurs equal throughput in long term regardless of the channel conditions. CSMA/CA - RTS/CTS was invoked from long time ago by different researchers [9], [10]. Their main contributions are to improve the saturation throughput and the delay by modifying the backoff model [11], [12]. However, these contributions, adapted for single band CSMA/CA, suffers from high RTS collision probability which lead the system inefficient. In our previous works [13], [14], we proposed a new model based on multiband CSMA/CA - RTS/CTS which reduce drastically the RTS collisions and improve the overall system performance in terms of saturation throughput, delay and packet drop probability. The main contribution was to assess a better performance by using the frequency channel division strategy only for RTS messages, while keeping the whole channel for the CTS, DATA and ACK transmissions. Moreover, when many RTS messages may be decoded by the AP, the AP can serve only one user which win the channel access and transmit its packets. The non-served users loose the channel access, and have to retry with another RTS transmission after revoking a new backoff procedure. This procedure force the non-served user to transmit a new RTS message and wait for a new CTS message which causes a high MAC overhead. To solve this issue, we propose in this work a new strategy which consist to serve many users once the CTS is detected by the transmitters. Section II will detail the motivations behind the proposed strategy which will be described in details in Section

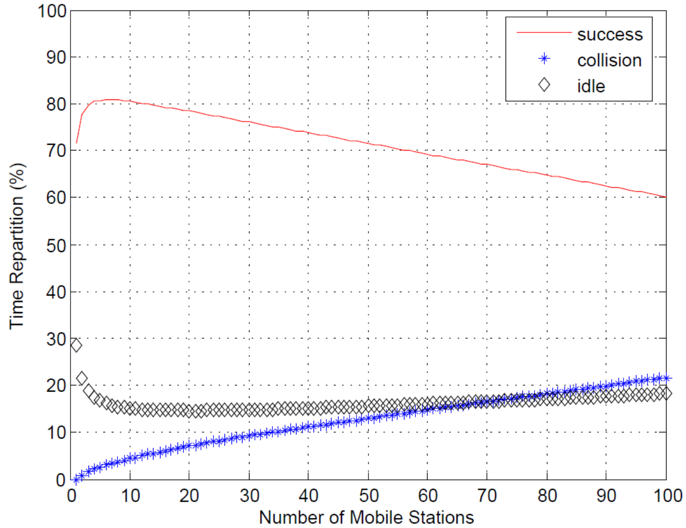

Fig. 1. Single band CSMA/CA - RTS/CTS time repartition vs. number of mobile stations.

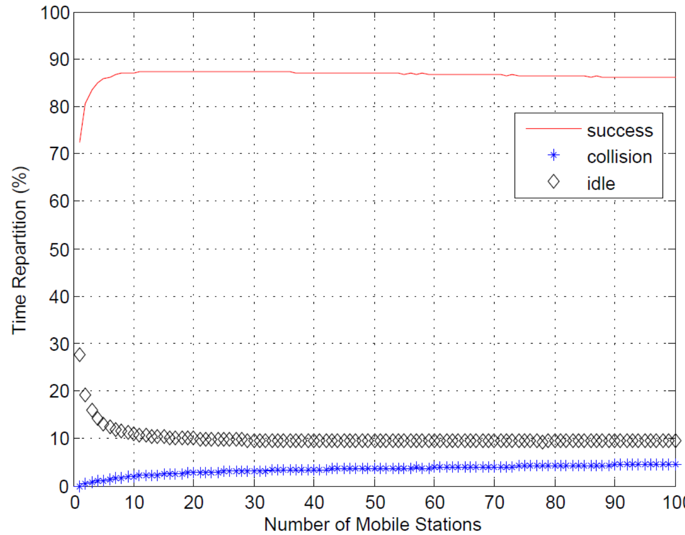

Fig. 2. CSMA/CA - RTS/CTS time repartition vs. number of mobile stations for 3 RTS sub-bands.

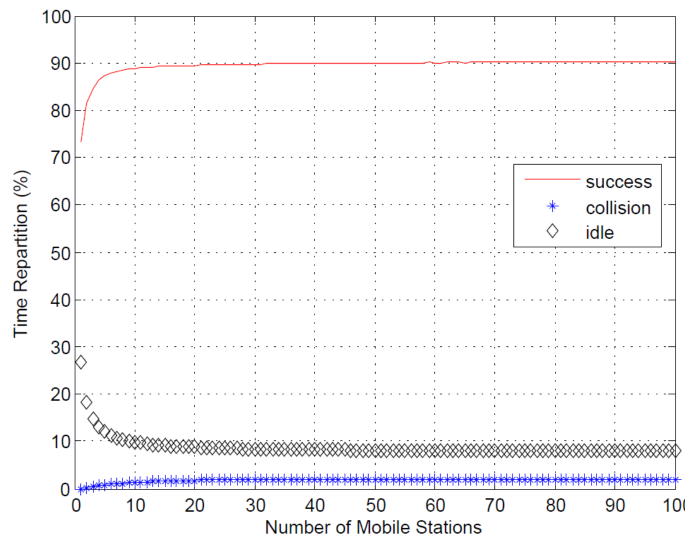

Fig. 3. CSMA/CA - RTS/CTS time repartition vs. number of mobile stations for 5 RTS sub-bands.

III. In Section IV we will evaluate the performance of the proposed strategy and Section V is reserved to conclude this work.

II. Motivations

In this Section an overview of the CSMA/CA with different variant will be presented and a discussion will take place around the motivations which lead to propose the new strategy.

A. Single band CSMA/CA - RTS/CTS

The single band CSMA/CA - RTS/CTS was studied from long time ago [9][15] and it was proof that the system performance degrades rapidly when the number of stations increases. The protocol is working like following. Each nodes with a packet to transmit should first sense the channel. If the channel is sensed to be idle for a time period greater than the distributed inter-frame space (DIFS) time, the node with a packet to transmit sends a RTS packet. If the RTS packet is received without collision, a CTS is sent back to inform all nodes in the cell that the channel is reserved. All nodes defer their transmissions for the duration specified by the RTS: this mechanism is called virtual sensing. After the successful reception of a data packet, an ACK packet is sent back. If the channel is not sensed idle, the backoff procedure is invoked. Under the hypothesis of a perfect transmission, collisions may only occur on RTS packets and transmission of data packets can proceed without interference from other nodes.

In order to better understand the protocol and to analyze the causes of system performance degradation, an analysis of the time repartition vs. the number of mobile stations is depicted in Figure 1. When the number of mobile stations increases, the time spent in success period decreases and the time wasted in idle and collision period increases. Hence a high waste of time (40%) is showed for dense network because of collisions. To reduce the time period wasted in collisions and idle, a multiband protocol was proposed in our previous works [13], [14] and it will be briefly described in the following sub-section.

B. Multiband CSMA/CA - RTS/CTS

Since collisions only occur on RTS packets [1], reducing the time period wasted in collisions is related to the reduction of the RTS collisions probability. For that, we have proposed orthogonal frequency multiplexing for RTS messages on different sub-bands. Hence a single band is divided into n sub-bands during RTS transmission. We assumed also that both transmitter (TX) and receiver (RX) have the knowledge of the sub-bands size and central positions. Note that this

[1]In the case of perfect transmission.

kind of protocols may be easily implemented by allocating many sub-carriers for different RTS messages. Multicarrier modulation can fulfill the requirements for such implementations particularly in the context of latest 802.11 standards [16], [17]. Based on this protocol, Figures 2 and 3 depict the time repartition vs. the number of mobile stations for three and five RTS sub-bands. It is clearly seen that the multiband protocol improves the proportion of time period passed in successful transmission and reduces significantly the time period wasted in collision and non-transmission (idle), especially for loaded network. For example, when 3 RTS sub-bands are considered with 100 stations, the collision and idle proportions time period are reduced from (22%) to (5%) and from (20%) to (10 %) respectively. The time period spent in successful transmission is improved from (60%) to (87%). The difference between the success proportion is equal to the sum of the difference between the collision and idle proportions, hence the improvement in term of collision and idle (27%) are transformed to success. Moreover, increasing the number of RTS sub-bands leads to better time exploitation (see figure 3). Also, it is clearly showed that the time period wasted in collision and idle period decreases especially for loaded scenario. The proportion of success time period tends to 90% which indicates better channel usage. It is also shown that increasing the number of RTS sub-bands decreases the collision probability but the time period wasted in idle is quite the same (no major difference for the time period wasted in idle between the use of 3 and 5 sub-bands). Actually for every data packet transmitted with success a complete mechanism should be implemented. The mechanism is the CSMA/CA - RTS/CTS which need a RTS, CTS and ACK packets to be transmitted due to each data packet transmission. In fact, high performance loss is present because of the MAC overhead which makes the system suboptimal. How could we reduce the time wasted in idle periods? Which factors can be attacked to reduce the overhead time introduced by the nature of the protocol? The response is in the next Section, where the multiband protocol will be enhanced to improve the system performance by reducing the time wasted in idle periods.

III. System Model

Without loss of generality, we consider the scenario where many stations would transmit some packets to an AP. Considering a symmetrical and ideal channel with RTS/CTS mechanism, behind the loss in terms of RTS collision, MAC overhead significantly reduce the system performance. In fact, the RTS and CTS messages introduce a high overhead which make the system suboptimal. In the case of multiband protocol [13], many RTS messages may be decoded by the AP simulatenously. For that, it will be interesting to implement a polling mechanism which serves many stations one after the other[2]. Such mechanism is the object of this Section. The proposed strategy is based on CSMA/CA protocol with RTS/CTS scheme. According to this strategy, a source node wishing to transmit data should first apply the multiband protocol investigated in Section II-B. When the RTS is transmitted by the station, the AP decode the RTS messages and reply with the CTS message which contains the information about the winners (transmitters who gain the channel access). Depending on the priority, the winner either transmits directly (once the CTS is received) or it waits its turn to transmit data over the complete frequency bandwidth. An ACK is transmitted by the AP if the data are successfully decoded. Note that the RTS message duration is multiplied by the number of RTS sub-bands in order to maintain the same quantity of information.

Let's consider a simple example composed of four STAs ready to transmit (backoff=0), STA0, STA1, STA2, STA3 and an AP. Figure 4 show that collisions occur between the four transmitters while sending simultaneously the RTS messages for the classical single band scheme. We illustrate in Figure 5 the considered scenario in the case of the proposed strategy. STA1 and STA2 choose the first and third sub-bands respectively. STA0 and STA3 choose the second band. All the stations, send their RTS messages on the chosen sub-bands. Therefore, the AP detects RTS from the STA1 and STA2 but it is not able to decode the RTS on sub-band 2 due to

[2]the station for which RTS message do not collide

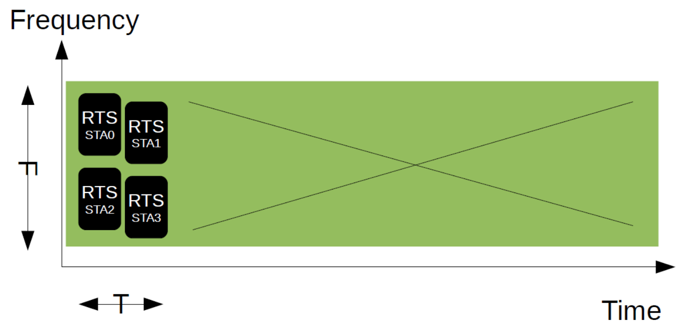

Fig. 4. Single band CSMA/CA with RTS/CTS mechanism.

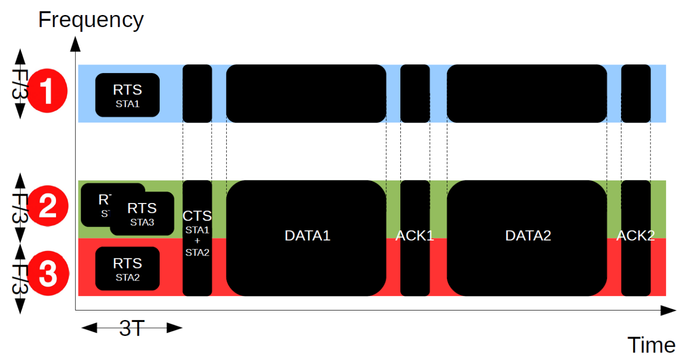

Fig. 5. Scheduled multiband CSMA/CA with RTS/CTS mechanism with scheduler size=1.

Frame Control	Duration	Receiver Address	Authorized Band	Frame Check
2 byte	2 byte	6 byte	3 byte	4 byte

Fig. 6. CTS frame format.

collision. The AP broadcasts the CTS message over all the sub-bands. All the stations receive and decode the CTS and only STA1 and STA2 are allowed to transmit. Once the ACK for STA1 is received, the channel becomes clear and STA2 will be authorized to send DATA. The ACK for STA2 is broadcasted indicating successful transmission and the channel becomes free for a new backoff procedure. The priority between stations may depend on sub-bands conditions and stations priorities. The proposed CTS frame format is presented in Figure 6 in which one more field was introduced to choose the authorized sub-bands able to transmit data. The size of the authorized band field is equals to 3 bytes which may be divided into 6 blocks of 4 bits. Each block correspond to a band index. If the block value is 0, it means that the block is not assigned to any band. The priority starts from the right to the left. This field can support up to 15 sub-bands and serve at most 5 stations successively. In this case, the authorized band field (00 00 21) indicates that the STA1 is prior to the STA2, hence after the CTS reception the STA1 transmit its packet and wait for acknowledgement.
The proposed strategy permits to serve transmitters successively with reducing the RTS collision and reducing the overhead introduced by the control messages (RTS and CTS) and the backoff especially for large cells (when the propagation delay is important).

IV. Performance Evaluation

In this Section, we study the saturation throughput and the delay for the proposed strategy and the related gain compared to the single band and to the multiband protocols studied in [13], [14]. The scenario of one AP and many stations is considered for simulation. The protocol and channel parameters are reported in Table I and correspond to those of $802.11n$ standard. The minimal contention window (CW_{min}) has been chosen constant and equal to 16. It is worth mentioning that as the study focuses on the MAC mechanisms, an ideal physical layer (no path loss, no fading, no shadowing, ...) is considered.

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

TABLE I
PHY layer parameters for 802.11n

A. Time Repartition

In this Section the time repartition of the proposed strategy is analyzed. Figure 7 depicts the time repartition vs. the number of mobile stations for 5 RTS sub-bands with scheduler size=2. Comparing Figure 3 and Figure 7, the time period wasted in collision is the same. As expected the proposed enhancement do not reduce the collision probability. However

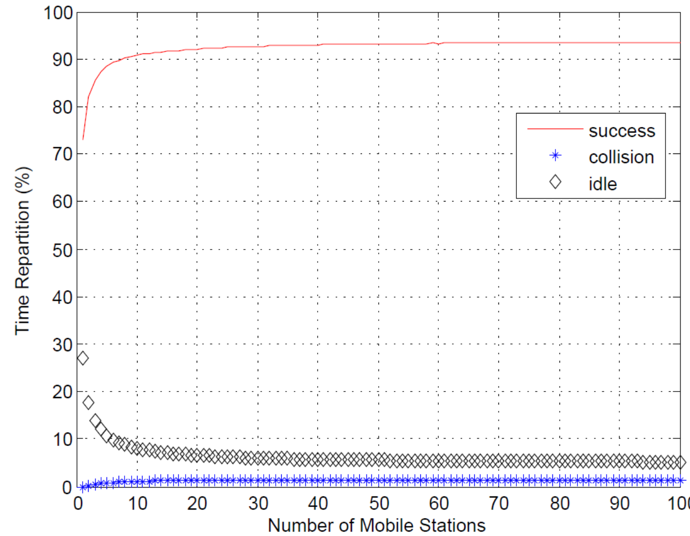

Fig. 7. CSMA/CA - RTS/CTS time repartition vs. number of mobile stations for 5 RTS sub-bands with scheduler size=3.

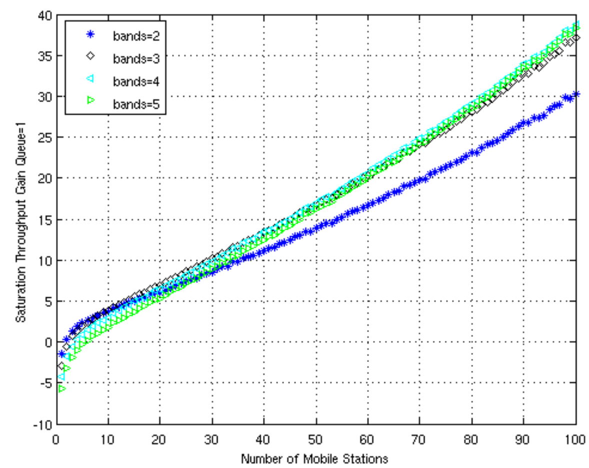

Fig. 8. Saturation Throughput Gain (%) vs. number of stations for scheduler size=1.

the time period wasted in idle is decreased by 4% to reach 6% and the time period spent in success transmission is improved by 4% as well to reach 94%. Hence, adopting the overhead reduction strategy we achieve 4% of gain in term of time spent in successful transmission for loaded network.

B. Saturation Throughput

In this Section, the throughput of the proposed strategy is evaluated under the saturation conditions (each station has at least one packet ready for transmission). Figure 8, 9 and 10 depict the saturation throughput gain between the single and multiband protocols vs. the number of mobile stations for various number of RTS sub-bands and scheduler sizes. As expected, the gain between the multiband and single band scenarios is more important when the number of RTS sub-

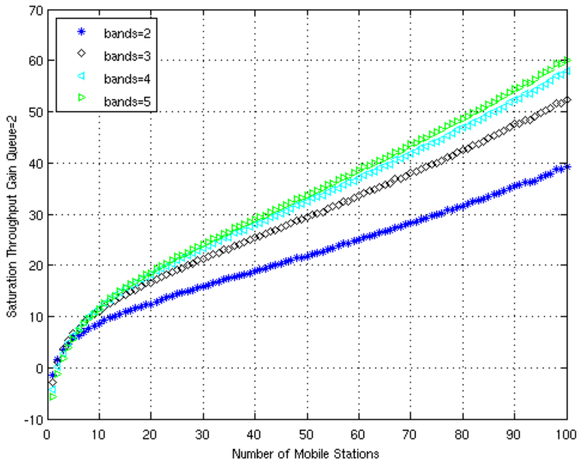

Fig. 9. Saturation Throughput Gain (%) vs. number of stations for scheduler size=2.

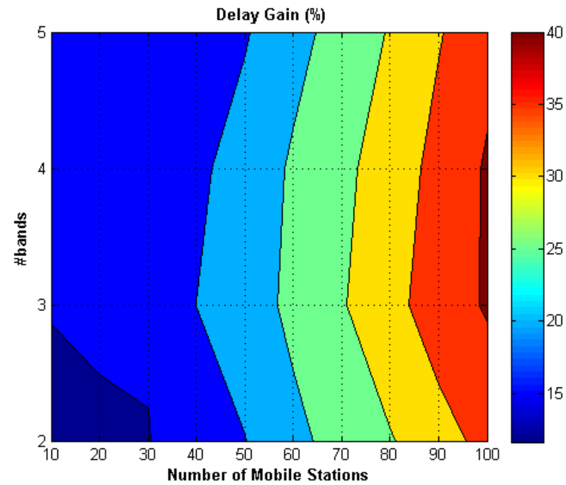

Fig. 11. Delay Gain (%) vs. number of stations for various number of sub-bands with scheduler size=1.

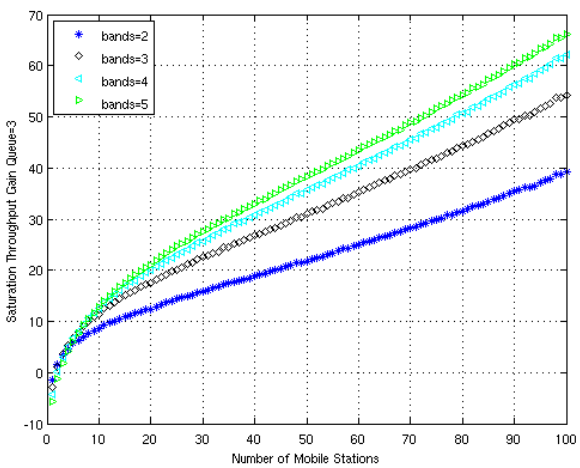

Fig. 10. Saturation Throughput Gain (%) vs. number of stations for scheduler size=3.

bands is high and especially in the case of loaded networks. This improvement is due to the reduction of the RTS collision probability thanks to the division of the RTS band. Moreover, the use of scheduler sizes greater than one can improve the saturation throughput gain. This is due to the possibility to serve many stations (which correspond to the successful transmitted RTS) without revoking a new backoff procedure (without introducing more overhead). For example, in the case of 5 RTS sub-bands and 50 active stations, the saturation throughput gain is 17%, 33% and 40% for scheduler size=1, scheduler size=2 and scheduler size=3. Also, based on Figure 9 and Figure 10 it could be mentioned that the gain is the same when the number of RTS sub-bands is lower or equal to the scheduler size (for example: 2 RTS sub-bands with scheduler size=2 or scheduler size=3). Hence, there is no need to use scheduler sizes larger than the number of RTS sub-bands because a system with n sub-bands can serve at most n stations one after the other (in the case of non RTS collisions).

It should be mentioned also that the gain is negative in the case of unloaded networks (number of stations is less than 5) and it is due to the RTS messages extensions (the original RTS duration is multiplied by the number of sub-bands to maintain the same quantity of information) which introduces more overhead not amended with the reduction of collision probability [13].

C. Transmission Delay

In this Section we study the gain in term of delay between the proposed strategy and the single band protocol for various scheduler size. The transmission delay is defined as the time needed to transmit a packet. In order to compare the delay between the two strategies, we extract from simulation the cumulative density function (CDF) of the delay for various number of stations. We have plotted the results for a CDF of 99% on Figures 11, 12 and 13 for various number of RTS sub-bands and various number of stations from 1 to 100 with scheduler sizes equal to 1, 2 and 3 respectively. Despite of the extended duration of the RTS messages due to the RTS band division, These results demonstrate that the delay gain is always positive. It means that the reduction in term of collision probability is much more efficient comparing to the time extension of the RTS messages. Also, when the size of scheduler is greater than two, the delay gain is more important especially in loaded networks and it is due to the capability to serve many stations without waiting for next backoff round. Hence, stations are served one after the other with lower MAC overhead (avoiding loosing time due to RTS, CTS and backoff). For instance, considering the case of 50 stations present is the network with 5 RTS sub-bands. The gain is 17%, 27% and 30% when the scheduler size is equal to 1, 2 and 3.

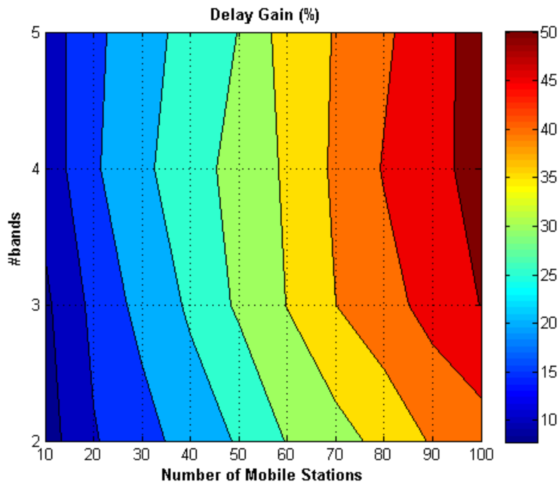

Fig. 12. Delay Gain (%) vs. number of stations for various number of sub-bands with scheduler size=2.

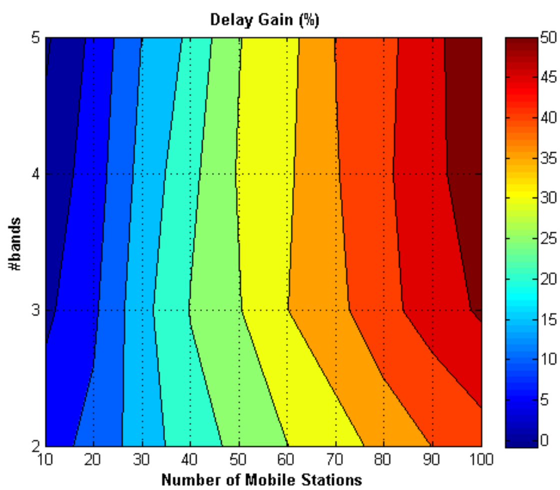

Fig. 13. Delay Gain (%) vs. number of stations for various number of sub-bands with scheduler size=3.

V. Conclusion

In this work, we proposed a novel strategy based on multi-band CSMA/CA-RTS/CTS which is characterized by serving many stations one after the other to reduce the MAC overhead. We prove by simulation that the proposed strategy is able to achieve very high gain in term of saturation throughput and delay. Since the gain is very important in loaded networks, the proposed strategy may be adapted to M2M communication where very high number of stations simultaneously communicate. For instance, when considering 5 RTS sub-bands with 50 stations in saturation conditions, the achieved gain for scheduler size equals to three is 40% in term of saturation throughput and 30% of gain in term of delay.

To conclude, in this contribution we proposed a study about the overhead reduction by introducing a scheduler to serve transmitters successively, but it should be mentioned that in practical application there is a limit on the scheduler size. For these reason the scheduler size should be reasonable and adapted for each application. Also, the proposed strategy may be easily implemented by allocating many sub-carriers for different RTS messages. Multicarrier waveforms already introduced into latest 802.11 standards can fulfill the requirements for such implementations.

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