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Energy Efficient MAC for M2M Communication Using Dynamic TDMA in IoT Network

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ABSTRACT

In the Internet of Things (IoT) context, the relevance of M2M communication increased, creating the need for practical solutions. MTCDs, or Machine Type Communication Devices, frequently encounter issues such as collisions and delays while transmitting data, ensuring network scalability and maintaining the quality of service (QoS) for all devices participating in the communication. To address these challenges, this paper presents the protocol for switching MAC that optimizes energy usage with Dynamic Time Division Multiple Access (EMAC-DTDMA). The EMAC-DTDMA protocol involves grouping, dynamic MAC switching, and timeslot allocation. The Harris Hawks Optimization (HHO) algorithm is applied to choose the cluster head of the machine type communication devices (MTCH) while the CSMA/CA and CSMA/CARP protocols with different backoff times are used to minimize collisions based on device density, backlog, and active nodes. The timeslots are allocated based on data size and QoS requirements using Dynamic TDMA. The Markov chain model is employed to overcome synchronization issues with traditional TDMA. The EMAC-DTDMA's performance is evaluated through simulation using a network simulator tool, considering access delay, energy usage, collision probability, and throughput.

1. Introduction

M2M communication is rapidly gaining attention due to its ability to enable autonomous interaction between intelligent devices. M2M communications, both capillary and cellular M2M, have applications in various fields, such as smart grid, e-health, and industrial automation, and enable automated data exchange between devices, including satellite-based systems applicable to SGs [1-3]. High-performance Medium access protocols are essential for M2M networks to cater to the unique requirements of M2M devices, including low data rates, tolerance/sensitivity to delay, and energy constraints. Various MAC protocols for M2M communication have been proposed, including contention-based Carrier Sense Multiple Access. (CSMA), time division multiple access (TDMA) schemes, and hybrid grouping-based MAC mechanisms that utilize energy beamforming and access point scheduling strategies [4-7].

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Random-access techniques in M2M communication focus on minimizing delay, ensuring energy saving, managing the congested network, controlling collisions, and managing resources. To achieve Quality of Service (QoS) in M2M communication, it is crucial to allocate satisfactory radio resource allocation, with delay-oriented metrics crucial in providing QoS. Scheduling techniques are used to address service metrics quality, which involves assigning predefined timeslots for data transmission [8,9]. Significant challenges exist in M2M communication networks, such as the Large-scale deployment of M2M devices in the network causing constraints on link connectivity strength and jitter, the need for efficient data transmission requiring the selection of relay nodes, and multiple MTCDs leading to increased collisions and traffic management challenges [10,11]. ALOHA, CSMA/CA which utilizes Carrier Sensing and Collision Avoidance to access the network channel, NOMA for channel access improves resource utilization in [12-15].

Random access, scheduling, and grouping techniques are some of the approaches proposed to address the unique requirements of M2M devices. While significant progress has been made, designing effective MAC protocols for M2M communication networks problems still exists due to the different requirements of M2M. There is a need to develop flexible and adaptable scheduling and random access techniques to handle changing traffic and channel characteristics to improve system performance.

To minimize energy consumption, collision scalability, and delay, the authors of this paper developed a novel Machine-to- Machine communication system that focuses on clustering, switching between MAC Protocol, and assignment of timeslots. MTCDs have unique characteristics compared to UEs in Cellular Networks and are critical components of M2M Networks

1.1 Motivation

M2M network Quality of Service(QoS) i.e., reduction in delay and energy consumption, requires the development of MAC protocols that use clustering, MAC protocol switching, and timeslot assignment. Each of these processes contributes to the overall improvement of network performance, despite significant progress already made in M2M communication [21, 22]. Hybrid MAC protocols can combine two different MAC designs into a single protocol through simultaneous or sequential processing. These protocols can be used either independently or in combination with standalone MAC protocols.

Traditional MAC protocols for M2M communication have various limitations, like poor channel access schemes leading to increased delays and collisions, time synchronization, and the lack of QoS support for critical applications.

1.2 Contribution

In the proposed system, contributions are,

- To reduce power consumption by grouping MTCDs, only the corresponding heads are permitted to request eNodeB access, resulting in fewer collisions. Hierarchical MTC heads (MTCH) are used to cover the entire range of the eNodeB in increasing levels of communication range while ensuring QoS of the network through clustering, Cluster Head Selection using Harris Hawks Optimization (HHO), based on Manhattan distance from the eNodeB, power, and remaining battery level.
- This work presents a new switching betweenE-CSMA/CA and CSMA/CARP protocols depending on delay and active MTCDs within a given group to compute the backoff time.

- The proposed system performs timeslot assignment using Dynamic -TDMA with assured QoS for data transmission. It synchronizes the timeslots by using a Markov chain model.

Section II comprehensively reviews M2M networks and identifies the problems. The next Section discusses the findings about the gaps in the existing works, while Section IV proposes solutions for improving M2M Network. Section V presents the analysis results, and Section VI concludes with a discussion on the future scope of the work.

2. Related Works

Channel access by the devices in M2M Network is based on the design of the MAC protocol. Resource allocation and MAC protocol design aim to improve QoS and QoE. M2M resource allocation based on data traffic to ensure reliable communication is discussed in [23]. Furthermore, a threshold-controlled access (TCA) protocol has been presented as a technique that guarantees QoS [24]. The TCA protocol, proposed in previous research, estimated thresholds based on QoS metrics. However, it was only suitable for a smaller number of M2M devices and should consider resource allocation for a huge number of devices. Minimizing delay metrics has been the focus for achieving QoS in M2M communication systems [25, 26]. A novel random-access scheme incorporating virtual preambles was developed to minimize access delay and collisions. The scheme creates opportunities for faster access with minimized delay and collisions. Additionally, unique preambles are selected to reduce collisions during access.

A combination of human-to-human (H2H) and M2M networks is proposed in [27] using time-slotted resource allocation with a priority-based queuing model considering delay also. However, the QoS requirements for M2M communication still needed to be met due to its lower priority. They also proposed resource allocation based on priority in the orthogonal variable spreading factor (OVSF) [28]. Kumarawadu *et al.*, [29], stated that an admission control, delay-sensitive, and delay-tolerant first requests will reduce the number of access requests submitted, but only some requests were accepted due to delay, and all M2M devices were not granted access. To compensate for energy and delay, Munir *et al.*, [30] proposed a recursive maximum expansion modified (RME-M) algorithm which arranges M2M devices d in ascending order according to a transmission time interval (TTI).

Crosby and Vafa [31] stated that the development of medium access control (MAC) Protocols in wireless sensor networks (WSNs) examined. Similarly, Hegazy *et al.*, [32] explored the evolution of clustering algorithms in WSNs, focusing on selecting cluster heads (CHs) based on cluster formation criteria and parameters. Standardization efforts such as IEEE 802.15.4 and WirelessHART were also discussed. In recent studies, researchers have explored MAC design for wireless sensors operating over cellular networks, as discussed by Chan *et al.*, [33], where gateways and base stations are used for communication between sensor nodes and data-gathering nodes in local area networks. [34] proposed a model for convergence between WSNs and LTE-Advanced networks. However, the studies often used overly simplified energy consumption models that do not consider the significant variation in transmission energy in cellular networks.

Efficient MAC protocol designs for reducing Collision in data transmission in M2M communication were developed by researchers. Pawan Kumar Verma *et al.*, [35] designed a MAC protocol consisting of a notification, contention, and transmission period. The assignment of timeslots determined the data transmission [36]. The eHint protocol has been extended for multi-slot data transmission. Tanab *et al.*, [37] and Ali *et al.*, [38] proposed a hybrid MAC protocol and performed Monte Carlo simulations to obtain optimized values for successful contention and transmission duration probability. New protocols are needed in MANET to link the devices to the internet as it adopts a smart environment [42,43].

The M2M network proposed solves problems such as Collision, quality of service, and scalability by utilizing a switching MAC protocol, optimal MTCH grouping, and D-TDMA for communication. The importance of communication technology is clearly discussed in [39].

3. Problem Description

The current work has identified several critical issues. Verma *et al.*, [40] proposed a congestion mitigation access scheme, which groups MTCDs into clusters and selects an MTC gateway (MTCG) for data transmission. Spectral clustering is used to estimate the similarity between devices and determine the diagonal matrix, Laplace matrix eigenvalues, and eigenvectors, which is then given to K-means clustering for cluster formation, resulting in a significant amount of processing time. The traditional CSMA/CA MAC protocol is employed, limiting Collision but not reducing power consumption. The opportunistic splitting algorithm (M2M-OSA) is applied to enable resource allocation. In M2M-OSA, the system randomly chooses resource blocks, and each user equipment (UE) device has a retransmission retransmission limit for requesting resources. The UE uses threshold values that are a number of contending devices and requests from the base station if the condition is met. If feedback is unsuccessful due to Collision, the system updates the threshold. The problems identified in this M2M-OSA are,

- Allocated resources are not utilized efficiently due to randomly choosing resource blocks resulting in increases in the probability of failure in the M2M Network
- Poor network performance results from updating the threshold value only after experiencing a collision. Additionally, using similar threshold values for machine-type communication devices (MTCDs) with different communication characteristics further contributes to network inefficiency.
- The current M2M communication system is only suitable for a few devicesand can only support a small number of M2M devices as resource demands increase.

They adjust the contention window size based on power and delay factors such as retransmission, propagation, and packet transmission delays. The authors design a hybrid MAC protocol composed of a data transmission interval (DTI) and contention interval (CI), which performs TDMA after DTI. Issues in the power-based MAC and hybrid MAC were:

- It is not possible to accurately estimate the current window size by computing delay based on three metrics from the previous transmission, as M2M signal characteristics are dynamic, and there is a higher probability of Collision in slotted ALOHA
- The absence of time synchronization among M2M devices increases overhead when operating TDMA, as slot assignments and collision avoidance become more complex without a common reference time. This results in degraded scalability of TDMA-based data transmission.
- It is designed to address the problems of inefficient resource allocation and MAC protocol in M2M Networks.

4. The M2M Network

In the proposed M2M Network, the communication happens in two ways using an energy-efficient medium access protocol for intra-cluster communication from cluster members to cluster heads and other inter-cluster communications from cluster heads to the base station. The M2M system is designed with a three-phase processing approach.

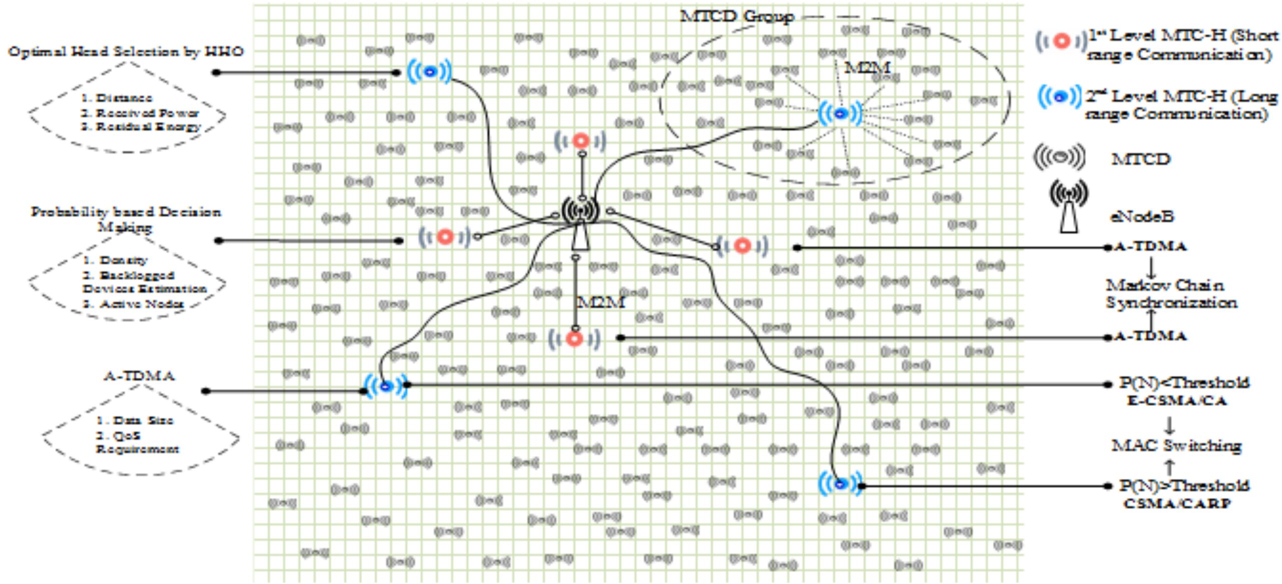

Fig. 1. Machine-to-Machine Network

4.1 System architecture

The proposed MAC protocol addresses the issues of existing MAC protocols in M2M communication. The model employs Long Term Evolution Technology, consisting of an eNodeB and 'n' number of MTCDs deployed randomly in an N×N network area. The MTCDs act a ssensors and communicate with each other. MTCDs are considered to have the same energy at zero time. Figure 1 illustrates the network architecture, where the MTCDs use existing LTE Technology to communicate with eNodeB and the proposed Energy-Efficient MAC protocol for data transmission between the MTCDs. In this system, the eNodeB is centrally located within the network. From MTCDS, it selects MTCHs hierarchically based on their coverage distance. The smart city environment is equipped with a system model that involves the strategic placement of sensors in various locations to monitor the surroundings effectively. The system encompasses several features such as intelligent transportation systems, energy management systems, smart buildings, water management systems, and waste management systems.

Using an optimization algorithm, the proposed M2M communication system selects group heads from the deployed MTCDs. The MTCHs then create their own groups by exchanging requests and responses with the included MTCDs to satisfy QoS requirements in a scalable network. In this system, MTCDs can communicate over both short and long ranges. The eNodeB, located at the center of the network, selects MTCHs hierarchically based on their coverage distance. Depending on the density of MTCDs in each cluster, the MTCHs operate with either E-CSMA/CA or CSMA/CARP MAC protocol. This system is designed for monitoring environmental changes in a smart city environment by deploying sensors.

The proposed system includes adaptive TDMA along with eNodeB synchronization using the Markov chain model to reduce Collision during data transmission. The system operates in three phases: grouping, MAC switching, and data transmission, to reduce Collision during resource allocation and data transmission.

4.2 Clustering of MTCDs

The M2M devices are clustered into groups based on their distance using the Manhattan distance metric. The following Equation selects the first level of M2M cluster heads (MTCHs) based on their proximity to the eNodeB. The Manhattan distance method is used to select the first level of cluster heads. Distance is given by

$$D = \sum_{i=1}^{n} |x_i - y_i| \tag{1}$$

It selects MTCHs close to the eNodeB, a total of four MTCHs are selected. HHO algorithm to select the optimal MTCHs for grouping based on three metrics: Inter distance between eNodeB and Device, power, and remaining energy of MTCDs. The MTCHs selected at the first level, then choose the next level of MTCHs for grouping. They apply HHO, a nature-inspired algorithm based on the hunting behavior of Harris hawks chasing their prey, where the MTCHs are (rabbits) and the first-level MTCHs are considered Harris hawks. The researchers consider the energy constraints of individual M2M devices that depend on their sensing and data transmission capabilities. To identify optimal MTCHs, the HHO algorithm follows exploration and exploitation states. The Hawk uses an exploration phase strategy.

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

The next iteration is represented as $(t+1)$given the current iteration t. The position vector of the hawks at the next iteration is denoted as $X(t+1)$while $X_{rabbit}(t)$represents the position vector of the rabbit. The present position of the hawks is denoted as $X(t)$,and random numbers $r_1, r_2 r_3, r_4, q$are generated in the range [0,1]. $X_{rand}(t)$denotes the position vector of a randomly selected hawk, while X_m is the average position vector of all hawks. The upper and lower bounds variables are denoted as UB and LB, respectively. Hawk's Position.

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

After exploration, the exploitation is performed based on the energy of the next level of devices, i.e., rabbit. The location of the Hawk at the t^{th} iteration is denoted by $X_i(t)$and K is first-level MTCHs. Hereby, the energy E is,

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

The position vector is updated based on the energy value after the energy has been computed in the exploitation phase.E_0 denotes the rabbit's initial energy, and T indicates the number of iterations. To perform the update, two techniques are used: soft besiege (SB) and hard besiege (HB). The soft besiege technique is represented using one mathematical expression, while the hard besiege technique is represented using a different mathematical expression.

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

$Soft\ besiege\ with\ progressive\ rapid\ dives$:

$x_{new} = Y\ , if\ F(Y) < F(x_i)$

$$Z, if\ F(Z) < F(x_i),$$
$$where\ F(x_i) = Fitness\ value\ of\ x_i$$
$$Y = x_{prey} - E\left|Jx_{prey} - x_m\right|,$$
$$Z = Y + S \times LF(D), where$$

$$S = Random\ vector\ of\ size 1 \times D, D = Dimensions \tag{6}$$

$$X(t+1)_{HB} = X_{rabbit}(t) - E|\Delta X(t)| \tag{7}$$
$$Hard\ besiege\ with\ progressive\ rapid\ dives:$$
$$x_{new} = Y, if\ F(Y) < F(xi)$$
$$Z, if\ F(Z) < F(xi),$$
$$where F(x_i) = Fitness value of x_i$$
$$Y = x_{prey} - E\left|Jx_{prey} - x_m\right|$$

,

$$J = 2(1 - r6), r6 = rand(),$$
$$Z = Y + S \times LF(D), where$$

$$S = Random vector of size\ 1 \times D, D = Dimensions \tag{8}$$

Where $\Delta X(t) = X_{rabbit}(t) - X(t)$, J is rabbit's strength, which randomly changes, is defined by the value J. A fitness value is then calculated using distance, power, and remaining energy. The Euclidean method is used to measure the distance between two devices. it is given as

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \tag{9}$$

(x_1, y_1) and (x_2, y_2)positions of devices. The friss Equation is used to find the received power R_P is given as,

$$R_P = \frac{P_T G_T G_R \lambda^2}{(4\pi d)^2} \tag{10}$$

The system calculates the residual energy of each MTCD based on its initial energy, using the received gain$G_{T,}G_R$, total power P_T, and wavelength(λ). Next, it evaluates the fitness of each device in the second level based on three constraints and selects the cluster Head.

The proposed M2M communication system employs a This M2M Network employs a hierarchical selection of MTCHs until the entire network is covered. The selection of MTCHs is performed using the HHO algorithm.

After choosing a cluster head, each cluster member is added by broadcasting to the devices from the selected Head, and other MTCDs within the coverage send join requests to the MTCH. On receiving the request, the MTCH delivers the join reply to the respective MTCD. This way, clusters are formed by chosen Heads of the communication network to ensure QoS. MTCH selection employs an optimization algorithm, as the random grouping of MTCDs cannot be sustained longer. The grouping of MTCDs significantly impacts network performance improvement.

4.3 Dynamic MAC switching

In an effort to develop a power-efficient MAC protocol for M2M Network, researchers introduced the E-CSMA/CA protocol and combined it with CSMA/CARP. To address the issue of long waiting times caused by the random selection of backoff values, they imposed constraints on the computation of backoff values. However, in high-density scenarios with different traffic types, they observed that CSMA/CARP performed better than CSMA/CA. To address this, the researchers introduced a novel MAC switching procedure that allowed the MTCDs to switch between the two MAC protocols based on probability estimates computed using parameters such as density, backlog, and active MTCDs.

Table 1
Pseudo code for HHO algorithm

Pseudo code for HHO algorithm

```
Input: Initial energies of all second hierarchical level MTCDs
Output: Final network with optimal selection of Cluster Head(s)-MTCH
Begin:
Initialize a random population of hawks (MTCDs) as $i = 1,2,3....N$
Initializing the iteration counter $t\ to\ 1$, and setting the maximum number of iterations as $T$.
While ($t \leq= T$) do
    Compute the fitness values of the Hawks. (MTCDs)
    Designate the location of the prey as X rabbit. (MTCH)
    for (each hawk ()) do
        Update the initial energy $E_0$ and jump strength $J$
        Update the solution by employing Equation _ 4
        If ($|E| \geq 1$) then // Exploration
            Update the solution by employing Equation _4
        end if
        if (($|E| < 1$) then
            // Exploitation
            if (($r \geq 0.5$ and $|E| \geq 0.5$ ) ) then //Soft besiege
                Update the solution by employing Equation _5
            else if ($r \geq 0.5$ and $|E| < 0.5$ ) then //Hard besiege
                Update the solution by employing Equation _ 7
            else if (($r < 0.5$ and $|E| \geq 0.5$ ) then Soft besiege with progressive rapiddives
                Update the solution by employing Equation_6
            else if ((($r < 0.5$ and $|E| < 0.5$ ) then
                Hard besiege with progressive rapid dives
                Update the solution by employing Equation _ 8
            end if
        end if
    end for $t = t + 1$ end while Return $X_{prey}$(Optimal position of the cluster head MTCH)
```

To minimize collisions between MTCDs, the researchers assigned each MTCH a set of preambles and avoided collisions by allotting different preambles to different MTCDs. The probability value for MAC switching was estimated by the MTCH and was based on density, backlog, and active MTCDs present in the group. This approach reduced energy consumption, collisions, and waiting time in the M2M communication system. The system determines the number of backlogged MTCDs by subtracting the number of successful MTCDs from the total number of active devices. Thus, the remaining number of active devices can be obtained. Then the number of active devices Na be,

$$N_a = \begin{cases} N_{a-1} - S_{a-1} + A_a, & if\ a \leq I_x \\ N_{a-1} - S_{a-1}, & otherwise \end{cases} \tag{11}$$

$S_a$issuccesses andA_a new MTCDs, $a = 1,2, \ldots\ldots I_x$. the average number of successes$\bar{S_a}$ is ,

$$\bar{S_a} \approx K(1 - e^{-N_a/K}) \tag{12}$$

K Indicates resource blocks. Then the probability of MTCHs $P(N)$ is determined by,

$$P(N) = (d_n, N_b, N_a) \tag{13}$$

The system determines whether to use CSMA/CARP or E-CSMA/CA based on the probability value, which is calculated based on backlogged MTCDs and the density of devices in the cluster. If the probability is more than the threshold value, the system switches to CSMA/CARP. Otherwise, it follows E-CSMA/CA

$$L_{st} = \left(\frac{CR}{d(n_i, n_j)}\right) + snr + (bw \log_2(1 + snr)) \tag{14}$$

After selecting the MAC protocol, the system calculates the link stability and channel bandwidth to minimize collisions. The estimation of link stability $L_{st}$is based range of the coverage CR of the device, the distance between the i^{th} andthe j^{th} MTCD, and the bandwidth bw and signal-to-noise ratio (SNR) snr are found. The MTCD monitors the radio channel in E-CSMA/CA to ensure that no other MTCD is transmitting data. Upon detecting a free channel, the MTCD initiates data transmission; otherwise, it waits for a specific backoff time period. The backoff time period is determined by considering an aggregate function, delay, and the number of active MTCDs. Hereby, the backoff BO time is given as,

$$BO = \left[\frac{2^l}{R_{agg}, d_e, N_a} \times ran()\right] \times T_s \tag{15}$$

During the MAC procedure, the MTCD waits for a specific backoff time before initiating data transmission. R_{agg}represents the aggregate function proportional to the data size, d_e denotes delay, T is the backoff timeslot, and l is a positive variable. In E-CSMA/CA, the exchange of request to send (RTS) and clear to send (CTS) messages is necessary. The MTCD waits for the backoff time, and recalculates the backoff time for the channel if it does not receive the CTS message within the stipulated time.

The CSMA/CA protocol was designed to handle contention windows and determine backoff values. The MTCH switches to CSMA/CARP when the probability value is high. The MAC protocol listens to MTCD traffic and computes waiting times using IFS. Waiting times are based on channel capacity, residual energy, and priority. The channel capacity reflects signal and noise levels, and the Shannon-Hartley theorem is used to compute it. High signal strength improves successful data transmission, while high noise levels enable MTCDs to use other channels.

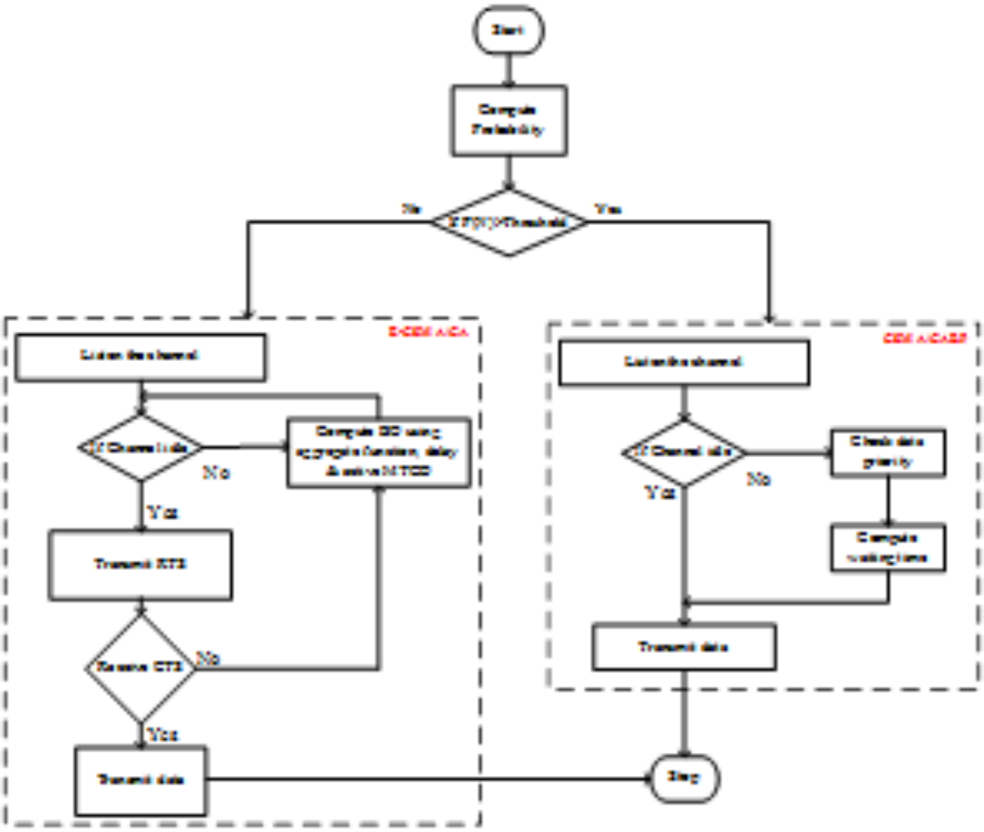

Fig. 2. Dynamic MAC switching

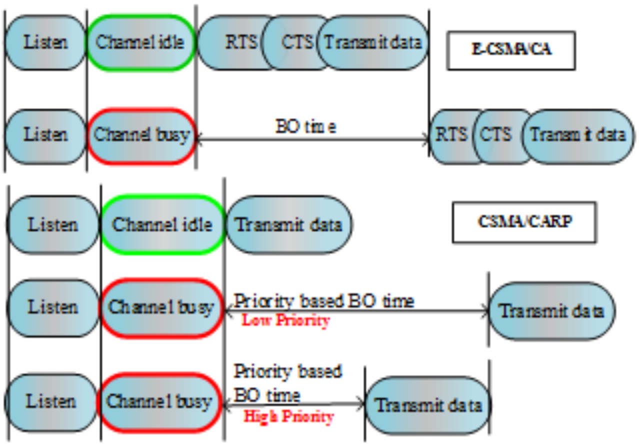

Fig. 3. E-CSMA/CA and CSMA/CARP

The proposed system's communication channel is prone to additive white Gaussian noise (AWGN), and collisions are avoided in the CSMA/CARP protocol. The waiting time for MTCD packets is determined based on their priority flag, with high-priority packets flagged as one and low-priority packets flagged as 0. Probability values are used to switch between E-CSMA/CA and CSMA/CARP protocols, reducing the likelihood of collisions. To further minimize collisions, a set of preambles is assigned. The MTCH determines the selection of the MAC protocol, and the MTCDs transmit data according to the selected MAC. Therefore, the MTCD members and MTCH establish M2M communication using the switched MAC protocol.

4.4 Communication between eNodeB and MTCH

In this phase, a specific time is allotted to the MTCHs to deliver the collected data to the eNodeB. The proposed M2M communication system utilizes a Dynamic time-division multiple access (D-TDMA) approaches. Unlike traditional TDMA, where time slots are allocated to devices for data transmission., The QoS requirements of the D-TDMA protocol are determined based on the necessary throughput and average access delay for delivering the collected data. The estimated data size is used to assign time slots for communication. The throughput is the QoS metric used in this protocol. Then the average access delay $E_{avg}$is formulated as

$$\mathrm{E}_{avg} = \mathrm{E}_{dc} + \mathrm{E}_{he} \tag{14}$$

The proposed M2M communication utilizes Dynamic-TDMA for transmitting data between the MTCH and eNodeB. $E_{dc}$is the collected data delayandE_{he} is the header data delay. The system transmits the header, which includes all credentials likesource address, destination address, and other relevant information.Traditional TDMA is only effective with synchronizing timeslots, so the proposed system uses adaptive synchronization through a Markov chain model.The D-TDMA is applied to the eNodeB, which assigns timeslots for all the MTCHs in the network. The two states in the Markov model are waiting and transmitting, which predicts events based on temporal sequences and computes the probability of transition states. The followingEquationspecifies the state transition from one state to another.

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

The state of i and j defines the probability states at the time period t+1 and t respectively. The x0 is the arbitrary notation for the constant X0 at time 0.   The transition probability matrix is given as,

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

In this work, we construct a matrix of D×D denoting the probability of transmission from state$i$ to j wherePij represents the probability. The matrix is illustrated in Figure 4 and involves two states: State 0, which represents transmission denoted as S1, and State 1, which represents waiting denoted as S2. Herethe transition matric is given as,

$$P = \begin{bmatrix} 1-p & p \\ q & 1-q \end{bmatrix} \tag{17}$$

The proposed M2M communication system enhances QoS and other network metrics by enabling communication in clustered MTCDs. The system facilitates communication between MTCDs and MTCHs and between MTCHs and the eNodeB. To ensure efficient data transmission, we assign equal time slots to MTCHs based on their QoS requirements and the amount of data they collect. Each MTCH is allocated non-overlapping time slots to perform their transmission. To resolve synchronization issues, we use a Markov chain model to predict the states of MTCHs and assign time slots accordingly. In cases where MTCHs use different channels for transmission, they can transmit data in the same time slot. However, if MTCHs use the same channel, they must wait until one MTCH completes its transmission before another can start.

5. Simulation

The simulation results and analysis are presented in this Section. The proposed M2M System uses network Simulator 3.26 on the Ubuntu operating system. This network simulation study explores the behavior and characteristics of a wireless network under various parameters. The simulation involves a network with a spatial dimension of 800m × 800m and consists of 100 MTCDs, transmitting 5000 packets with a packet interval of 0.1 ms. The initial energy of each MTCD in the network is set to 1000 J, and the network operates at a bandwidth of 25 Hz. The data transmission rate in the network is set between 10 – 20 Mbps, and the network protocol used for the simulation is EMAC-DTDMA. The simulation runs for a duration of 250 s. The parameters defined for the simulation help evaluate the network's performance and provide insights into the behavior of the network under different conditions.

The proposed system has been designed to address the challenges faced in a smart city environment. Smart cities are composed of many smart devices equipped with sensors to gather information and deliver it to people. These devices are used in various applications such as traffic management systems, Figure 5 explains the smart city concept which includes clustering, switching between two MAC protocols, and D-TDMA. Moreover, the system is suitable where QoS is vital in achieving effective results [41]. MTC devices such as vehicles, surveillance cameras, industrial machinery, and others can benefit from this system.

The workflow of the paper is that the eNodeB selects the first level of MTCHs based on the Manhattan Distance, and the first level of MTCH selects the next level of MTCHs using HHO. The MTCH gathers data from the MTCDs and selects the appropriate CSMA/CA or CSMA/CARP protocol for transmitting the data. The MTCH then requests synchronized Time Slots from the eNodeB, which allows them to the MTCH for efficient data transmission. The M2M Communication System facilitates seamless and reliable communication between devices, enhancing the performance and efficiency of the network.

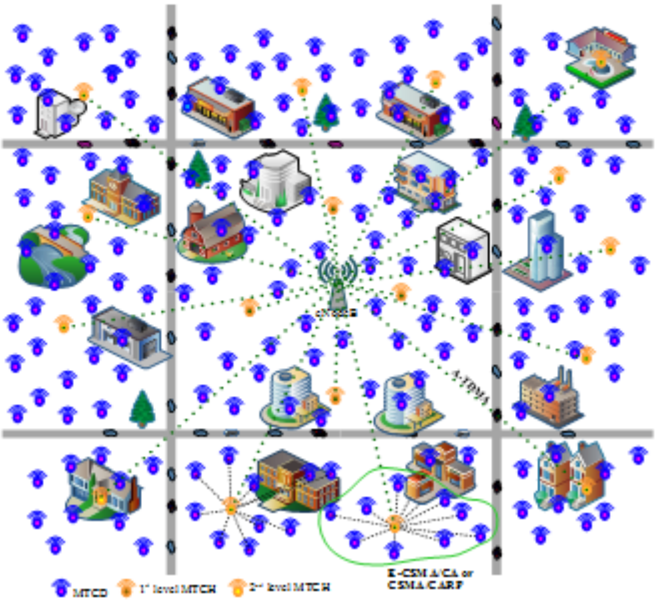

Fig. 4. Smart City application

5.1 Results

The results of the proposed EMAC-DTDMA system are compared with the existing CCAS in M2M communication. The CCAS uses CSMA/CA for collision mitigation and clustering, but it has certain limitations and consumes more power. The proposed MAC switching overcomes these limitations and aims to achieve QoS while minimizing power consumption. The evaluation of QoS improvement is based on delay and packet delivery, while the performance of the MAC protocol is measured by collision probability, access delay, energy consumption, and successful packet delivery.

5.1.1 Average access delay

Accessing the channel with minimal delay is a crucial metric for measuring the expected QoS of the system.

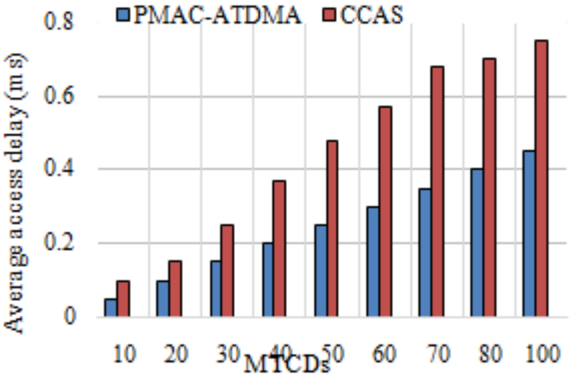

Fig. 5. Average access delay Vs Number of Devices

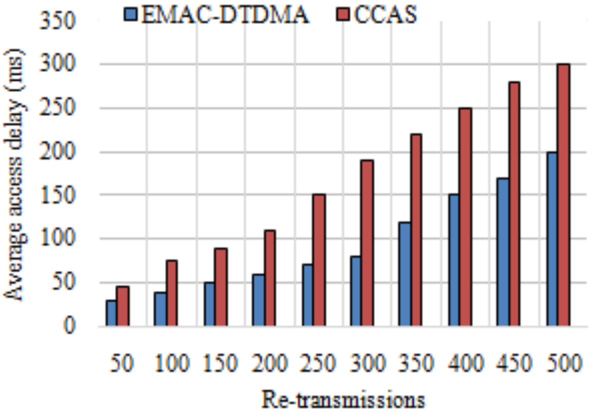

Fig. 6. Average access delay Vs Retransmissions

Figures 5 and 6 illustrate the performance of average access delay compared with increased number of devices, number of transmissions and retransmissions, respectively. As the number of MTCDs increases, the access delay also increases gradually. However, the EMAC-DTDMA reduces delay compared to CCAS. The MAC protocol is switched based on the estimated probability, which helps to minimize collisions among the devices. By considering delay as a significant factor, the E-

CSMA/CA MAC predicts a new backoff value leading to a reduction in delay. When using CSMA/CARP, data packets are sent by devices based on priority, resulting in prompt delivery of data packets without delay.

In contrast to the prior work of CCAS, which incorporated CSMA/CA to minimize collisions, PMAC-ATDMA's switching of MAC protocol based on the estimated probability reduces collisions while predicting a new backoff value to minimize the delay. However, in CCAS, although collisions are minimized, the use of random backoff values increases access delay. In CCAS and EMAC-DTDMA, the systems exhibit an average access delay of 0.40s and 0.20s, respectively, as the number of MTCDs increases. In CCAS and PMAC-DTDMA, the access delay increases with the number of retransmission counts, reaching 169 ms and 94 ms, respectively. The number of retransmission counts increases only when collisions occur frequently.

A poorly designed MAC can lead to increased collisions. In contrast, EMAC-DTDMA can perform better even with an increase in retransmissions. The access delay of 0.25s is achieved during the participation of 100 devices, and even with an increase in the number of devices in the network, the there is no sudden increase in delay in access. The improvement in QoS is reflected in the reduction of access delay. The maximum access delay of 0.8s for 100 devices is considered high. Hence, the reduction in average access delay also reduces energy consumption. The improved data transmission in M2M communication has impacted access delay and other performance metrics.

5.1.2 Average energy

The limited battery power of M2M devices makes energy consumption a significant constraint in communication systems. The reduction of delay in data transmission also results in less energy consumption in the M2M network. With the number of devices, data is more even though small data is from each device. The comparison is shown in Figure 8, where the proposed protocol consumes less energy than the existing one.

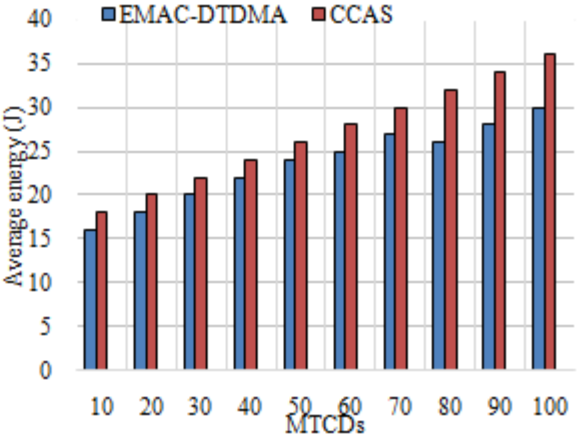

Fig. 7. Energy Vs. Number of Devices

Reduced energy consumption is due to successfully transmitting major data on the first attempt due to reduced collisions. Clustering reduces energy consumption by keeping devices closer and handling MTCD to MTCH communication over shorter distances. Reducing waiting time in M2M communication saves energy by preventing packet holding and buffer size increase, which occurs when waiting time is longer.

The present system reduces energy consumption even with more devices resulting in an average energy consumption of nearly 5J less than the existing CCAS method for 100 MTCDs. This improves QoS, but energy consumption will increase with more MTCDs.

5.1.3 Packet delivery

The proposed M2M communication system improves packet delivery rate by minimizing collisions and reducing delays and energy consumption, in contrast to the lower rate in the existing CCAS system. It evaluates the rate based on the number of MTCDs in the network to ensure successful data transmission.

Figure 8 shows that EMAC-DTDMA achieves more successful packet transmissions than CCAS by efficiently reducing collisions and computing backoff time. As the number of MTCDs increases, maintaining a high packet delivery success rate becomes crucial due to the increased number of transmitted packets.

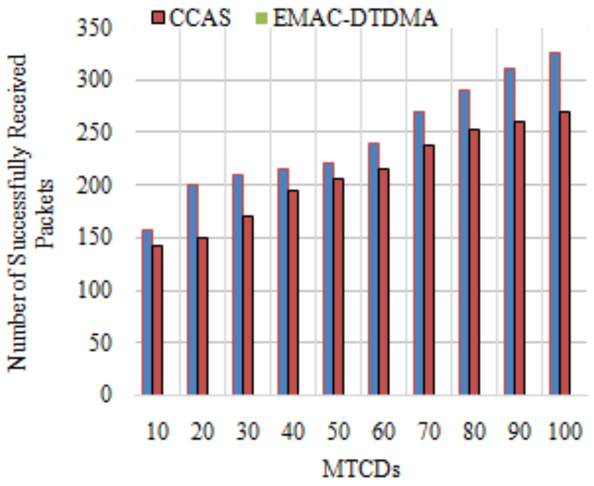

Fig. 8. Successful packet transmission

In a 100 MTCD network, EMAC-DTDMA successfully delivers 315 out of 340 exchanged packets, while CCAS delivers only 260. The proposed system's MAC switching significantly improves packet transmission efficiency, which is crucial in larger networks where CCAS lacks scalability.

5.1.4 Collision probability

Devices in the network increase, rise in collisions when they attempt to use the same transmission channel, necessitating the development of new protocols to minimize collisions.

In Figure 9, EMAC-DTDMA exhibits a lower collision probability than CCAS, a new backoff definition that reduces collisions and ensures more devices are connected in the network.

5.1.5 Clustering of MTCDs

Forming clusters enhances communication between MTCDs, but excessive clustering degrades network performance. The proposed M2M communication system improves performance by selecting optimal MTCHs to form an appropriate number of clusters based on network area. Figure 11 illustrates that CCAS forms too many clusters for fewer MTCDs, resulting in performance degradation. In contrast, this system chooses optimal MTCHs and forms clusters with join requests and responses, leading to a better quality of service and efficient resource utilization.

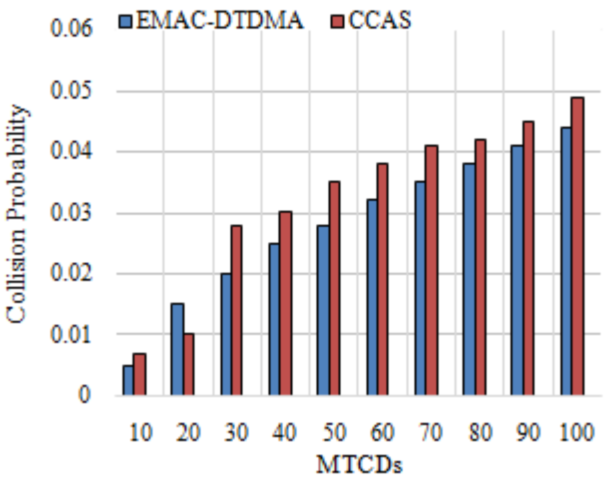

Fig. 9. Collision probability Vs. MTCDs

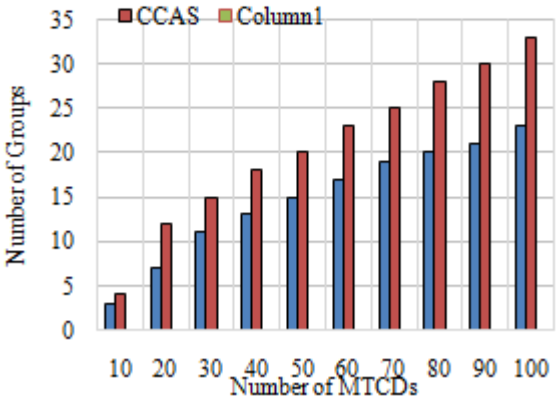

Fig. 10. Groups Vs MTCDs

5.2 Important Insights

The switching MAC protocol and D-TDMA in the proposed M2M communication system address collision and QoS issues between MTCDs, MTCHs, and eNodeB. Optimal MTCHs are selected and grouped to improve network performance and QoS. The proposed MAC protocols, including E-CSMA/CA, CSMA/CARP, and D-TDMA, are compared with traditional MAC protocols such as CSMA and TDMA, and their performance metrics are evaluated and summarized in Table III. The proposed MAC protocols improve QoS by reducing access delay and increasing packet delivery, which is reflected in the better network performance achieved by the proposed grouping, MAC switching, and D-TDMA.

6. Conclusion

The proposed M2M communication system aims to improve communication efficiency among MTCDs in a smart city application, utilizing MAC switching and group optimization. The eNodeB selects the MAC protocol and calculates backoff values based on system constraints. CSMA/CARP is used for MTCD to MTCH communication, while D-TDMA is used for communication between MTCH and eNodeB. The Markov chain model is used for synchronization in D-TDMA. This system reduces delay in access, energy consumption, probability of Collision, and packet delivery while enabling efficient data sharing among MTCDs with varying requirements.

Future plans include the development of a hybrid MAC protocol and testing the system's performance in a large-scale sensor network in 5G and 6G Technology.

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