A Scalable and Power Efficient MAC Protocol with Adaptive TDMA for M2M Communication

Narender Reddy (narenderrkampelli@gmail.com)
JNTUH College of Engineering: Jawaharlal Nehru Technological University Hyderabad College of Engineering
B N Bhandari
JNTUH College of Engineering: Jawaharlal Nehru Technological University Hyderabad College of Engineering

Research Article

Keywords: Collision mitigation, Grouping, M2M communication, MAC protocol, QoS

Posted Date: July 25th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1862352/v1

A Scalable and Power Efficient MAC Protocol with Adaptive TDMA for M2M Communication

Narender Reddy Kampelli [1] **Dr. B N Bhandari** [2]

[1] Assistant Professor, Electronics & Communication Engineering, JNTUH College of Engineering, narenderreddy.kampelli@gmail.com

[2] Professor & Director of School of Continuing & Distance Education, Electronics & Communication Engineering JNTUH College of Engineering, bnb@jntuh.ac.in

***Abstract*— In 5G cellular networks Machine type communication devices (MTCD) for Machine-to-Machine (M2M) communication are subjected to the problem of collisions, delay, scalability and quality of service (QoS) during data transmission. The M2M communication has become ubiquitous into Internet of things (IoT). A power efficient MAC switching protocol and adaptive Time Division Multiple Access (PMAC-ATDMA) is presented to solve the issue of collision, QoS and scalability in this paper for M2M Communication. This consists of grouping, dynamic MAC switching and allotment of timeslots. In grouping processing of MTCDs, using Harris Hawks Optimization (HHO) algorithm is used for selecting a head i.e. MTC head (MTCH). CSMA/CA and CSMA/CARP protocols differ in back off time are used, switching between them happens based on the density, backlogged devices and active nodes that reduces collisions. The timeslots are assigned by ATDMA, in accordance with the data size and requirements of QoS. The problem of synchronization in traditional TDMA is overcome by the use of Markov chain model the simulation of this PMAC-ATDMA is performed in network simulator tool. The evaluation is performed in terms of access delay, energy, probability of collision and successful packet transmissions.**

Index Terms: Collision mitigation, Grouping, M2M communication, MAC protocol, QoS

I. Introduction

Machine-to -Machine Communication called Machine Type Communication in Cellular IoT is main constituent of Internet of things (IoT) which enables seamless information exchange between autonomous intelligent networked machine type communication devices (MTCD) without explicit human intervention by using different mechanisms, algorithms and technologies. MTC in IoT supports multiple smart environments as home, healthcare, city, industry and others [1], [2], [3], [4], [5]. The MTC in cellular devices enabled for long distance communication using the technologies 2G, 4G and 5 G. Medium Access Control (MAC) protocol is designed for M2M communication as a solution to scalability [6], [7], [8], [9], [10].

The random-access techniques focused on access delay, energy efficiency, traffic overload, collision control and management of resources. The MAC design is associated with grouped MTCD. The guaranteed QoS requirements in M2M communication is enabled by sufficient allocation of radio resources. Delay oriented metrics play a vital role in providing QoS. The QoS metrics in M2M communication is solved by incorporating scheduling i.e. the assignment of pre-defined timeslots for performing data transmission [11], [12]. The common features in MTC are illustrated in table I.

The major challenges that exists in M2M communication network,

- Link connectivity strength and Jitter constraints due to massive participation of M2M devices in the network
- Selection of relay nodes for efficient data transmission in the network
- Management of traffic and increased collisions from multiple MTCD
- Requires reliable data transmissions and ability to satisfy QoS

Table I
Main Features of MTC

Feature	Description
Device mobility	Infrequent movement of devices within a region. Very low mobility.
Delay	Tolerant to delay during data transmission
Data delivery	Time based data transmission with respect to the time determined for scheduling method.

The massive increase in MTCD devices managed by grouping of devices [13],[14]. M2M communication is performed directly or indirectly via relay devices. The process of sharing resource within a group of MTCDs minimizes the under-utilization of the resources. The resource utilization is also improved by the channel access MAC protocols Slotted ALOHA, ALOHA-NOMA, carrier sensing multiple access with collision avoidance (CSMA/CA) [15], [16], [17], [18]. The time division multiple access (TDMA) is also involved for allotting timeslots for data transmission.

In general, the MAC protocol is of three types as contention-based, reservation based and hybrid MAC protocols. The hybrid MAC protocol is designed as a combination of two MACs [19], [20]. The effective development of MAC protocol impacts on the improvement of multiple performance metrics the design of priority-based MAC is enabled to support QoS.

In this paper, M2M communication system is designed with the objective of minimizing energy consumption, number of collisions and delay. These objectives are achieved from grouping, MAC switching and efficient assignment of timeslots for data transmission. The earlier research work focused on normal characteristics of UEs. This system developed based on the characteristics of MTCDs which are part of M2M Network.

1.1 Motivation

In M2M communication lot of progress has happened but still there exist a lot of scope to improve QoS of the network i.e. performance improvement in terms of delay and energy efficiency. Performance is achieved by the development of MAC Protocol using clustering, switching of MAC Protocol and timeslot assignment. Each process results in improvement of the network performance [21], [22]. Existing MAC protocols are used stand alone or as a hybrid. The design of hybrid MAC protocol combines processing of two MAC design into one or it is performed sequentially one after the other.

The common limitations that are identified in traditional M2M communication MAC protocols are,

- High delay due to poor channel access scheme which increases collision between MTCDs during communication.
- Time synchronization required between the pairs of MTCDs during communication to improve successive data transmission.
- QoS support for different critical applications

1.2 Contribution

The contributions of this proposed M2M communication system are,

- Grouping of MTCD mitigates power i.e. not all the MTCD access eNB, only the corresponding heads requests eNB which mitigates power and collision. The entire coverage range of eNB is selected with hierarchical MTC-heads (MTCH) in increasing levels of communication range. Grouping is also presented to guarantee QoS in the network. The MTC head (MTCH) is selected from Harris Hawks Optimization (HHO) by estimating distance with eNB, received power and residual energy.
- A novel switching of MAC protocol is introduced. The switching is performed between enhanced CSMA/CA (E-CSMA/CA) and CSMA/CARP. In enhanced CSMA/CA, the back-off time is computed using aggregate function, delay and active MTCDs in the particular group.
- Also, appropriate timeslot assignment for data transmission is performed using Adaptive-TDMA (A-TDMA) with assured QoS. The timeslots of individual MTCD are synchronized by the incorporation of Markov chain model.

In section II details of related work on M2M communication systems and the limitations in priori research; section III illustrates the identified problems in the existing work, section IV presents the possible solutions for improved M2M communication system, section V result analysis.VI conclusion with future directions.

II. Related Works

In M2M communication system the channel access by the MTCDs are incorporated based on the MAC protocol design. The improvement of QoS and Quality of Experience (QoE) was the major concentration while designing a resource allocation and MAC protocol.M2M/IoT traffic-based resource allocation was proposed for reliable communication [23]. A QoS guaranteed technique named threshold-controlled access (TCA) protocol was presented [24]. The proposed TCA protocol estimated threshold in accordance to QoS metric. This work was not studied for massive number of devices with allocation of resources and hence suitable only for a smaller number of M2M. The QoS in M2M was attained by minimizing the delay metric [25], [26]. A novel random-access scheme with the incorporation of virtual preambles was developed. Unique virtual preambles create the opportunities of faster accessing with minimized access delay and collision. The selection of unique preamble ensures with the reduction of collision during access.

In [27], the authors developed a delay-aware time-slotted resource allocation with priority-based queuing model used for both human-to-human (H2H) communication and M2M communication, in which H2H was provided with higher priority and M2M with lower priority. hence lower priority for M2M fails to assist QoS. The resource allocation in orthogonal variable spreading factor (OVSF) also based on the priority [28]. An admission control model with delay-sensitive and delay-tolerant first requests [29]. This was implemented to mitigate number of requests submitted to access. In this admission control algorithm, certain requests were rejected due to their delay constraint. Hence, this work fails to provide access to all the requesting M2M devices. A recursive maximum expansion modified (RME-M) was proposed to compensate energy and delay [30]. In RME-M, the transmission time interval (TTI) was computed and then the M2M devices are arranged in ascending order.

A collision-aware resource access (CARA) scheme which aims to minimize collision was proposed [31]. However, in this work, the probability of collision was not detected earlier. This leads to prolong the time in data transmission and re-transmission that degrades network performance. The problem of congestion was resolved using Q-learning approach as a random-access channel scheme [32]. In this approach, the assignment of multiple preambles for each M2M and H2H is efficient only when the number of devices is lesser in number.

Resource allocation also focuses on improving the network performances in terms of energy, QoE, throughput and delay. A fair and efficient resource allocation in MTCD by solving Nash bargaining solution [33]. The allocation of resources was based on the channel quality. The minimum rated MTCDs were allotted with resources based on the differing channel conditions. The energy efficiency among the groups of M2M devices was presented [34]. For power allocation, Lagrange multipliers was proposed to compute optimal transmit power for MTCD and MTCG.

In order to ensure QoE in data forwarding, a network dimensioning and radio resource partitioning was established [35]. The quality of experience (QoE) is maximized by taking in account of outage probability constraint and minimum

MTCD density constraints. The packets from MTCD are collected by MTC gateway and transmitted to BS via random requests procedure. Here, the resource blocks are allocated for MTCD-to-MTCD and MTCD-to-BS. A network throughput maximization by selecting optimal back-off values based on access class barring (ACB) factor and uniform back-off (UB) window size was proposed [36]. These constraints were tuned by taking in account of traffic type input from machine type device (MTD). The MTD generates random number and compares it with ACB factor, if condition satisfied then request will be sent else the request will be barred temporarily. If collision exists, then a random UB window size was selected and waits till zero was reached. The random selection of UB could be too longer.

MAC protocol design in M2M communication that was used for reducing collision in data transmission. An efficient MAC protocol design that composes notification period, contention period and transmission period was developed [37]. Traditional TDMA based data transmission was presented in this work with the condition of signal-to-interference plus noise ratio (SINR). If the slots are busy, then SINR value was determined and checks with the threshold to reserve slots for data transmission. The slots reserved for longer time could be used for other M2M data transmissions. Data transmission was performed based on the assignment of timeslots [38].The authors have employed extend eHint protocol designed with multi-slot for data transmission. The multi-slot allocation of communication channel deals with three process as broadcast, allocate and random. The previous two virtual frame (2VF) was filed to select a satisfactory seed when there was an increase in number of IoT devices. To solve this problem, an iterative-virtual-frame was presented that selects seed using iterative based on specified time bound. The initial seed values were considered randomly without taking in account of significant network constraints. Also, many numbers of iterations were performed for seed selection until the time bound was reached, in case if an unsatisfied seed was estimated, then previous best seed was used. However, the time utilized for unsatisfied seed estimation degrades network performance.

The design of combining two MAC protocols were designed in M2M communication system [39], [40]. Ahybrid MAC protocol was proposed as a combination of slotted-ALOHA and TDMA mechanism. The Monte Carlo simulations were performed for retrieving optimized values of probability of successful contending and duration of transmission. The contention mechanism of non-persistent carrier sense multiple access with collision avoidance (NP-CSMA-CA), S-ALOHA and P-persistent carrier sense multiple access with collision avoidance (P-CSMA-CA). The optimization problems defined were the probability of successful contending and duration of transmission. However, the optimization was presented the MAC used here was not based on any peculiar constraint. If time slots are available, then they are reserved earlier for data transmission. As per the existence of key issues on each process, the major problems are extracted from this literature and resolved in proposed M2M communication system.

III. Problem Description

Several key problems identified in the existing work. A cluster-based congestion mitigating access scheme (CCAS) was proposed in which MTCDs are clustered i.e. grouped and then a MTC gateway (MTCG) was selected for data transmission [41]. In this clustering, initially similarity was estimated, then spectral clustering was used to determine diagonal matrix, Laplace matrix eigen values and eigen vectors which was given into K-means clustering for cluster formation which takes more time to process. Traditional CSMA/CA MAC protocol was used which enabled only to limit the collision but failed to reduce power consumption. For enabling resource allocation, M2M opportunistic splitting algorithm (M2M-OSA) was applied [42].In M2M-OSA the resource blocks were randomly chosen. Every user equipment (UE) device was provided a maximum retransmission limit, within which the device was allowed to request for resource. UE uses two known threshold values based on the number of contending devices, if condition satisfied UE request base station. If the feedback was unsuccessful due to collision, then the threshold was updated. The problems identified in this M2M-OSA are,

- Random selection of resource blocks leads to under-utilization of resources and also increases the probability of failure.
- The threshold value was updated only after the experience of collision in M2M communication. Poor network performance due to use of similar threshold values for MTCDs for dissimilar characteristics of communication between M2M devices.
- Suitable of M2M communication with limited number of devices and does not support large number of M2M devices as resources demand increases.

The MAC protocol developed for ensuring energy efficiency in M2M communication system in [43], [44]. A power adaptive methodology used that follows processing in two phases as: phase 1 power adaptive slotted Aloha (PASA) MAC protocol and phase 2: spectrum provisioning for devices. The contention window size was adjusted with respect to power and delay (retransmission delay, propagation delay and packet transmission delay). The hybrid MAC protocol was composed of contention interval (CI) and data transmission interval (DTI) that performs DTI followed by TDMA. The main issues identified in power-based MAC and hybrid MAC are,

- Delay time was computed based on three metrics from previous transmission. So, the computation of delay in accordance with prior transmission does not possible to estimate accurate current window size, due to dynamic M2M signal characteristics and in slotted ALOHA more probability of collision.
- TDMA based data transmission degrades scalability since it is asynchronous; using TDMA requires time synchronization among M2M devices. The operation of TDMA in the absence of time synchronization introduces overhead.

From these problems in resource allocation and MAC protocol, the proposed system is designed with efficient M2M communication system.

IV. Proposed M2M Communication System

The proposed M2M communication system addresses the problematic issues discussed in MAC protocol and M2M data transmission. The MTC devices are employed in the network environment. This section deals with the three-phase processing in the proposed M2M communication.

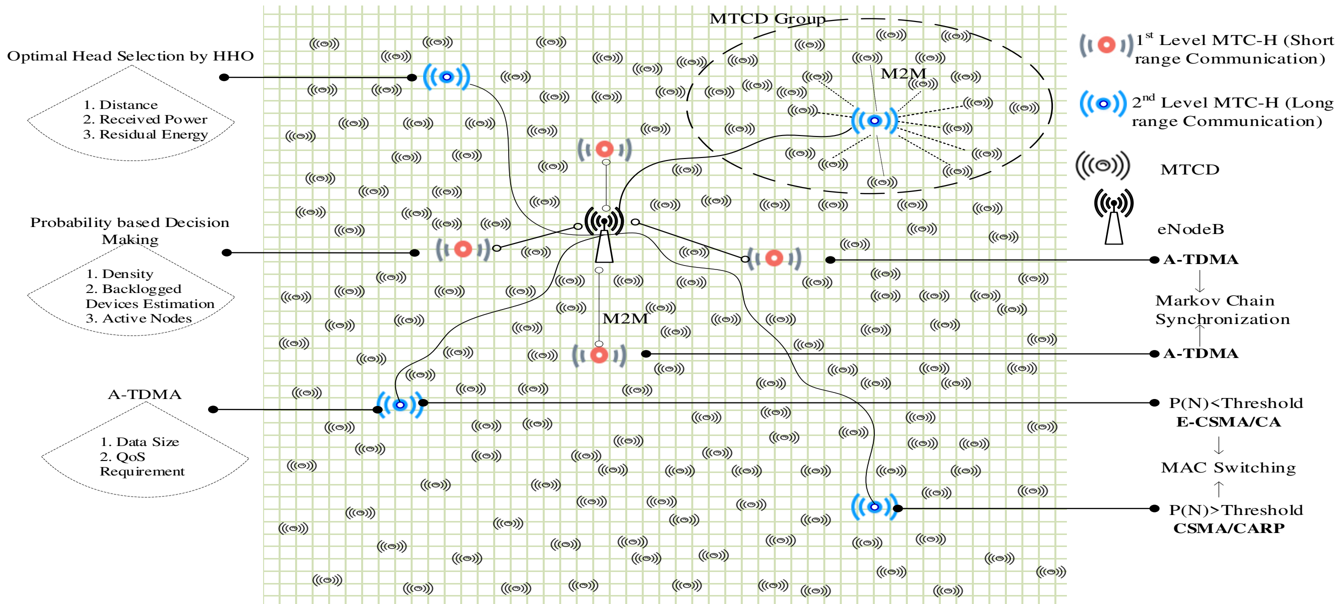


Fig 1. Proposed M2M Communication Network

4.1 System model

This M2M communication system model use LTE communication technology. It consists of n number of MTCDs and eNB with network area of $N \times N$. The MTCDs are randomly deployed in different position on the network. MTCDs are the sensors that are capable of sensing the surroundings and communicate with the other MTCDs. All the MTCDs are fed with similar amount of energy during initial deployment. Fig 1 depicts the network architecture in which the MTCDs perform data transmission using proposed MAC protocol. The network is equipped with an eNB for allotting resources using which the data transmission is performed.The eNB is positioned at the center of the network and the MTCHs are selected in hierarchical order with respect to the coverage distance. This system is considered for a smart city environment where the sensors are deployed to measure the environmental changes.

Initially, group heads are selected among the deployed MTCDs using optimization algorithm. Then the MTC heads (MTCH) creates its own groups by including the MTCDs with the exchange of request and responses.As in [41], the MTCDs in this work are enabled to communicate in short range as well as long range. The grouping of MTCDs ensures to solve QoS requirements in scalable network. The MTCHs is operated with anyone of the MAC protocol as E-CSMA/CA or CSMA/CARP. In E-CSMA/CA, the collision is avoided, whereas CSMA/CARP also avoids collision and transmits data abased on the priority. To improve the data transmission efficiency, this system proposes switching of MAC protocol. As per the density of the MTCDs in each group the MAC protocol is chosen.An adaptive TDMA is incorporated along with the synchronization by eNB using Markov chain model. This synchronization ensures with the minimization of collision during data transmission. The proposed M2M communication system is presented for the objective of reducing collision during resource allocation and data transmission. This system is operated in three phases phase I, phase II and phase III as: (i) grouping, (ii) MAC switching and (iii) data transmission.

4.2 Phase I – Grouping of M2M devices

In this phase, the MTCDs grouped into different levels based on their distance. Manhattan distance is applied for selecting first level of MTCHs and then these first level MTCHs will select next level of MTCHs using HHO algorithm. The first level of MTCHs selected from Manhattan distance expressed as,

$$D = \sum_{i=1}^{n} |x_i - y_i| \quad (1)$$

The distance between eNB and n number of MTCDs at the first level is given from the current position points x_i with respect to the MTCD position y_i. The MTCDs that are closer and adjacent to eNB is selected. In total four MTCHs are selected by the eNB based on this distance. Then, these MTCHs selected next level of heads for the purpose of grouping. The grouping is performed only after all the MTCHs in the network is elected.HHO algorithm is applied, in which MTCHs are selected by estimating the fitness values. This HHO algorithm is a nature-inspired algorithm that is developed from the Harris Hawks chasing their prey.The optimal head selection is performed based on three metrics as distance between MTCD and eNB, received power and residual energy of MTCD.The MTCDs are sensors devices that are extremely energy constrained and depending on their sensing and data transmission, the energy in individual MTCD is dropped. In HHO, rabbit is the target prey of Harris hawks, hence in this MTCH selection the MTCHs are rabbits and the selectors are first level MTCHs i.e.harris hawks.

The HHO algorithm follows two phases of processing as exploration and exploitation. Two strategies are activated to identify optimal MTCH. The exploration phased strategy for the hawk is given as,

$$X(t+1) = \begin{cases} X_{rand}(t) - r_1 |X_{rand}(t) - 2r_2 X(t)| & q \geq 0.5 \\ (X_{rabbit}(t) - X_m(t)) - r_3(LB + r_4(UB - LB)) & q < 0.5 \end{cases} \quad (2)$$

Let$t$ be the current iteration, $(t+1)$ is the next iteration, $X(t+1)$ be the hawks's position vector at $(t+1)$ iteration, $X_{rabbit}(t)$ is the rabbit's position, $X(t)$ is present position of the hawks, certain random number are included as r_1, r_2 ,r_3 ,r_4, qthat ranges between [0,1]. Then $X_{rand}(t)$ be the randomly selected hawks andX_m is the defined as average position of hawks, UB and LB represents upper bound and lower bound variables respectively. Hereby, the average position of hawks is given as,

$$X_m(t) = \frac{1}{K}\sum_{i=1}^{K} X_i(t) \quad (3)$$

The $X_i(t)$ denotes the hawk location at t^{th}iteration, K be the number of participating hawks i.e. first level MTCHs in the network. Then, as per the energy of the next level of MTCDs i.e. rabbit, the transition from exploration to exploitation is performed. Hereby, the energy$E$ is mathematically formulated as,

$$E = 2E_0\left(1 - \frac{t}{T}\right) \quad (4)$$

T indicates the number of iterations and E_0 denotes the amount of initial energy of the rabbit. On computing the energy, exploitation phase is performed in soft besiege or hard besiege. The position vector is updated in this phase based on the energy value. The soft besiege (SB) and hard besiege (HB) is mathematically expressed as,

$$X(t+1)_{SB} = \Delta X(t) - E|JX_{rabbit}(t) - X(t)| \quad (5)$$

$$X(t+1)_{HB} = X_{rabbit}(t) - E|\Delta X(t)| \quad (6)$$

Where $\Delta X(t) = X_{rabbit}(t) - X(t)$, the value J defines the strength of the rabbit which randomly changes.The fitness value is computed from distance, received power and residual energy. The distance between two MTCDs is determined based on Euclidean distance given as,

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (7)$$

(x_1, y_1) and (x_2, y_2) are the position coordinate points of individual MTCDs. Then the received power $R_P$is determined using Friis equation that is given as,

$$R_P = \frac{P_T G_T G_R \lambda^2}{(4\pi d)^2} \quad (8)$$

Where $G_{T,}G_R$ indicates received gain,P_T is the total power andλ is the wavelength. Then the residual energy of the MTCD is determined from the initial amount of energy that is present for MTCD. Based on the three constraints the fitness is estimated for each MTCDs in second level and the MTCHs are selected.

Pseudo code for HHO algorithm

```
Input: 2nd level MTCDs
Output: Selected MTCHs as X_rabbit
Begin
initialize population X_i i.e. hawks // 1st level MTCHs
While (stopping condition not reached)
        do
          {
            Compute hawk's fitness value
 Assign best location for X_rabbit
 For eachX_i do
           Update energy E_0 and strength // 2nd level MTCHs
    Update E using equ (4)
  If (|E > |1)                    //Exploration phase
        Update position vector
   If (|E| < 1)                    // Exploitation phase
      update position vector
Return X_rabbit //Optimal MTCH
End
```

In this way, the MTCHs are selected in hierarchical levels of the network until the entire network coverage is reached.The above pseudo code shown for HHO algorithm by which MTCH is selected. Once the MTCHs are selected, the group members are added. The elected MTCH broadcasts it as the group hence, then the other MTCDs within the coverage sends join request to the MTCH. The MTCH, on receiving request, it then delivers back the join reply to corresponding MTCD. Hereby, the groups are constructed in by the selected MTCHs in the network. This grouping is performed to guarantee QoS. Random grouping of MTCD will not be able to be maintained for longer time so employed an optimization algorithm for MTCH selection. Hence, the grouping of MTCDs reflect on the improvement of the network performance.

4.3 Phase II –Dynamic MAC switching

The energy efficient MAC protocols E-CSMA/CA is developed having less energy consumption over conventional

CSMA/CA and used along with CSMA/CARP.The larger waiting time is due to random selection of back-off values which is overcome in this work by computing back-off with significant constraints. However, in larger density with different traffic CSMA/CARP is better than CSMA/CA. Hereby a novel MAC switching procedure is incorporated.

The collision between the MTCDs are mitigated by assignment of set of preambles to each MTCH. Due to the selection of same preamble by more than one MTCD causes collision and so, in this work a set of preambles are allotted. Each MTCH estimates a probability value for switching MAC, the probability is computed from density, backlogged devices and actives MTCDs. Here the density defines the total number of MTDCs that are present in that group.

The backlogged devices are determined as the difference estimated between numbers of active MTCDs with respect to the number of successes. Then the number of active devices N_a be,

$$N_a = \begin{cases} N_{a-1} - S_{a-1} + A_a, & if\ a \le I_x \\ N_{a-1} - S_{a-1}, & otherwise \end{cases} \quad (9)$$

S_a and $A_a$denotes the number of successes and new MTCDs, $a = 1,2, \ldots\ldots I_x$. hereby the average number of successes$\bar{S}_a$ is given as,

$$\bar{S}_a \approx K(1 - e^{-N_a/K}) \quad (10)$$

K is the number of resource blocks. From this the probability of the MTCHs$P(N)$ is determined as follows,

$$P(N) = (d_n, N_b, N_a) \quad (11)$$

Let N_b andd_n be the number of backlogged devices and density of MTCDs in that group. If the probability value goes beyond the threshold then CSMA/CARP is followed else E-CSMA/CA is used. From the estimated probability value, the MAC protocol is switched.

$$L_{st} = \left(\frac{CR}{d(n_i,n_j)}\right) + snr + (bw \log_2(1 + snr)) \quad (12)$$

Once the MAC protocol is chosen, then the link stability and bandwidth in the channel is computed for minimizing collisions. The link stabilityL_{st} is estimated based on the coverage range CR of the MTCD, distance between i^{th} and j^{th}MTCD. Then$bw$and snr represents the bandwidth and signal to noise ratio (SNR) respectively.

In E-CSMA/CA the radio channel is monitored by the MTCD for assuring that that particular channel is not occupied by any other MTCD. If the channel is free, then data transmission is performed else the MTCD waits for a period of back-off time. The back-off time is determined by taking in account of aggregate function, delay and active MTCD. Hereby, the back-offBO time is given as,

$$BO = \left[\frac{2^l}{R_{agg}, d_e, N_a} \times ran()\right] \times T_s \quad (13)$$

Where R_{agg} denotes the aggregate function that is proportional to the data size,d_e is delay, T_s is the back-off timeslot and l is the positive variable. The MTCD waits up to back-off time and then it begins data transmission as per the MAC procedure. In E-CSMA/CA, the request to send (RTS) and clear to send (CTS) messages are exchanged. Hereby in E-CSMA/CA the MTCD has to wait for the BO time and also if the CTS is not received then BO is computed again for that channel.

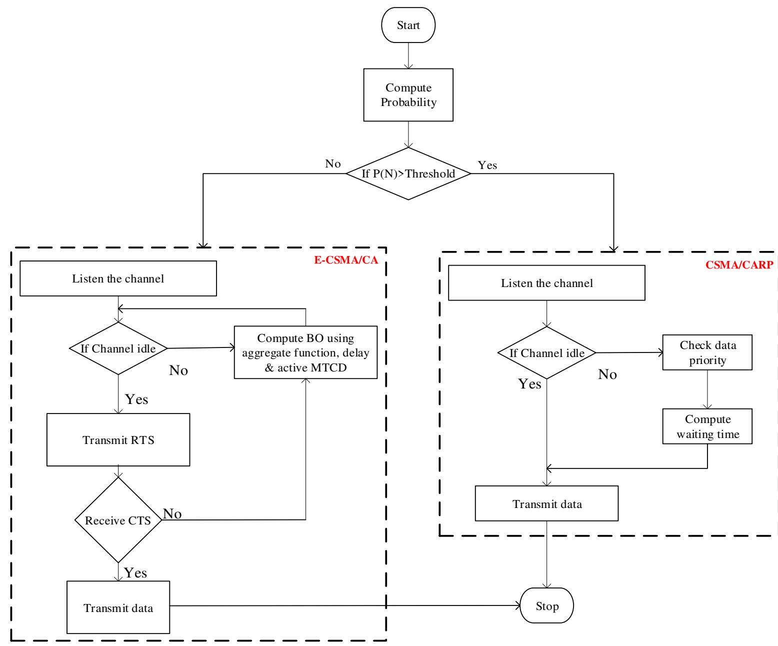
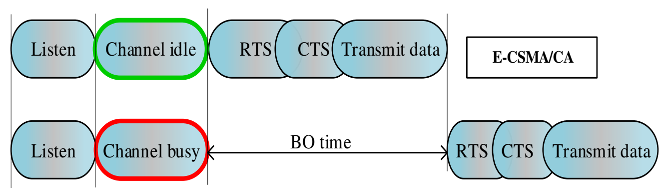


Fig 2. Dynamic MAC switching

In CSMA/CA it deals with contentions window with which the back-off value is determined. When the obtained probability value is larger, this CSMA/CARP is switched over by MTCH. This MAC protocol is listens to the traffic of the MTCD, if the channel is idle it directly sends the data. If not, then the waiting time is computed with Inter Frame Space (IFS) in which the waiting time is short for higher priority data and larger waiting time for lower priority data. The waiting time is determined by computing the channel capacity and residual energy of the MTCD along with their priority. The channel capacity defines the amount of signal and noise that are present in the channel. The channel with higher signal denotes stronger channel that can be assured for successful data transmission. In case, the noise present is larger amount then that channel has many possibilities to be used by another MTCD. Shannon-Hartley theorem is used for computing channel capacity from the bandwidth and SNR in the channel.



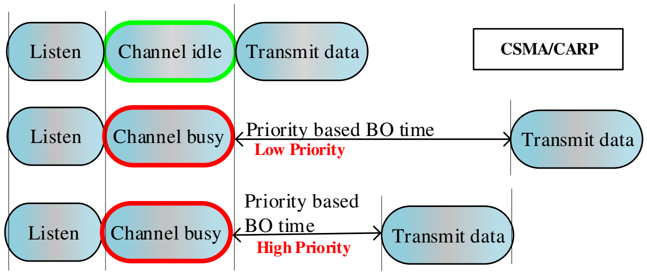


Fig 3. E-CSMA/CA and CSMA/CARP

In communication channel is generally subjected to additive white Gaussian noise (AWGN). In CSMA/CARP, the collisions are avoided and the waiting time is computed with respect to the priority of the MTCD packet. This priority is defined in a flag i.e. if flag = 0, the packet is at low priority and if flag=1, then the packet is at high priority. Let the periodic data from MTCD be the low priority packets and any event data be the high priority packets. Hence the MAC switching between E-CSMA/CA and CSMA/CARP based on the probability values minimizes the collision and also the assignment of a set of preamble minimizes the chances of collision. The MAC protocol decision is performed by MTCH and then the MTCDs are activated to the insisted MAC for transmitting the gathered data. Here, the M2M communication between MTCD member and MTCH is established as per the switched MAC protocol.

4.4 Phase III –Data transmission

In this phase, the MTCHs are allotted with particular time to deliver the gathered data to eNB. A-TDMA is proposed in this M2M communication system. In traditional TDMA, the time slots are allotted for devices on which they can perform their data transmission. In A-TDMA, the timeslots are assigned from the estimated data size and QoS requirements. The QoS requirements are determined from throughput and average access delay that is required to deliver the collected data. The QoS metric throughput is defined as the successful transmission of data from one MTCD to another within a particular time period. Then the average access delayE_{avg} is formulated as,

$$\mathrm{E}_{avg} = \mathrm{E}_{dc} + \mathrm{E}_{he} \quad (14)$$

E_{dc} and E_{he}indicates the time required for transmitting the collected data and header data transmission respectively. The header is initially transmitted, which includes the information as device identity, protocol, source address, destination address and others. The data is the collected packets from the MTCDs that are present in that group.

The traditional TDMA procedure fails to perform well in the absence of synchronization of the timeslots. So, the proposed M2M communication system between MTCH and eNB is established using A-TDMA that enables with adaptive synchronization by Markov chain model. In this work, the A-TDMA is applied on eNB i.e. the eNB assigns time slots for all the MTCHs in the network. The Markov model is designed with two states for MTCHs as waiting state and transmitting state. This stochastic model estimates the possible events based on the temporal sequences. Markov model predicts the possible states and computes the probability of transition states.

The probability of a MTCD moving from one state to another. Let X denote the stochastic process that has two possible states of transmission and waiting. In general, the device can stay in same state for longer time period and hence their transition will be held within the same state. The state transition from one state to another is given as,

$$P(X_{t+1} = i|X_t = j) = P(X_{t+1} = 1|X_t = j, \dots, X_0 = x_0) \quad (15)$$

In the above equation, the state of i and $j$defines the probability states at the time period $t+1$ and t respectively. The $x_0$is the arbitrary notation for the constant X_0 at time 0.

The transition probability matrix is given as,

$$P = \left(p_{ij}\right)_{i,j\in D} \quad (16)$$

Where p_{ij} denotes the probability of transmission from state i to j, henece P constructs a matrix of $D \times D$. In this work two states are involved as illustrated in fig 4. The state 0 represents transmission that is represented as S_1, then state 1 represents waiting that is denoted as S_2. Hereby the transition matric is given as,

$$P = \begin{bmatrix} 1-p & p \\ q & 1-q \end{bmatrix} \quad (17)$$

According to the estimated probability matrix the states of MTCHs are predicted and equal time slots are assigned to MTCHs. Hereby, the MTCHs using different channels for data transmission can transmit at a in same slot whereas, the MTCHs using same channel has to wait until one MTCH completes its data transmission. The timeslots are assigned based on the QoS requirements and the size of the data collected by MTCH. Non-overlapping timeslots are split and provided for each MTCH to perform their current data transmission. In this A-TDMA the problem of synchronization is resolved by the Markov chain model in which the states of MTCHs are identified by eNB before assigning the timeslots for data transmission.

The proposed M2M communication system performs M2M communication in clustered MTCDs. The M2M communication is handled between MTCD to MTCH and MTCH to eNB. Hereby this system ensures with the improvement of the QoS and other network metrics.

V. Simulation

This section details with the complete justification for the proposed M2M communication system.The composed solutions for the problematic issues are tested and the results are evaluated. This section is categorized into three as simulation environment, comparative analysis and research highlights.

5.1 Simulation Setup

The Proposed M2M System is implemented in network Simulator 3.26 on Ubuntu operating system

Table II
Simulation Specifications

Parameter	Specification
Simulation area	1000m×1000m
Number of MTCDs	100
Number of eNBs	1
Packet size	512 bits
Number of packets	10000
Packet time interval	0.1 ms
Initial energy	1000 J
Bandwidth	25Hz
Data rate	10 – 20 Mbps
MAC protocol	E-CSMA/CA CSMA/CARP
Simulation time	300 s

The key specifications that are used to build a M2M communication system is depicted in table II. Apart from these specifications, default parameters are also initialized duringsimulation. The workflow of the proposedM2M communication system isas shown in fig 4.

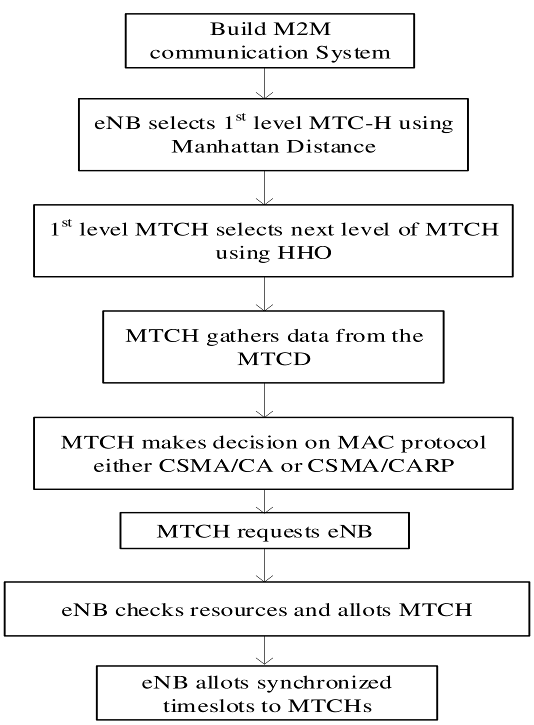


Fig 4. Proposed Communication Work Flow

5.2 Application Scenario

The proposed M2M communication system is developed considering smart city environment. A smart city contains large number of smart things which are sensor enables to gather information from the city and deliver it to people. Like traffic management system, garbage management system, smart health care and smart homes in which M2M communication is performed. Since massive number of devices are deployed in such applications, M2M communication is to be handled effectively. In fig 5 the smart city application scenario is demonstrated based on the proposed M2M communication system with grouping, MAC switching and A-TDMA.

The proposed M2M communication system is also suitable for other application in which QoS plays a vital role expected to achieve effective results on different applications. The MTC devices includes vehicles, surveillance camera, industrial machineries and others.

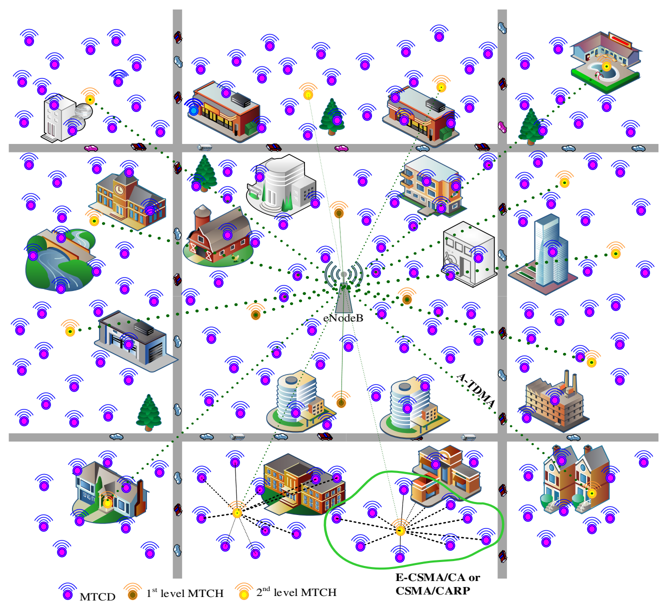


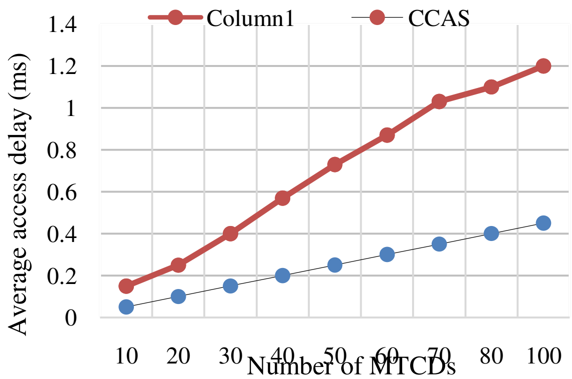
Fig 5. Smart City application

5.3 Results

This result of PMAC-ATDMA compared with existing CCAS in M2M communication. The CCAS for M2M communication involves processing of clusters used CSMA/CA for collision mitigation. The clustering in CCAS is with certain limitations and CSMA/CA mitigate collision, but it consumes larger power. Hereby, those limitations are overcome by proposed MAC switching. The main objective of this proposed M2M communication system is to attain QoS and minimize power. The improvement of QoS is evaluated from the delay and packet delivery. The better performances of MAC protocol are measured from the probability of collision. The performance metrics that are measured are access delay, energy, successful packet delivery and collision probability.

a. Average access delay

Delay is one of the significant metrics to measure the QoS in the system expected to be lesser in accessing the channel.



of

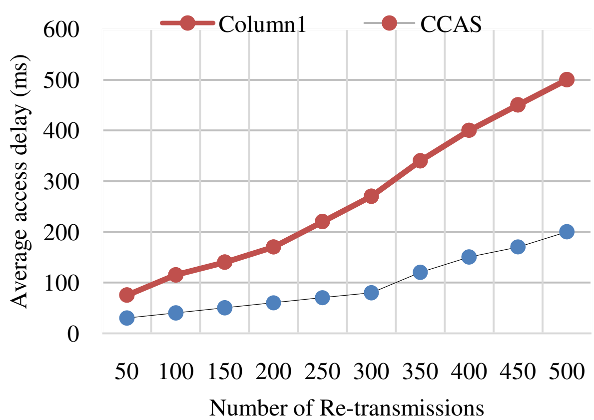


Fig 7. Average access delay Vs Number of Re-Transmissions

The performance of average access delay is illustrated in fig 6 and fig 7 in terms number of MTCDs with respect to number of transmissions and re-transmissions respectively. The increase in number of MTCDs also gradually increases the access delay, Comparatively, the proposed PMAC-ATDMA shows lesser delay than the previous CCAS. The minimization of access delay is due to,

- The switching of MAC protocol in accordance to the estimated probability. The selection of MAC based on current devices leads to minimize the collisions.
- The E-CSMA/CA MAC predicts a new back-off value by taking in account of delay which is the major reason for the reduction of delay.
- While CSMA/CARP is used, there the devices send their data packet based on priority and hence the data packets are promptly delivered without any delay.

In contrast, the prior work of CCAS have incorporated CSMA/CA for minimizing the collision. However, the collision is minimized, the random back-off values increases access delay. An average access delay with respect to increasing MTCDs is 0.45s and 0.25s in CCAS and PMAC-ATDMA respectively. Similarly, the access delay is 171ms and 97ms in CCAS and PMAC-ATDMA with the increasing number of retransmission count. The number of retransmission counts are increased only when the occurrence of collision is large. The poor design of MAC will certainly lead to increase collisions. Hereby, our proposed M2M communication system is enabled to perform better even at the increase of re-transmission. The delay of 0.25s is attained during the participation of 100 MTCDs, even more number of MTCDs increase in the network, the access delay is not suddenly increased.

The reduction of access delay illustrates the increase of QoS in the network. The maximum access delay is up to 0.8s which is high for 100 MTCDs. Hereby, the minimization of average access delay reflects on the minimization of energy consumption which is also the key objective of proposed M2M communication system. Energy is significant since all the M2M devices are associated with limited battery power and hence they are able to sustain until their power exist. The better transmission of data in M2M have improved the access delay that also impacts on other performance metrics.

b. Average energy

Energy consumption is significant constraint due to limited battery power expected to be less in communication system. The minimization of delay also reduces the energy consumption in M2M communication. This metric is evaluated with respect to the increasing number of MTCDs due to which the data transmission takes place even though the data from each device is small. The comparative plot for average energy is depicted in fig 8. As shown, the proposed PMAC-ATDMA MAC results with lesser energy consumption than the existing CCAS method in M2M communication.

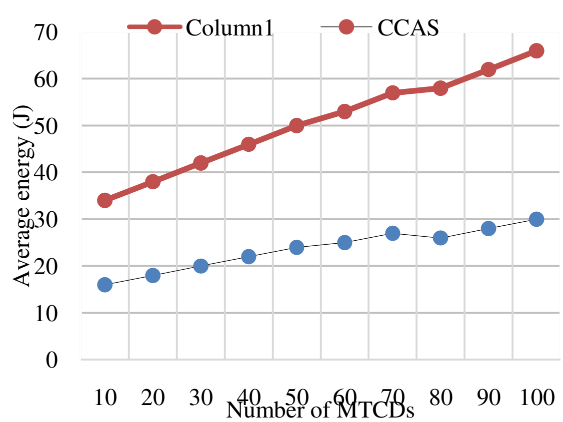


Fig 8. Average energy with respect to Number of MTCDs

This reduction in energy is achieved due to the following reasons that are involved in proposed M2M communication system,

- Collision reduction ensures successful transmission at single attempt that saves the energy for re-transmissions.
- Long distance communication requires larger energy when compared with short distance communication, here clustering is performed and so the devices are not located at too far distances. Communication of M2M i.e. MTCD to MTCH is handled in shorter distance which also impacts in reducing energy.
- The efficient reduction in the waiting time of M2M communication also reduces energy, since longer waiting time requires to hold on the packets and even the buffer of each device will be increased.

Based on this, the proposed M2M communication system mitigates the energy consumption with the increase in number of MTCDs. The maximum energy at 100 number of MTCDs is 36J in existing CCAS and 30J in proposed PMAC-ATDMA. From this, nearly 6J is the difference in average energy of proposed and existing. Energy is also one of the metrics in improving QoS of the system which is achieved in proposed M2M communication system. The energy minimization in proposed M2M communication system is gradually increased and so the further increase in number of MTCDs will increase the energy consumption gradually.

c. Packet delivery

The packet delivery defines the success in the data transmission between MTCDs in the network which needs to be improved when compared with CCAS system. In order to increase the packet delivery, the occurrence of collision is minimized that improves packet delivery between the MTCDs in the network. The packet delivery is measured with respect to the number of MTCDs.

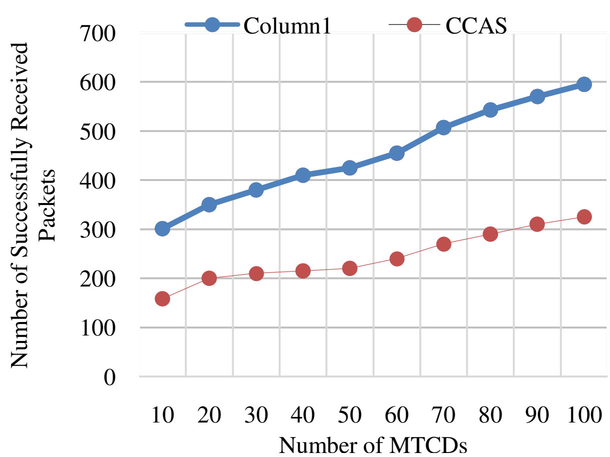


Fig 9. Successful packet transmission

As shown in fig 9.The PMAC-ATDMA has higher number of successful packets transmission than the CCAS. The design of MAC switching reduces collisions along with delay and energy. The reduction in collision and efficient computation of back-off time have increased the successful packet transmission count. As per the increase in number of MTCDs, the packet transmission count will also increase and so the successfulness in packet transmission has to be increased.

For 100 MTCDs, a maximum of 330packets is exchanged in the network among MTCDs. In this case, 325 packets are successfully delivered in PMAC-ATDMA and 270 packets in CCAS. So, the PMAC-ATDMA with MAC switching improves the efficiency in packet transmission. This tends to degrade the network performed while there is increase in the number of MTCDs and hence the CCAS fails to support scalability of the network.

d. Collision probability

Due to massive increase in the number of MTCDs in the network, collisions increase as they try to utilize same channel for transmission. In order to minimize collision, efficient MAC protocols are to be developed. The probability of collision used to express the intensity of the collisions.

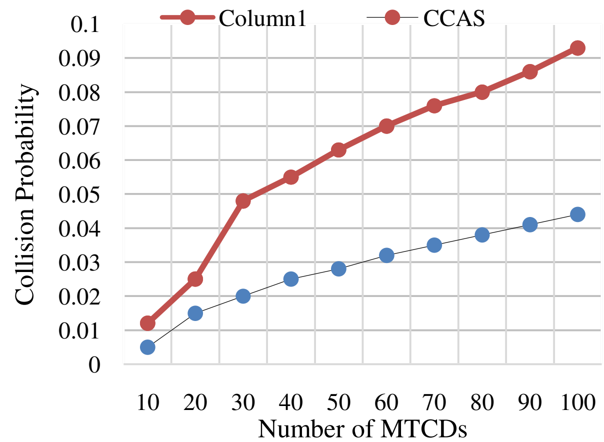


Fig 10. Collision probability with respect to number of MTCDs

As shown in fig 10. the collision probability of PMAC-ATDMA is comparatively lesser than CCAS due to proposed idea of MAC switching and new back-off that defines the waiting time. Hence reduced collisions guarantee scalability in the network.

e. Grouping of MTCDs

Clusters improves the network performance in terms of effective communication between the MTCDs. Even though the clustering provides better results, it also degrades when excess number of clusters formed. According to the area of network, the groups have to be formed else it leads to inefficient utilization of the network resources. More than required groups for MTCDs in the network results with poor performance. In proposed M2M communication system, optimal MTCHs are selected for efficient grouping.

The number of groups created depicted in fig 11. The CCAS constructs high number of groups for smaller number of MTCDs. The reason is random clustering i.e. absence of optimal head selection. In proposed work, optimal the MTCHs are selected and the clusters are formed with join request and join response in turn improves QoS since, the network resources are not wasted. Hence the proposed M2M communication system attained better results.

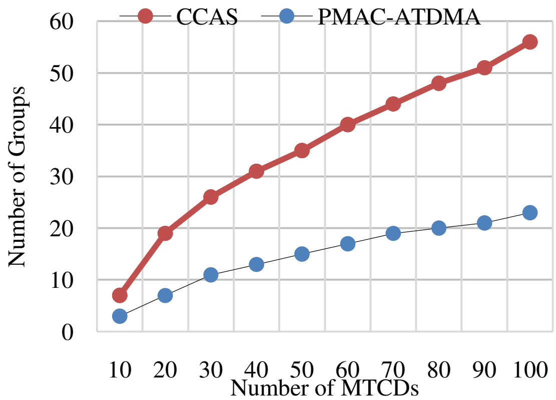


Fig 11. Groups with respect to number of MTCDs

5.4 Research Highlights

The proposed M2M communication system addresses the issues of collision and QoS using the switching MAC protocol for communication between MTCD to MTCH and A-TDMA for MTCH to eNB communication. In this work, initially optimal MTCHs are selected and groups are formed which improves network performance with QoS improvement

The proposed MAC protocols are compared with traditional MAC protocol. The significant performance metrics that are evaluate in MAC is illustrated in table III for tradition MAC as CSMA, TDMA and proposed MAC as E-CSMA/CA, CSMA/CARP and A-TDMA. The design of MAC has benefitted by improvising QoS in terms of access delay and packet delivery. As a result, the proposed grouping, MAC switching and A-TDMA shows better results in network performances.

VI.Conclusion

The proposed M2M communication system is for smart city application in which the data sharing of MTCDs are different from one another. The idea of MAC switching is developed for enabling congestion free communication between MTCDs. Initially, the MTCDs in the network are grouped for efficiency of resource allocation. For this grouping, a group head is selected using HHO algorithm and then the MTCDs are added into the group. The eNB validates significant constraints and selects a MAC protocol, then the chosen E-CSMA/CA or CSMA/CARP is activated. A new back-off value is computed by taking in account of aggregate function, delay and active MTCDs in the group. In CSMA/CARP, the data is transmitted in the priority basis and hence the delay is shorted for high priority packets than the low priority packets. This MAC switching is applied for MTCD to MTCH communication. Then, A-TDMA is presented for communication between MTCH to eNB by which the data gathered from the group of MTCD is delivered. In A-TDMA synchronization is attained by using Markov chain model. Hence this M2M communication system improves performances in terms of access delay, energy, collision probability and packet delivery.

In future, this M2M communication system is planned to be extended with the develop of hybrid MAC protocol Also, the performance of this work will be tested in a large-scale network environment in 5G system.

CONFLICT OF INTEREST

✓ All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.

✓ This manuscript has not been submitted to, nor is under review at, another journalor other publishing venue.

✓ The authors have no affiliation with any organization with a direct or indirectfinancial interest in the subject matter discussed in the manuscript

✓ The following authors have affiliations with organizations with direct or indirectfinancial interest in the subject matter discussed in the manuscript:

I. ‘THE AUTHOR(S) DECLARE(S) THAT THERE IS NO CONFLICT OF INTEREST’

DECLARATION OF INTEREST:

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influencethe work reported in this paper.

Data Availability

No associated data is available.

References:

[1] Oluwatosin Ahmed Amodu, Mohamed Othman, “Machine-to-Machine Communication: An Overview of Opportunities”, Computer Networks, Elsevier, Vol. 145, pp. 255 – 276, 2018.

[2] Ming Zhao, Arun Kumar, Tapani Ristaniemi, Peter Jan Joo Chong, “Machine-to-Machine Communication and Research Challenges: A Survey”, Wireless Personal Communications, pp. 3569 – 3585, 2017.

[3] Kazem Sohraby, Daniel Minoli, Benedict Occhiogrosso, Wei Wang, "A Review of Wireless and Satellite-Based M2M/IoT Services in Support of Smart Grids", Mobile Networks and Applications, pp. 881 – 895, 2018.

[4] N.V. Rajeesh Kumar, B.S.B. Praveen, A.V. Sarveswara Reddy, B. Baron Sam, "Study on IoT with reference of M2M and WiFi", International Conference on Information Communication and Embedded Systems (ICICES), 2017.

[5] D. Chang, T. Hsu, H. Yang, Y. Tsai, ―An M2M computing model for improving the performance among devices‖, Microsystem Technologies, pp 1 – 8, 2019.

[6] Fatima Hussain, Alagan Anpalagan, Rath Vannithamby, "Medium access control techniques in M2M communication: survey and critical review", Transactions on Emerging Telecommunications Technologies, 2014.

[7] Shao-Yu Lien, Hsiang Hsu, "Medium Access Control, Resource Management, and Congestion Control for M2M Systems", Cambridge University Press, pp. 402 – 422, 2017.

[8] Ce Zhou, Yunmin Kim, Tae-Jin Lee, "A Group-Based Energy Harvesting MAC Protocol with AP Scheduling in Machine-to-Machine Networks", Proceedings of the 12th International Conference on Ubiquitous Information Management and Communication, no. 73, 2018.

[9] Guowang Miao, Amin Azari, Taewon Hwang, "E^2-MAC: Energy Efficient Medium Access for Massive M2M Communications", IEEE Transactions on Communications, Vol. 64, No. 11, pp. 4720 – 4735, 2016.

[10] Nargis Khan, Jelena Mišić, Vojislav Mišić, "Priority-Based Machine-To-Machine Overlay Network over LTE for a Smart City", Journal of Sensor and Actuator Networks, Vol. 7, No. 3, 2018.

[11] Samir Dawaliby, Abbas Bradai, Yannis Pousset, Christian Chatellier, "Joint Energy and QoS-Aware Memetic-Based Scheduling for M2M Communications in LTE-M", IEEETransactions on Emerging Topics in Computational Intelligence, Vol. 3, No. 3, pp. 217 – 229, 2018.

[12] Goksu Karadag, Recep Gul, Yalcin Sadi, Sinem Coleri Ergen, "QoS-Constrained Semi-Persistent Scheduling of Machine-Type Communications in Cellular Networks", IEEE Transactions on Wireless Communications, Vol. 18, No. 5, pp. 2737 – 2750, 2019.

[13] Younghwan Jung, Daehee Kim, Sunshin An, "Scalable group-based machine-to-machine communications in LTE-advanced networks", Wireless Networks, Springer, 2018.

[14] Ning Li, Yingqing He, Cong Wang, Yancheng Chen, Jianhui Xu, "Energy-efficient power allocation for massive M2M communication over LTE-A cellular uplink", EURASIP Journal on Wireless Communications and Networking, 2018.

[15]Eren Balevi, Faeik T. Al Rabee, Richard D. Gitlin, "ALOHA-NOMA for Massive Machine-to-Machine IoT Communication", IEEE International Conference on Communications (ICC), 2018.

[16] Asim Mazin, Mohamed Elkourdi, Richard D. Gitlin, "Comparison of Slotted Aloha-NOMA and CSMA/CA for M2M Communications in IoT Networks",

[17] Mohammad Shurman, Wafa Alkahla, Haya Hasan, "Priority-Based Channel Access for SAN protocol in M2M Communication", IEEE 88th Vehicular Technology Conference (VTC-Fall), 2018.

[18] Suk Jin Lee, Hongsik Choi, Sungun Kim, "Slotted CSMA/CA Based energy efficient MAC Protocol Design in Nanonetworks", International Journal of Wireless & Mobile Networks (IJWMN), Vol. 10, No. 1, 2018.

[19] Anurag Gaurav, Atul Kumar Pandey, "A Survey: Hybrid Medium Access Control Protocol for M2M Communication", International Conference on Wireless Communications, Signal Processing and Networking (WISPNET), 2018.

[20] Oluwatosin Ahmed Amodu, Mohamed Othman, "A survey of hybrid MAC protocols for machine-to-machine communications",Telecommunication Systems,Springer, 2018.

[21] Nurzaman Ahmed, Debashis De, Md. Lftekhar Hussain, "A QoS-aware MAC protocol for IEEE 802.11ah-based Internet of Things", Fifteenth International Conference on Wireless and Optical Communications Networks, 2018.

[22] Shree Krishna Sharma, Xianbin Wang, "Towards Massive Machine Type Communications in Ultra-Dense Cellular IoT Networks: Current Issues and Machine Learning-Assisted Solutions", IEEE Communications Surveys & tutorials, 2018.

[23] M. Bacco, P. Cassarà, M. Colucci, A. Gotta, ―Modeling Reliable M2M/IoT Traffic over Random Access Satellite Links in Non-saturated Conditions‖, IEEE Journal on Selected Areas in Communications, vol. 36, no. 5, pp 1042 – 1051, 2018.

[24]A. Ali, G. Shah, J. Arshad, "Energy Efficient Resource Allocation for M2M Devices in 5G", Sensors, vol. 19, no. 8, 2019.

[25]J. Kim, S. Lee, M. Chung, "Efficient Random-Access Scheme for Massive Connectivity in 3GPP Low-Cost Machine-Type Communications", IEEE Transactions on Vehicular Technology, vol. 66, no. 7, pp 6280 – 6290, 2017.

[26] Wen Zhan, Lin Dai, "Access Delay Optimization of M2M Communications in LTE Networks", IEEE Wireless Communications Letters, 2019.

[27] S. A. AlQahtani, "Delay-Aware Resource Allocation for M2M Communications Over LTE-A Networks", Arabian Journal for Science and Engineering, vol. 44. No. 4, pp 3639 – 3653, 2018.

[28] V. Balyan, D. Saini, B. Gupta, "Service Time-Based Region Division in OVSF-Based Wireless Networks with Adaptive LTE-M Network for Machine to Machine Communications", Journal of Electrical and Computer engineering, 2019.

[29] J. Huang, C. Xing, S. Shin, C. Hsu, "Optimizing M2M Communications and Quality of Services in the IoT for Sustainable Smart Cities", IEEE Transactions on Sustainable Computing, vol. 3, no. 1, pp 4 – 15, 2018.

[30]Hajer Ben Rekhissa, Cecile Belleudy, Philippe Bessaguet, "Energy Efficient Resource Allocation for M2M Devices in LTE/LTE-A", sensors, MDPI, 2019.

[31] Z. Alavikia, A. Ghasemi, "Collision-Aware Resource Access Scheme for LTE-Based Machine-to-Machine Communications", IEEE Transactions on Vehicular Technology, vol. 67, no. 5, pp 4683 – 4688, 2018.

[32] A. El-Hameed, K. Elsayed, "A Q-learning approach for machine-type communication random access in LTE-Advanced‖, vol. 71, no. 3, pp 397 – 413, 2019.

[33] N. Liao, G. Zhang, J. Qian, D. Cheng, K. Yang, "Fair and Efficient Rate Allocation for Wireless-Powered Machine-Type Communication Networks", Mobile Information Systems, 2019.

[34] N. Lin, Y. He, C. Wang, Y. Chen, J. Xu, "Energy-efficient power allocation for massive M2M communication over LTE-A cellular uplink", Journal on Wireless Communications and Networking, 2018.

[35] D. Han, H. Minn, U. Tefek, T. Lim, "Network Dimensioning, QoE Maximization, and Power Control for Multi-Tier Machine-Type Communications", IEEE Transactions on Communications, vol. 67, no. 1, pp 859 – 872, 2019.

[36] W. Zhan, L. Dai, "Massive Random Access of Machine-to-Machine Communications in LTE Networks: Modeling and Throughput Optimization", IEEE Transactions on Wireless Communications, vol. 17, no. 4, pp 2771 – 2785, 2018.

[37] E. Hegazy, W. Saad, M. Shokair, "An Efficient Proposed MAC Protocol for M2M Networks", Wireless Personal Communications, vol. 96, no. 2, pp 2253 – 2269, 2017.

[38] T. Chan, Y. Ren, Y. Tseng, J. Chen, "Multi-Slot Allocation Protocols for Massive IoT Devices with Small-Size Uploading Data", IEEE Wireless Communications Letters, vol. 8, no. 2, pp 448 – 451, 2019.

[39] W. Saad, A. El-Feshawy, M. Shokair, M. Dessouky, "Optimised approach based on hybrid MAC protocol for M2M networks", IET Networks, vol. 7, no. 6, pp 393 – 397, 2018.

[40] Pawan Kumar Verma, Rajesh Verma, Mohammad Meftah Alrayes, Arun Prakash, Rajeev Tripathi, Kshirasagar Naik, "A novel energy efficient and scalable hybrid-mac protocol for massive M2M networks", cluster computing, springer, 2018.

[41] L. Liang, L.Xu, B. Cao, Y. Jia, "A Cluster-Based Congestion-Mitigating Access Scheme for Massive M2M Communications in Internet of Things", IEEE Internet of Things Journal, vol. 5, no. 3, pp 2200 – 2211, 2018.

[42] M. Tanab, W. Hamouda, "Machine-to-Machine Communication with Massive Access: Congestion Control", IEEE Internet of Things Journal, vol. 6, no. 2, pp 3545 – 3557, 2019.

[43] A. Ali, G. Shah, M. Shoaib, "Energy Efficient Uplink MAC Protocol for M2M Devices", IEEE Access, vol. 7, pp 35952 – 35962, 2019.

[44] P. Verma, R. Verma, M. Alrayes, A. Prakash, R. Tripathi, K. Naik, "A novel energy efficient and scalable hybrid-mac protocol for massive M2M networks", cluster computing, springer, pp 1 – 12, 2018.