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Proposed MAC Protocol for M2M Networks

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Abstract: Machine-to-Machine (M2M) communication is defined as the ability of machines to communicate without any human interaction. M2M network is expected to be widely utilized in many fields of Internet of Things (IOT) applications in which simplex (reservation - or contention based) Medium Access Control (MAC) protocols may not be able to provide a scalable solution for M2M networks with large number of devices. In this paper, a proposed MAC protocol for M2M Network will be suggested, which consists of a contention period and a transmission period. In this protocol, different devices contend on the transmission opportunities by using conventional based on Non - Persistent Carrier Sense Multiple Access (NP-CSMA) mechanism which is not clarified until now in M2M network. The successful devices only will be assigned a time slot for transmission during the transmission period depending on the reservation based Time Division Multiple Access (TDMA) mechanism. Moreover, comparisons between proposed MAC technique and other techniques such as Pure Aloha (P-ALOHA), Slotted Aloha (S-ALOHA), NP-CSMA will be made in terms of some parameters such as throughput, average delay time and Packet Delivery Ratio.

Keywords: M2M, MAC protocols, contention protocols, contentionless protocols.

1. INTRODUCTION

Machine-to-Machine (M2M) represents a future IOT where billions of everyday objects and the surrounding environments are connected and managed through a range of devices, communication networks, and cloud-based servers [1]. M2M communication, also known as Machine Type Communication (MTC) enables information to be exchanged between machines and machines without any human interactions. It can be utilized in many fields of IOT applications [2], including industrial and agricultural automations, health care, transport systems, and electricity grids.

Actually, MAC layer is responsible for channel access for nodes within a network that uses a shared medium. There are two main categories of MAC protocols which are reservation based MAC protocol and contention based MAC protocols. The reservation MAC protocol belongs to contentionless protocols and also known as collision free access scheme. Proposed MAC Protocols were described before in [3-5] but recently the design of a smart and an efficient MAC stays a key requirement for successful deployment of any M2M networks in [6]. In fact, the main MAC layer challenge for M2M communication is to facilitate channel access to very large number of devices while providing diverse service Requirements for devices in these networks. Moreover, MAC protocols for M2M communications should be efficient, scalable, consume low power, and have low latency.

In 3GPP systems and IEEE 802.16, MAC protocol for M2M networks focused on contention – based random access (RA) schemes [7] which allows all of the devices contend the transmission opportunities in entire frame. Instead of the advantages of contention – based random access (RA) schemes such as popular due to its simplicity, flexibility, and low overhead. The main problem is that the transmission collisions increase when large numbers of M2M devices try to communicate to base station at the same time. To overcome this problem, reservation based scheme such as TDMA [8] was used in M2M networks. In TDMA, the transmission time is divided into time slots and each device transmits only during only its own time slots. But, TDMA has man defect which is low transmission slot usage if only a small part of devices have information to transmit.

In [9], due to offering the weakness of the pure contention-based scheme or reservation-based scheme, pure contention-based or reservation-based cannot give a scalable, flexible solution for M2M network with large number of devices. A hybrid MAC protocol has been suggested in [6, 9].

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In [10-11], the efforts of the researches to combine benefits of both of contention-based and reservation-based result in a hybrid scheme. Hybrid MAC scheme for sensor network was designed to adapt the level of contention in the network under low contention; it behaves like CSMA, and under high contention, like TDMA in [10]. In [11], the authors suggested a hybrid MAC protocols for supporting video streaming over wireless networks trying to adapt to different bandwidth conditions depending on demand.

In this paper, a hybrid MAC protocol for M2M network will be suggested which collects the advantages of both reservation-based and contention-based protocols. In our proposed protocol, the transmission time is divided into frames and each frame consists of three parts: Notification Period (NP), Contention Only Period (COP) and Transmission Only Period (TOP). BS broadcasts a notification messages to the devices at each frame. The COP is based on NP-CSMA mechanism where the devices contend over transmission opportunities. Only the successful devices will be allowed to transmit their data during TOP that provides TDMA type of data communication. Each device has random number of packets to transmit in its buffer which with infinity size. Moreover, comparisons between the conventional MAC protocols such as P-ALOHA, S-ALOHA, and NP-CSMA with the proposed protocol will be indicated through the simulation result.

2. SYSTEM MODEL

M2M network in our simulation composes of one base station (BS) and K number of devices $\{D_1, \ldots\ldots, D_K\}$ as shown in Fig1. BS donates medium access control for all the devices. In this model, all devices are assumed that the amount of data will be varied with the same priority. Therefore, each device has different number of packets to transmit. It has to contend the transmission opportunities when it has data to transmit. There will be M devices succeed in COP, and get a transmission time slot in TOP. For each active device, the data packet arrival process follows Poisson arrival process with packet average arrival rate λ. Here, for simplicity, we assume that all devices have the same average packet arrival rate, known by BS.

Hence, all K devices will contend for transmission slots during T_{cop} in each frame with the same contending probability which follows Poisson distribution and each device generates variable n number of packets to send in its buffer which with infinity size. The probability in which a device generates n packets following Poisson distribution at time t is given by,

$$P_n(t) = \frac{e^{-\lambda t}.(\lambda t)^n}{n!} \quad (1)$$

The probability that the first packet generates after time t is denotes as follows

$$P(t) = 1 - e^{-\lambda t} \quad (2)$$

For t=T_t , λ=1/T_{int}

$$P(t) = 1 - e^{-\frac{T_t}{T_{int}}} = \frac{G}{M_{num}} \quad (3)$$

$$T_{int} = \frac{-T_t}{\log(1 - G/M_{num})} \quad (4)$$

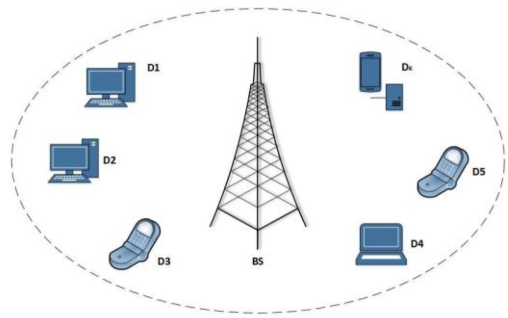

Figure 1. M2M Network Structure.

Where T_t represent the transmission time of one packet which equals to slot duration T_{slot}. T_{int} Donates expectation value of one packet generation interval and λ is average packet arrival rate. G is offered traffic and M_{num} is number of devices.

3. Related Works

MAC protocols can be classified into: contention-based and contentionless MAC protocols. Each protocol can be divided into two types. For simplicity, three types of traditional MAC protocols were mentioned [12-13]: P-ALOHA, S-ALOHA, and NP-CSMA mechanism. All these types are common in that they belong to repeated random access protocols class in which a device cannot be sure that a transmission will not collide because other devices may be transmitting at the same time. In [13], NP-CSMA algorithm achieved higher throughput compared to P-ALOHA and S-ALOHA with lower delay. Contention-based MAC protocols are not suitable for M2M communications because of collisions and the poor performance as number of devices increases. TDMA protocol belongs to contentionless protocols which known as collision free MAC protocols where the devices transmit in an orderly scheduled manner which leads to eliminate the issue of collisions. Although these protocols improve the average channel utilization at high loads, the utilization drops at low loads and the average packet delays are high. Combination between contention and contentionless was made before in [14]. A hybrid MAC protocols which compose of a contention period and a transmission period was proposed for M2M networks as in [6, 9]. The COP is based on p-persistent CSMA technique, the TOP provides TDMA type of communication as shown in [6, 9].

4. THE PROPOSED MAC PROTOCOL

In this section, a proposed MAC protocol for M2M network will be discussed. The protocol description is introduced followed by some analytical illustrations and definition of the system performance measurement parameters.

A. The Protocol Architecture:

The operation of M2M network is performed on frame-by-frame basis. Each frame consists of three parts as shown in Fig.2. These parts are mentioned before as NP, COP, and TOP. In each period, BS and the devices operate as follows:

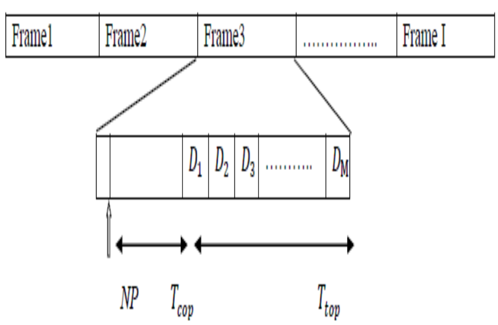

Figure 2. The Frame structure.

1) *Notification Period (NP):* This is the region where the BS broadcasts notification messages to all devices at the start of each frame to notify the beginning of the contention. Also, it is used for time synchronization and providing network information for new registered devices. Upon receiving the notification message, only the devices that have data to transmit will contend the transmission time slots during COP. Other devices that do not have packets to transmit keep its energy by entering sleep mode.

2) *Contention Only Period (COP):* the devices contend the transmission opportunities based on NP-CSMA access method in this period. The contending devices randomly send the transmission request (REQ) message to the BS. When only one device transmits REQ message, the device success in contention. Upon receiving the acknowledgement (ACK) message from the BS, the device stop sending REQ message. The ACK message contains information about index of the transmission time slot in which the device is allowed to transmit in TOP.

3) *Transmission Only Period (TOP):* Each device successfully contends the transmission slots in COP, assigned the same time slot to transmit its own packets in each frame until it has no packet to transmit without loss of generality, assuming that each time slot has the same length.

In this proposed protocol, the BS broadcast a notification messages for all K devices during NP duration. DuringT_{cop}, only the active devices are wake up and their counters are turn on to calculate length of T_{cop} and the beginning time ofT_{top}. The devices that don not have any packets to send preserve their energy by entering the sleep mode. The active devices send a REQ messages to BS .If only one device transmit a REQ message to the BS, the contention is successful and that device receive an ACK message from the BS including its time slot number. Otherwise, the collision occur and a retransmission process occurring using Poisson distribution for the colliding devices. The active devices enter the sleep mode till the next activity. Upon T_{top} duration, a time slot has been reserved for each successfully contending device. Each active device successfully reserve a time slot in T_{top} will sleep till the same time slot in the next frame to send the reminder packets in its buffer.

B. The Analytical Representations:

According to our proposed MAC protocol, the duration of each frame T_{frame} for a given number of contending devices K. the contending probability for all K devices during COP is the same. The remaining period of T_{frame} after T_{cop} is divided into number of time slots each with T_{slot} duration. Packet arrival rate is assumed to follow Poisson distribution.

Based on NP-CSMA mechanism [6], the successful contention can be defined as the event that the transmission request from a device is successfully received by BS. Let $t_i$is the time between the (i-1) th and the i th successful contention. Ni denotes the number of collisions that occurred during t_i, then [9]

$$t_i= \sum_{j=1}^{N_i}\{[Idle_{i,j} + Colli_{i,j}] + Idle\ N_i + S_i\} \quad (5)$$

$Idle_{i,j}$ Is the duration of the j th idle time that precedes the channel busy period (either collision or success) in each t_i duration, $Colli_{i,j}$ is the duration of the j th collision given that a collision occurs, S_i is the length of the request message.

Let $$t_i = A \,.\, T_{int} \quad (6)$$

t_i Is a matrix of x*1 dimension, A is also a random matrix of x*y dimension following Poisson distribution and T_{int} is a matrix of y*1 dimension.

T_{cop} Which is the sum of random variablet_i, Denotes the duration of the COP in each frame

$$T_{cop} = \sum_{i=1}^{M} t_i$$

$$= \sum_{i=1}^{M}\{\sum_{j=1}^{Ni}[Idle_{i,j} + Colli_{i,j}] + Idle\ N_i + S_i\} \quad (7)$$

T_{cop} Is assumed to be constant and equals to 3msec in this protocol.

C. The System Performance Parameters:

In our Proposed MAC protocol, there are some parameters which must be defined before taking our results. These parameters are explained as follows:

1) Throughput: The Throughput can be defined as the quantity of the packets that are successfully transmitted in a time interval [15].

$$S = \frac{T*n}{R} = \frac{\left(P_{succ}/S_{rate}\right)}{t} \quad (8)$$

T is the quantity of information in a packet and n is number of packets successfully transmitted in a unit interval. R is data rate to be transmitted. S is also defined as ratio of number of packets successfully transmitting over total number of packet transmission in a time interval t. P_{succ} Is the total offered capacity, S_{rate} is the symbol rate and equal to 256 kb/s.

2) Average Transmission Delay: The average transmission delay can be defined as the time elapsed between the start of the frame and the end of its transmission to BS during the frame [15]. It can be calculated as follows:

$$\text{Average Delay} = \frac{\left(\frac{T_{delay}}{succ}\right)}{T_{slot}} \quad (9)$$

T_{delay} Is the total packet delay time and SUCC is the total number of successful packets (achieved capacity) and it equals to P_{succ} * packet length L_p. T_{slot} is the duration of a time slot.

3) The Packet Delivery Ratio: The Packet Delivery Ratio can be defined as the ratio of the number of blocked packets (which equal to offered traffic minus throughput) to the offered traffic G during the simulation duration.

5. Simulation Results

A. Simulation Setup:

The network consists of K number of devices distributed around one BS following the normal distribution in a certain area with a radius of r. Each device generates a data packet based on Poisson distribution which is subdivided in to a random number of packets and stored in its unlimited buffer. Hence, each device has random several packets to be transmitted in its infinity size buffer.

Extensive MATLAB programs are done to simulate the performance of our proposed protocol. The system parameters are shown in Table-I. In addition, comparisons of the proposed MAC protocol with contention based such as NP-CSMA, S-ALOHA, and P-ALOHA are done. The effect of some parameters such as delay time, Packet Delivery Ratio and number of users will be investigated.

TABLE I. Simulation Parameters

SIMULATION PARAMETERS	
Parameter value	Parameter name
T_{frame}=10ms	The duration of a frame
T_{slot}= 0.5msec	The duration of each slot
T_{packet} = 0.5msec	One packet transmission time
T_{cop}= 3msec	The duration of COP
T_{NO}=10µsec	The length of the notification period.
T_{ack}=7 µsec	The ACK message length.
T_{req}= 22 µsec	The length of notification period
N_{slot}=14	Number of time slots
Users=200,500,1000	Number of devices

B. The System Throughput:

Figure 3 shows throughput of the proposed protocol in comparison with contention based techniques such as NP-CSMA, S-ALOHA, and P-ALOHA in terms of packet arrival rate in 500 devices. From this Figure, we conclude that, our proposed protocol performs better performance at lower values of λ and remains constant for higher values at 0.6395 which higher than the maximum throughput at 0.51, 0.3582 and 0.1819 of NP-CSMA, S-ALOHA, P-ALOHA, respectively . At certain value of λ = 10 packet/sec per user, the proposed protocol throughput reaches to 0.635 which represents the higher value than NP-CSMA that reaches to 0.4827, S-ALOHA and P-ALOHA that achieved a throughput of 0.3313 and 0.0771, respectively at that value of λ. Hence, with growing number of packets to be sent, the proposed protocol reserves a time slot for each device successfully to contend the transmission in each frame until it sends all packets in its buffer and it has no packet to be sent.

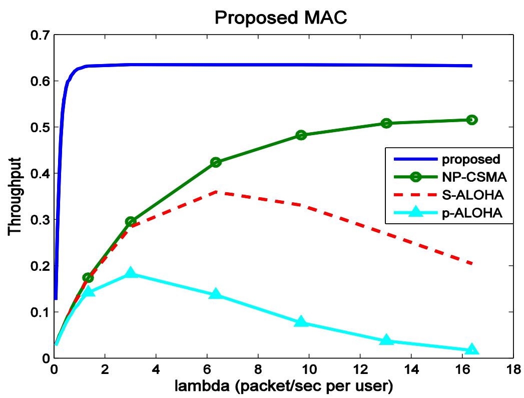

Figure 3. Throughput in terms of packet arrival rate in 500 devices.

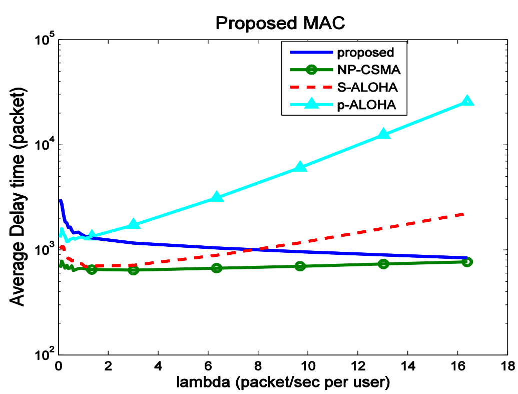

Figure 4. Average Delay time in terms of packet arrival rate λ in 500 devices

C. The System Average Delay:

In Figure 4, comparisons with the average delay time in terms of packet arrival rate among the proposed protocol, NP-CSMA, S-ALOHA, and P-ALOHA in case of 500 devices. It shows that proposed protocol average delay is a decreasing curve that reach to 800 packets at higher value of λ as NP-CSMA delay time. Under lower values of λ, it achieved an average delay time around 1200 packets which lower than P-ALOHA average delay time. Under higher values of λ, it achieves a lower average delay time than S-ALOHA average delay. As number of devices increase, more packets have to be contend transmission which leads to more collision and delay. At λ=10 packets/sec per user, NP-CSMA, S-ALOHA and P-ALOHA achieved increasing delay with a values of 710, 1172 and 6078 packets, respectively. At λ=15 packets/sec per user, our proposed protocol delay time equals to 800 packets. With increasing the number of packets that transmit per user, our proposed protocol average delay time will be reduced below 800 packets and NP-CSMA average delay time will be increased over 800 packets.

D. The System Packet Delivery Ratio:

Figure 5 shows the Packet Delivery Ratio of proposed protocol in 500 devices case when each device has random number of packets in its buffer. We observe that Packet Delivery Ratio of proposed protocol is lower than NP-CSMA, S-ALOHA, and P-ALOHA. However increasing number of devices that contend transmission opportunities each with a random packets number, proposed protocol preserves lower Packet Ratio with a maximum value of 0.84 that results from the analysis of that protocol in reserving a time slot for each successful device in each frame until send all its packets. With increasing devices, NP-CSMA maximum Packet Ratio is higher at 0.8918, S-ALOHA and P-ALOHA have higher maximum Packet Ratio due to collision and no reservation technique found that reaches to 0.9141 and 0.9829.

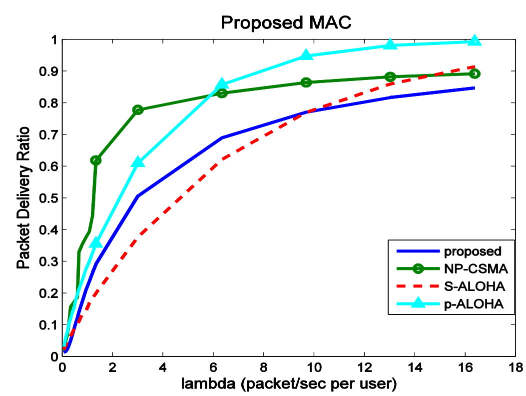

Figure 5. Packet Delivery Ratio in terms of lambda λ in case of 500 devices.

E. The Effect of The Number of Users:

Figure 6 approves that our proposed protocol remains at higher throughput with increasing number of devices in the network to 1000 devices with a maximum value of 0.6395. Our protocol is designed to accommodate very large number of devices as it transmits all packets for a device that successfully contend the transmission by reserving a constant time slot in each frame for that device. At a certain value of λ = 8 packet/sec per user, our proposed protocol achieved the same maximum throughput at 0.6395 in three different number of devices cases (at number of devices equals to 200, 500, 1000).

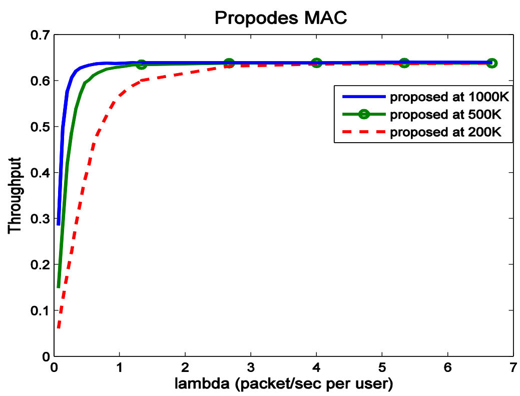

Figure 6. Throughput of proposed protocol in terms of lambda λ at different number of devices K.

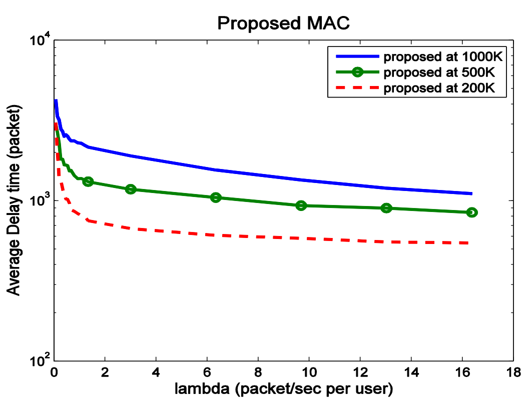

Figure 7. Average Delay time of proposed protocol in terms of λ at different number of devices K.

Figure 7 presents average delay time in terms of λ in three cases of proposed protocol with different number of devices K (at K = 200, 500, 1000 devices). Our proposed protocol with 200 devices achieved lower average packet delay around 600 packets in comparison with that protocol in two 500 and 1000 devices cases that achieved a decreasing delay time around 900 and 1300 packets, respectively. With increasing number of devices each with a random number of packets in its buffer to transmit, more collisions occur and more packets waiting to transmit in the buffer which leads to large delay time for larger number of devices in the network. For example at λ= 8 packet/sec per user, our proposed protocol in 1000 devices achieved a large delay at 1600 packets, it reached to a medium value in 500 devices at 1100 packets but it achieved a lower delay value in 200 devices at 653 packets.

Figure 8 shows Packet Delivery Ratio of our proposed protocol which has lower performance with minimum number of devices at 200 devices. Increasing number of devices each with different number of packets to transmit results in more collisions and higher Packet Ratio. Therefore, our proposed protocol with 200 devices achieved lower Packet Ratio with a maximum value at 0.70899, it reached to a maximum Packet Ratio of 0.8463 at 500 devices and it achieved a higher maximum Packet Ratio with 1000 devices at 0.92.

CONCLUSIONS

In this paper, we focused on designing a proposed MAC protocol for M2M network with different number of devices each with a random number of packets in its buffer. In this protocol, the operation of each frame is divided into NP, COP and TOP. The devices only send contending requests during COP and transmit its data during COP. From simulation results, we showed that with increasing number of devices each with a random number of packets that send, our proposed protocol preserves achieving a high throughput, a lower average delay and a lower Packet Delivery Ratio in comparison with other contention based protocols such as NP-CSMA, S-ALOHA, and P-ALOHA mechanisms.

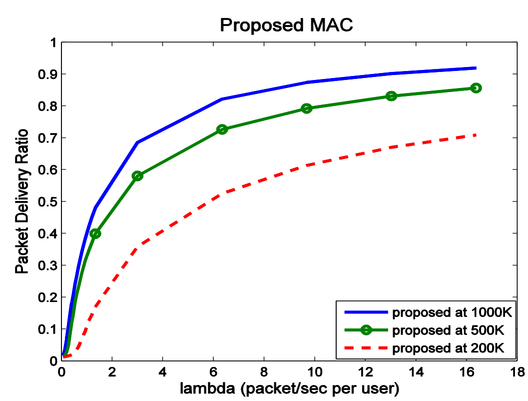

Figure 8. Packet Delivery Ratio of proposed protocol in terms of λ at different number of devices (K = 200, 500, 1000 devices).

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