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Energy Efficient MAC Protocol for M2M Communication in IoT

Narender Reddy Kampelli [1*], B.N. Bhandari [2], *Member, IEEE*
[1,2] Department of ECE, JNTUH College of Engineering, Hyderabad, India-500085

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***Abstract*—In cellular-based machine-to-machine communication, a massive number of battery-operated sensor devices are connected to the network used in the Internet of Things. The development of energy-efficient MAC protocols is required to minimize energy consumption and to increase network lifetime. Along with power consumption, scalability, collisions, delay, and Quality of Service (quality of service) problems of M2M Networks. A cluster-based MAC protocol for M2M Communication (CMAC) was proposed to solve the collision, quality of service, and scalability issues in M2M communication. The model considers grouping and dynamic MAC switching. First, we present a clustering model using the HHO algorithm. Second, switching between CSMA/CA and CSMA/CARP protocols based on the density of backlogged devices and active nodes. The energy, probability of collision, and successful packet transmissions are evaluated. The simulation results show that the proposed clustering, cluster head selection, and communications protocol design prolong the lifetime of the M2M Network.**

***Index Terms*— Internet of Things, M2M Communication, MAC Protocol**

I. INTRODUCTION

Machine-to-Machine Communication, called Machine Type Communication in the Cellular Internet of Things (IoT), enables the communication between autonomous intelligent networked machine-type communication devices (MTCD) without direct human intervention. The applications of IoT are home automation, healthcare, smart city, industry, and others [1], [2]. Medium Access Control (MAC) protocol is available for M2M communication as a solution to scalability [3], [4], [5]. The existing protocols

focused on access delay, energy efficiency, traffic overload, collision control, and management of resources. The quality of service metrics in M2M communication improved by incorporating scheduling, i.e., assigning pre-defined timeslots for performing data transmission [6], [7].

The major challenges that exist in massive M2M communication networks,

- 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 the ability to satisfy QoS.

The massive increase in MTCD devices is managed by grouping devices [8]. M2M communication is performed directly or indirectly via relay devices. The process of sharing resources 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) [9],[10]. The time division multiple access (TDMA) is also involved in allotting timeslots for data transmission.

In this paper, the M2M communication system is proposed to minimize energy consumption, the number of collisions, and delay. These objectives are achieved in three stages grouping, MAC switching, till now, research focused on the typical characteristics of UEs. This proposed model considers the characteristics of MTCDs which are part of the M2M Network.

II. RELATED WORK

In the M2M communication system, the channel access by the MTCDs is incorporated based on the MAC protocol design. The improvement of Quality of Service (quality of service) and Quality of Experience (QoE) are significant design aspects of MAC protocol. For reliable communication in M2M/IoT, traffic-based resource allocation is suggested in [11]. As a QoS-guaranteed technique, the threshold-controlled access (TCA) protocol was introduced in [12]. The suggested TCA technique estimated the threshold based on the quality of service metric only valid for fewer M2M devices. In [13] employed a delay-aware time-slotted resource allocation with a priority-based queuing model for both human-to-human (H2H) and machine-to-machine (M2M) communication, giving H2H a higher priority and M2M a lower priority. Because of this, M2M fails to assist the quality of service. Data transmission was carried out using the timeslots assigned in [14]. A hybrid MAC protocol was proposed as a combination of slotted ALOHA and TDMA mechanisms in [15], [16].

III. PROBLEM DESCRIPTION

Several critical problems were identified in the current research work. A cluster-based congestion mitigating access scheme (CCAS) was proposed in the MAC Protocol in which MTCDs are clustered, i.e., grouped, and then an MTC gateway (MTCG) was selected for data transmission in [41]. In this clustering, initially, the similarity was estimated. Spectral clustering was used to determine diagonal matrix, Laplace matrix Eigen values, and Eigen vectors which were 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.

IV. Proposed M2M Communication System

This M2M communication system model uses LTE communication technology. It consists of an 'n' number of MTCDs and eNodeB with a network area of N×N. The MTCDs are randomly deployed in different positions on the network. MTCDs are the sensors capable of sensing the surroundings and communicating with the other MTCDs. All the MTCDs are fed a similar amount of energy during initial deployment. Fig 1 depicts the network architecture in which the MTCDs perform data transmission using the proposed MAC protocol. The network is equipped with an eNodeB for allotting resources, using which the data transmission is performed. The eNodeB 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 environmental changes.

An optimization algorithm selects the group heads among the deployed MTCDs. Then the MTC heads (MTCH) creates their groups by including the MTCDs in the exchange of request and responses. As in [41], the MTCDs in this work can communicate in short and long ranges. The grouping of MTCDs ensures solution quality of service requirements in a scalable network. The MTCHs use any of the MAC protocols as E-CSMA/CA or CSMA/CARP. In E-CSMA/CA, the collision is avoided, whereas CSMA/CARP also avoids collision and transmits data based on priority. The data transmission efficiency increased as the system used switching of MAC protocol. Based on the density of devices, MAC protocol is selected in each group. The clustering of devices was performed using the HHO algorithm for energy-efficient cluster-based MAC Protocol.

The MTCDs are grouped into different levels based on distance. Manhattan distance is applied for selecting the first level of MTCHs, and then these first-level MTCHs will select the next level of MTCHs using the 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 eNodeB and n number of MTCDs at the first level is given from the current position points xi with respect to the MTCD position yi. The MTCDs that are closer and adjacent to eNodeB are selected. In total, four MTCHs are selected by the eNodeB based on this distance. Then, these MTCHs selected the next level of heads for the purpose of grouping. The grouping is performed only after all the MTCHs in the network are 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 by the Harris Hawks chasing their prey. The optimal head selection is performed based on three metrics the distance between MTCD and eNodeB, received power, and residual energy of MTCD. The MTCDs are sensor devices that are extremely energy-constrained; depending on their sensing and data transmission, the energy in individual MTCDs 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 exploration and exploitation. Two strategies are activated to identify optimal MTCH. The exploration phased strategy for the hawk is given as,

$$X(t+1) = \begin{cases} X_{rand}(t) - r_1|X_{rand}(t) - 2r_2X(t)| & q \geq 0.5 \\ (X_{rabbit}(t) - X_m(t)) - r_3(LB + r_4(UB - LB)) & q < 0.5 \end{cases} \quad (2)$$

Let t be the current iteration, $(t+1)$ is the next iteration, $X(t+1)$ be the hawk's position vector at $(t+1)$ iteration, $X_{rabbit}(t)$ is the rabbit's position, $X(t)$ is the present position of the hawks, certain random number is included as r_1, r_2 , r_3 , r_4, q that ranges between $[0,1]$. Then $X_{rand}(t)$ is the randomly selected hawks, and X_m is defined as the average position of hawks, UB and LB represent the 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. In 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 the 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, and λ 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 MMTCD in the 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 the best location for X_{rabbit}
For each X_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

This way, the MTCHs are selected in hierarchical levels of the network until the entire network coverage is reached. The above pseudo-code is shown for the 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, the other MTCDs within the coverage send requests to the MTCH. The MTCH, on receiving the request, then delivers back the join reply to the corresponding MTCD. As a result of this, the groups are constructed 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 a longer time, so employing an optimization algorithm for MTCH selection is needed. Hence, the grouping of MTCDs reflects the improvement of the network performance. The proposed M2M communication system performs M2M communication in clustered MTCDs. The M2M communication is handled between MTCD to MTCH and MTCH to eNodeB and ensures less energy consumption.

V. SIMULATION

This section is categorized into the simulation environment, comparative analysis, and research highlights. The Proposed M2M System is implemented in network Simulator 3.26 on Ubuntu operating system.

The main requirements for creating an M2M communication system are shown in table II. The simulation also initializes default settings in addition to these criteria. Fig. 4 depicts the workflow of the proposed M2M communication system.

Table I
Simulation Specifications

Parameter	Specification
Simulation area	1000m×1000m
Number of MTCDs	100
Number of eNodeBs	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

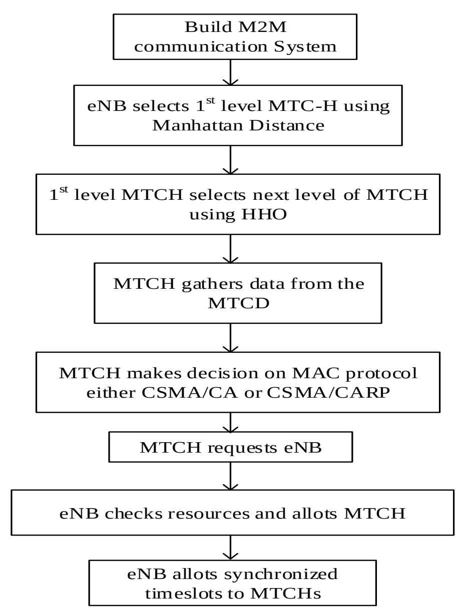

Fig 1. Proposed Communication Work Flow

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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 the random selection of back-off values, which is overcome in this work by computing back-off with significant constraints. However, in larger densities with different traffic, CSMA/CARP is better than CSMA/CA. Hereby a novel MAC switching procedure is incorporated.

The collision between the MTCDs is mitigated by the assignment of a set of preambles to each MTCH. More than one MTCD selects the same preamble by more than one MTCD causes a collision, so a set of preambles are allotted in this work. Each MTCH estimates a probability value for switching MAC. The probability is computed from density, backlogged devices, and active 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 the number of active MTCDs with respect to the number of successes.

5.2 Application Scenario

The proposed M2M communication system is developed considering the smart city environment. A smart city contains many smart things, which are sensors that enable gathering information from the city and delivering it to people. Like traffic management systems, garbage management systems, smart health care, and smart homes in which M2M communication is performed. Since a massive number of devices are deployed in such applications, M2M communication is to be handled effectively. Fig 5 demonstrates the smart city application scenario based on the proposed M2M communication system with grouping and MAC switching. The proposed M2M communication system is also suitable for other applications in which QoS plays a vital role and is expected to achieve effective results on different applications. The MTC devices include vehicles, surveillance cameras, industrial machinery, and others.

V. RESULTS

The objective of the proposed CMAC is less power consumption. The power consumption in the proposed CMAC is less than the existing CCAS. Consumption. The measured performance metrics are energy and successful packet.

A. Average energy

Energy consumption is a significant constraint due to limited battery power expected to be less in the communication system. The minimization of delay also reduces the energy consumption in M2M communication. The metric evaluation 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. The proposed CMAC results in less energy consumption than the existing CCAS method in M2M communication.

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

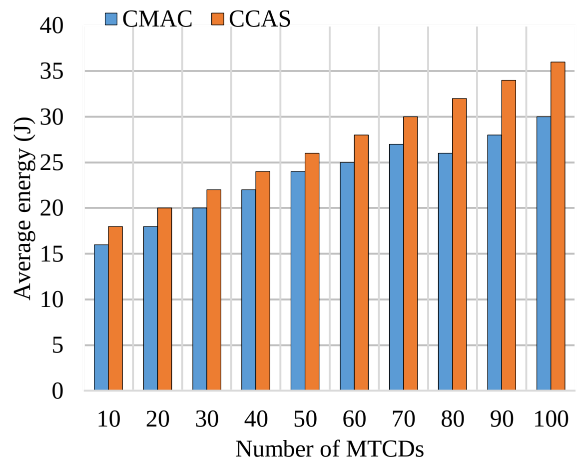

Fig 2. Average energy with respect to the Number of MTCDs

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

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

B. 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 the CCAS system. In order to increase the packet delivery, collisions are minimized, which improves packet delivery between the MTCDs in the network.

The packet delivery is measured with respect to the number of MTCDs.

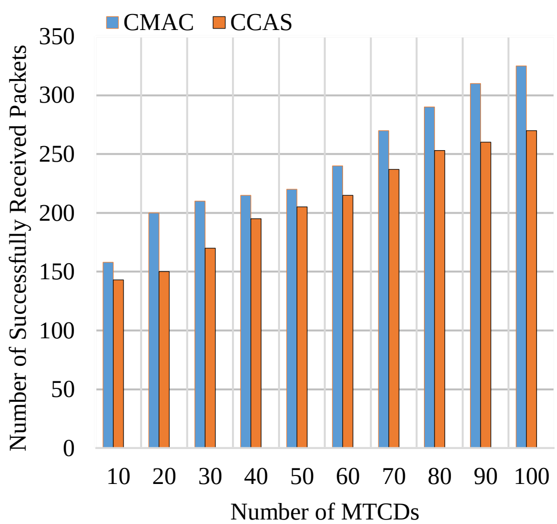

Fig 3. Successful packet transmission

As shown in fig 3. The CMAC has more successful packet transmission than the CCAS, and MAC switching reduces collisions along with delay and energy. The reduction in a collision and efficient computation of back-off time have increased the successful packet transmission count. As per the increase in MTCDs, the packet transmission count will also increase, so the success of packet transmission has to be increased.

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

C. Grouping of MTCDs

Clusters improve the network performance in terms of effective communication between the MTCDs. Even though the clustering provides better results, it also degrades when an excessive number of clusters is formed. According to the network area, the groups have to be formed; otherwise, it leads to inefficient utilization of the network resources. More than the required groups for MTCDs in the network results in poor performance. The proposed M2M communication system selects optimal MTCHs for efficient grouping.

The number of groups created is depicted in fig 4. The CCAS constructs a high number of groups for a smaller number of MTCDs. The reason is random clustering, i.e., the absence of optimal head selection. In the proposed work, optimal MTCHs are selected, and the clusters are formed with join request and join response, in turn, improves the quality of service since the network resources are not wasted. Hence the proposed M2M communication system attained better results.

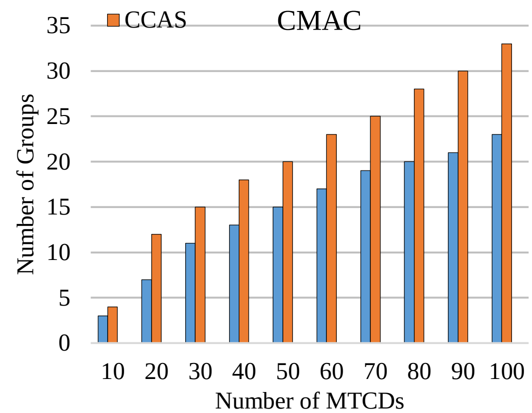

Fig 4. Groups with respect to the number of MTCDs

VI. Conclusion

The proposed M2M communication system is for smart city applications in which the data sharing of MTCDs is different. The MTCDs in the network are grouped for the efficiency of resource allocation. A group head is selected using the HHO algorithm for this grouping, and then the MTCDs are added to the group. The eNodeB 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 into account an aggregate function, delay, and active MTCDs in the group. In CSMA/CARP, the data is transmitted on a priority basis; hence, the delay is shorter for high-priority packets than the low-priority packets. This MAC switching is applied for MTCD to MTCH communication. Hence, this M2M communication system improves access delay, energy consumption, and packet delivery performance. The performance of this work will be tested in a large-scale network environment in a 5G system.

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