Multi-population Firefly Algorithm (MFA) based MAC protocol for Dynamic Sleep Scheduling in Clustered IoT Sensor Networks

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ABSTRACT

In IoT Sensor Networks, majority of MAC protocols did not consider the quality of wireless links. Bidirectional and concurrent transmissions occur more often than traditional WSN. The sleep/wakeup period should adaptively varied based on the variance in the network loads. In this paper, we propose a Multi-population Firefly Algorithm (MFA) based MAC protocol for Dynamic Sleep Scheduling in Clustered IoT Sensor Networks. In the system model, the IoT devices are grouped into clusters based on their requirements and architecture. The cluster heads are randomly selected in each cluster based on their remaining energy levels. The sleep wakeup period of each node adaptively fixed using Multi-population Firefly Algorithm (MFA) based on the Energy Level, Expected Load and Channel quality parameters. Simulation results show that the MFA MAC protocol has lesser energy consumption with higher packet delivery ratio, when compared to existing work.

Keywords: MAC; IoT; MFA; Sensor; LTE

1. INTRODUCTION

Internet of Thing (IoT) is one of the greatest involved themes for investigators and inventors. IoT permits stuffs that can interconnect openly with one another, like illuminations on streets, aboard radars in means of transportation, radars in medical devices or even systematic electronic devices in our day-to-day life. When the stuffs are proficient of swapping their data amongst similar devices or dissimilar ones, several shrewd applications have ascended. [1]. IoT mostly targets to join several stuffs, e.g., phones, tablets, sensor, actuators, cars and other mobile devices. IoT communications is categorized into human-to-human (H2H), things-to-human (T2H) and things to things (T2T) communications [2].

IoT nodules have the inadequate battery period and the batteries ought to be substituted. One vital feature of IoT devices is the dynamic efficacy: as numerous devices are energy-constrained and interconnect by means of a comparatively energy-demanding radio, a huge form of investigation has arisen for power-consuming Medium Access Control (MAC) procedures [3].

Afar from the MAC layer features, its chief utilities can be quoted as structure limit demarcation, structure organisation, conduct of base and terminus addresses, recognition of physical medium broadcast faults, and impact prevention [4]. MAC procedures have a substantial impression on the dynamic depletion of radars. The part of MAC procedures is to agree how nodules acquire a special contact to the communal medium and to confirm that only one nodule access the network at a spell. Besides, MAC procedures regulate the structure for network recognizing and impacts can be abridged with well-organized strategy of MAC procedures [5]. Hence, the study of MAC layer procedures can express the way to plan an appropriate technical resolution for an application. MAC procedure is split into three major classifications: controversy free procedure, contention-based procedure and fusion procedure. [6].

1.1 Problem Identification

- Majority of MAC protocols in IoT networks did not consider the quality of wireless links [2]
- Bidirectional and concurrent transmissions that occur more often than traditional WSN [1].
- Network throughput should be enhanced [2].
- The sleep/wakeup period should adaptively varied based on the variance in the network loads.

In order to solve the above issues, this paper designs an efficient MAC protocol in IoT environment.

2. RELATED WORKS

Tanapoom Danmanee [1] has developed CU-MAC protocol to competently enhance the IoT standard. It requires bi-directional communication. It utilises multiple channels to achieve unceasing and bidirectional data transmission at little duty-cycle. It also consists of a device to overwhelm the concealed fatal issue.

Fangming Chai et al [2] have proposed method called link correlation (LC) which helps in receiver initiated acknowledgement (RI-ACK). They also suggested a multicast protocol to furthermore increase the output.

Rowayda A. Sadek [7] has overcome the space amid the physical wireless radar system atmosphere and the actual assorted Cyber IoT environment. His article embattled not only giving an effectual fusion dynamic alert grouping communication procedure IoT network. Hy-IoT, but also offers an actual IoT system design for inspecting the suggested procedure related to generally occurred procedures. Effectual cluster-head collection increases the use of the nodules dynamic contents and accordingly upsurges the network lifespan along with the packages broadcast rate to the base station. Hy-IoT utilises diverse biased selection prospects for choosing a Cluster-head centred on heterogeneity level of the area.

Arjun Bakshi et al [8] have announced introductory concepts of EMIT by embodying the overall intrusion data regarding single-device procedure and advances power-rate distribution approaches to assure low-delay high-reliability presentation. A substantial share of our effort is targeted at authenticating these hypothetical ideologies in investigational testbeds.

Bitan Banerjee et al [9] have suggested a novel MAC procedure for little power sensor devices, appropriate for IoT systems. They have assimilated back-off freezing mechanism, where the back-off stand freezes on every occasion the accessible period for data broadcast is inadequate in that super-frame period. A new slumber procedure is intended to lessen power depletion in indolent stages also. The suggested MAC procedure is demonstrated by means of a 3-dimensional Markov series for investigative presentation assessment.

3. MFA-DSS-MAC PROTOCOL

3.1 Brief Description

In this paper, a cluster based MAC protocol for dynamic sleep scheduling is proposed. In the system model, the IoT devices are grouped into clusters based on their requirements and architecture. The devices are then grouped into various clusters depending on their priority. The cluster heads are randomly selected in each cluster based on their remaining energy levels. During scheduling, TDMA slot is assigned for each node based on their priority. Using this time slot, data transmission is done through a common control channel (CCC) between the nodes. Clusters which are not competing for transmission are forced to enter the sleep mode with different sleep schedules. The sleep wakeup period of each node adaptively fixed using Multi-population Firefly Algorithm (MFA) based on the Energy Level, Expected Load and Channel quality parameters.

3.2 Estimation of Metrics

3.2.1 Energy Level

The energy consumed by a node during the interval t is given by [1]

$$E(t) = n_{tx} * \varepsilon + n_{rx} * \delta \qquad (1)$$

where n_{tx} and n_{rx} denote the number of packets transmitted and received by the node during t, ε and δ are constants whose values lie between (0,1)

The residual energy (E_r) of a node during t is then given by

$$E_r = E_i - E(t) \qquad (2)$$

where E_i is the initial energy of the node.

3.2.2 Expected Load

Load (L(i)) refers to the traffic density of the node which is the sum of traffic queue of node and the traffic queue of all its neighbours.

$$L(i) = \sum_{\forall j \in N(i)} l_i \qquad (3)$$

where N(i) = neighbourhood of the node
l_i = size of the traffic queue
L_i = sum of traffic queue of all neighbours of node i

3.2.3 Channel Quality Indicator (CQI)

The CQI is estimated in terms of the signal to noise ratio (SINR) as follows:

$$CQI = \frac{Q}{|CR_j|} \sum_{n \in CR_j} \log_2 (1 + SINR_{nj}) \qquad (4)$$

where,

Q = channel bandwidth

CR_j = cognitive radio

SINR = signal to interference-plus noise ratio of the pilot embedded in the token by the n^{th} CR.

3.3.4 Objective Function

An objective function (Y) is derived in terms of following metrics: Estimated in section 3.2.1 and 3.2.3))

- Energy Level
- Expected Load

- Channel quality

$$Y = \{\max \sum_{i=0}^{N} E_i, CQI, \min \sum_{i=0}^{N} L_i \} \quad (5)$$

3.3 Cluster formation

In this network, the IoT devices are grouped into clusters based on their requirements and architecture.

The cluster formation procedure is explained as follows:

Let T_{th} be the total trust threshold value.

1. During node deployment, each node broadcasts a HELLO message to its neighbors ($Neigh_i$).

$N_i \rightarrow Neigh_i$: HELLO

The format of HELLO message is shown in Table 1

Node ID	Higher Battery Energy (B)	Processing Capacity (C)	Communication Range (R)	Memory Space (G)	Resources Availability (A)	Residual Energy (RE)

Table - 1 Format of HELLO message

2. Based on received HELLO Message, each node maintains the neighbors list (L_{neigh}).

3. The nodes with higher battery energy, processing capacity, communication range and memory space are assigned higher priority. Eg. some mobile phones, smart controllers, etc.

4. Similarly, nodes having limited resources are assigned lower priority. Eg. sensors, actuators, RFIDs, etc

5. The devices are then grouped into various clusters depending on their priority.

6. Within the cluster, the cluster head is randomly selected based on their remaining energy levels.

7. N_i within the cluster declares itself as the cluster head based on the following case:

If RE is high, then

N_i is declared as CH.

End if

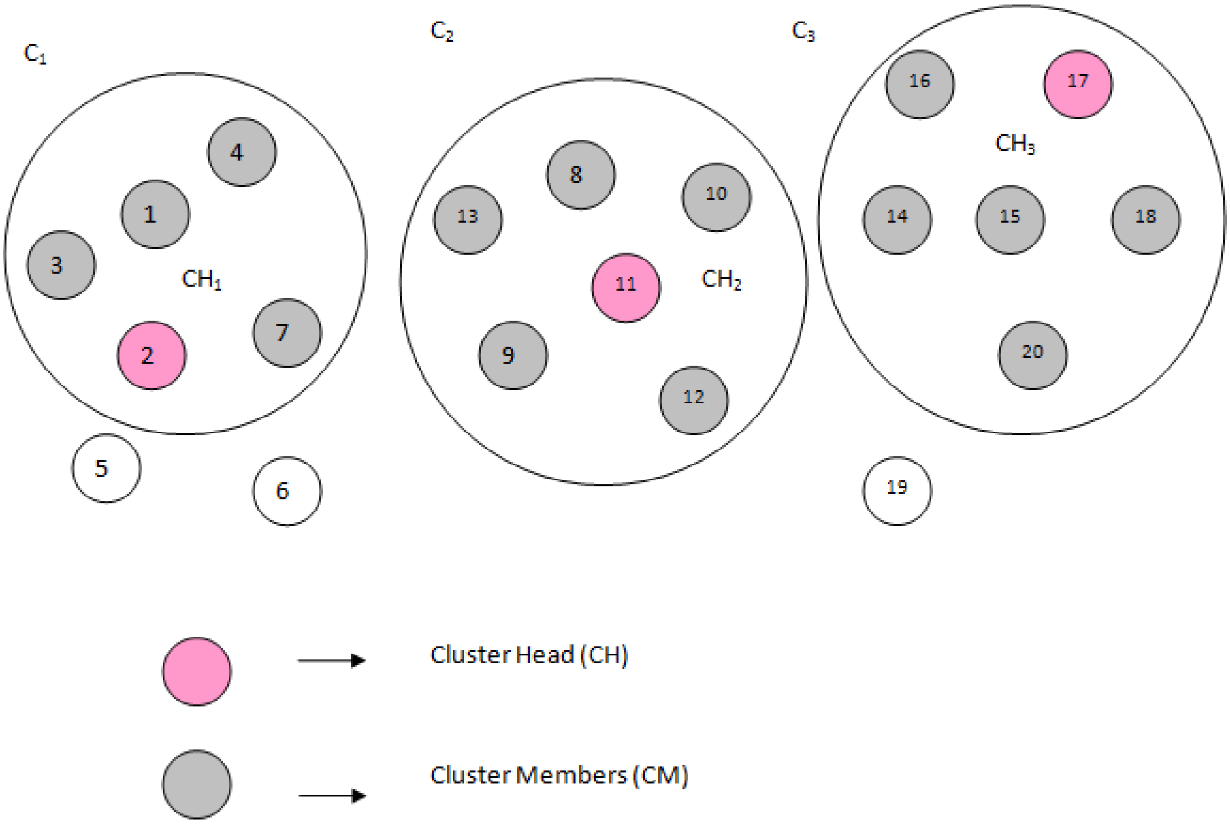

Figure 1 Cluster Formation

Figure 1 demonstrates the cluster formation. Node 1, 2, 3, 4, and 7 holds high priority and Node 2 with high residual energy is selected as cluster head.

Similarly, node 8, 9, 10, 11, 12, 13 holds low priority and Node 11 with high residual energy is selected as cluster head.

3.4 Assigning Sleep Schedule

Let z be the TDMA slots

Let x be the scheduling table

Let O be the contention period

- In the initial phase of the scheduling scheme, CH_i assigns z based on the node priority.
- The nodes with higher priority are allocated fewer z slots when compared to other subgroups.
- This time slot is used data transmission between the nodes through CCC.
- Initially, the node sends x message after the beacon message and schedules the nodes to have longer sleep mode rather than longer O.

- During O, clusters will be allowed to obtain the channel access and transmit data.

3.5 Dynamic Sleep Scheduling

3.5.1Multi-population Firefly Algorithm (MFA)

Multi-population Firefly Algorithm (MFA) and it is regarded as the one among the meta-heuristic method built to resolve optimization problems utilizing the simulation of behavior of the fireflies. The algorithm derives its inspiration from the flashing lights of fire-flies in nature. It consists of three kinds of fireflies: searching firefly, listening firefly, and updating firefly.

Attractiveness depends on the brightness and distance between the firefly. So one firefly moves forward to the next, based on the attraction between them. [10][11].

3.5.2 MFA based adaptive duty-cycle estimation

Let G, H and M be the searching, listening and updating firefly respectively.

The steps involved in Multi-population Firefly Algorithm (MFA) are as follows:

1. Initially CH retrieves the information (estimated in section 3.3).

2. CH_i will create M with the following initial fluorescence intensity.

$$W(M) = \frac{W_S}{\| D_M - D_S \|^{\beta}} \quad (6)$$

where W_S = fluorescence intensity of S at the sink node

$0< \beta <1$ = fluorescence update rate

D = represents the Euclidean distance

M then travels along cluster members and updates H's fluorescence intensity for each nodes it visited as per following equation:

$$\Delta W_i = \frac{W(M).\| D_M - D_i \|}{\sum_{n \in CH} \| D_M - D_j \|} \quad (7)$$

where, n is the random node in CH

3. Otherwise CH will be added in the current routing node.

4. G will move to neighbour N_j as per the following probability

$$Pr_{ij} = \frac{V_j - V_i}{\sum_{k \in N_i} (V_k - V_i)} \quad (8)$$

where N_i is the neighbour set of CH_i

5. The displacement value of the firefly that is attracted to more attractive firefly is determined using the following equation:

$$\Delta D_i = \alpha_0 e^{-\partial d^2}(D_j - D_i) + \lambda . f \tag{9}$$

d = distance between two fireflies

α_0 = attractiveness

F = random variable from a Gaussian Distribution.

λ = step factor in the range (0, 1)

6. Simultaneously, fluorescence intensity of H at N_j should be updated as per the following equation

$$\Delta V_i = (D_j - D_i)^w . e^{-\partial d^2} \tag{10}$$

Here, w represents the fluorescence depletion rate.

7. The objective function is estimated (as per section 3.3.4)

8. If the node within the cluster experiences channel failure or collision, then the length of the sleep period will be extended.

Thus the energy required to access the channel becomes less as some nodes are changed to sleep mode.

4. EXPERIMENTAL RESULTS

4.1 Experimental Settings

The proposed MFA based for Dynamic Sleep Scheduling MAC protocol (MFA-DSS-MAC) is simulated in NS2 and compared with Hybrid MAC [6] protocol. The performance of these two protocols is evaluated based on end-to-rnd delay (E2D), packet delivery ratio (PDR), energy consumption and throughput. The experimental settings are shown in Table 2.

Number of Nodes	20 to 100
Topology Size	50 X 50m
MAC Protocol	IEEE 802.11
Traffic type	Exponential
Number of Flows	4
Propagation Type	Two Ray round
Antenna Model	Omni Antenna
Initial Energy	10.0 Joules
Transmit Power	0.8 watts

Receive Power	0.3 watts

Table 2 Experimental settings

Nodes	MFADSSMAC	HybridMAC
21	14.00668	20.10397
41	14.27038	25.79281
61	16.11621	28.55766
81	17.12171	33.64909
101	17.52869	34.80817

Table 3: Result Table of E2D for varying nodes

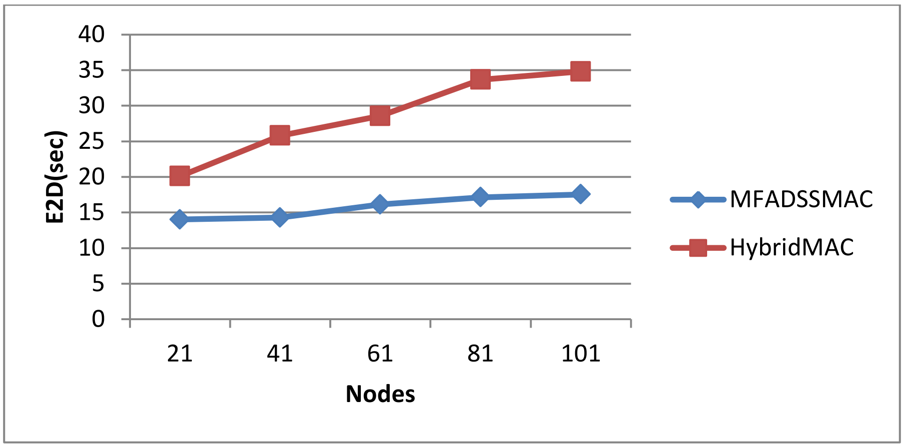

Figure 2: E2D for varying Nodes

Figure 2 shows the results of E2D for varying the nodes. The figure depicts that the E2D of MFADSSMAC is 43% less when compared to HybridMAC.

Nodes	MFADSSMAC	HybridMAC
21	0.83422	0.79585
41	0.803236	0.76025
61	0.76743	0.72033
81	0.70149	0.67302
101	0.68397	0.6475

Table 4: Result Table of PDR for varying nodes

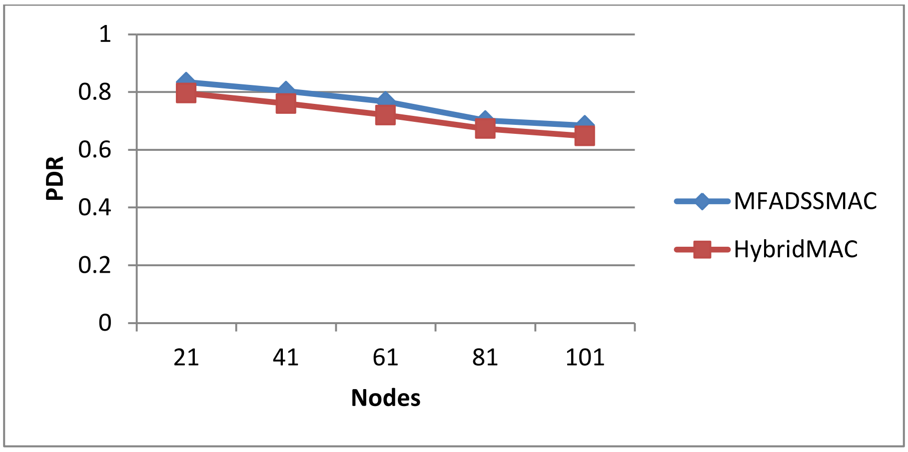

Figure 3: PDR for varying Nodes

Figure 3 shows the results of PDR for varying the nodes. The figure shows that PDR of MFADSSMAC is 5% higher when compared to HybridMAC.

Nodes	MFADSSMAC	HybridMAC
21	6.139994	6.88082
41	6.37873	7.367917
61	6.459655	7.390558
81	7.374434	7.648734
101	7.43481	7.706552

Table 5: Result Table of Energy consumption for varying nodes

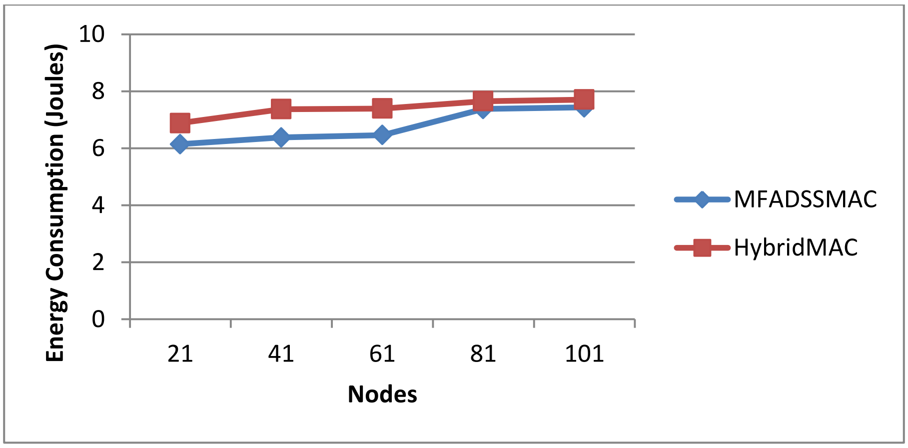

Figure 4: Energy Consumption for varying Nodes

Figure 4 shows the results of energy consumption for varying the nodes. The figure shows that energy consumption of MFADSSMAC is 9% lesser than HybridMAC.

Nodes	MFADSSMAC	HybridMAC
21	4472	3141
41	3514	2809
61	3199	2613
81	3093	2265
101	2414	1721

Table 6: Result Table of Throughput for Nodes case

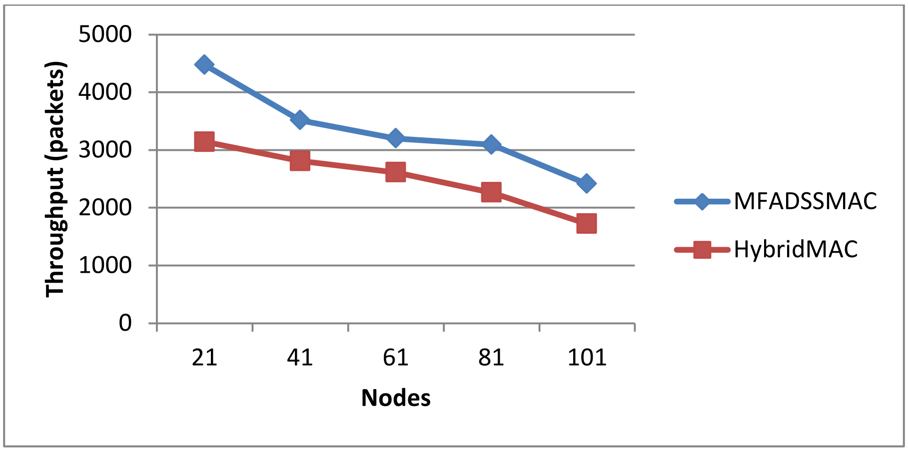

Figure 5: Throughput for varying Nodes

Figure 5 shows the results of throughput for varying the nodes. It shows that throughput of MFADSSMAC is 24% higher when compared to HybridMAC.

5. CONCLUSION

In this paper, we have proposed a Multi-population Firefly Algorithm (MFA) based MAC protocol for Dynamic Sleep Scheduling in Clustered IoT Sensor Networks. In the system model, the IoT devices are grouped into clusters based on their requirements and architecture. The cluster heads are randomly selected in each cluster based on their remaining energy levels. The sleep wakeup period of each node adaptively fixed using Multi-population Firefly Algorithm (MFA) based on the Energy Level, Expected Load and Channel quality. Simulation results show that the MFA MAC protocol has lesser energy consumption with higher packet delivery ratio, when compared to existing work

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