A Priority-based Dynamic TDMA-MAC Protocol for IoT-assisted WSNs

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Abstract

The integration of Wireless Sensor Networks (WSNs) with Internet of Things (IoT) have revolutionized many applications like health-care, industrial automation, transportation, and agriculture sectors. Such integration requires efficient utilization of resources in order to maximize bandwidth efficiency. This paper presents a dynamic Time Division Multiple Access (TDMA) MAC protocol for IoT-assisted WSNs. The proposed protocol improves bandwidth utilization by allocating slots based on data volume of the nodes. Unlike the conventional TDMA that assigns slots statically, the proposed protocol dynamically allocates slots to nodes according to their requests incorporating criticality, traffic load, and residual energies of the nodes. Such dynamic allocation enhances network performance by reducing delay and increasing throughput. Performance of the proposed protocol is evaluated using the state-of-the-art network simulator NS-3. For different number of nodes, packet sizes, and arrival rates, the proposed protocol outperforms the conventional TDMA in terms of delay and throughput. Overall, the proposed protocol reduces delay by 25% and improves throughput by 26% compared to the conventional TDMA for IoT-assisted WSN.

Keywords: IoT, WSN, TDMA, Traffic load, Residual energy

1 Introduction

The Internet of Things (IoT) consists of various smart nodes that are connected together and are able to freely exchange information. IoT devices are heterogeneous in terms of power and traffic load. These devices can have different energy levels such as low-power sensors, laptops, mobile phones, and CCTV cameras [1]. The development in IoT has initiated substantial improvements in the deployment of Wireless Sensor Networks (WSNs). This improved a lot of applications like smart cities, health monitoring, environmental monitoring and industrial automation [2-3]. A WSN is a wireless network that is composed of a large number of sensor devices scattered along extensive areas. These sensors sense outside environment, collect the data and send it to a central station. As this network is composed of resource constrained sensors, it faces significant challenges like limited energy resources, network scalability, fluctuating network traffic and maintaining robust data transmission [4-5]. These constraints have a direct impact on network's lifetime and performance. Efficient communication protocols are required to be designed to address these challenges and enable smooth communication among low-power sensors. For the effective functioning of WSNs, Medium Access Control (MAC) layer plays a vital role that facilitates the sensors to access the shared medium in an efficient way. It coordinates and organizes data transmissions in order to reduce collisions and optimize data transfer among devices [6].

Time Division Multiple Access (TDMA) is one of the efficient MAC protocols that supports structured communication where static slots are assigned to nodes for data transmission. TDMA avoids data collision, ensures efficient bandwidth usage and the orderly placement of transmissions in time due to fixed and pre-determined slot assignment [7]. However, the conventional TDMA can cause inefficiencies in IoT-assisted WSNs where heterogeneous nodes have different traffic and energy requirements. Dynamic TDMA can assign the time slots dynamically according to real-time network conditions and traffic loads and improves throughput, energy consumption and latency [8]. However, existing dynamic TDMA protocols are mainly designed for homogeneous networks like WSN, where nodes have same battery and traffic requirements. Moreover, they rarely consider priority levels of traffic which is an important aspect for IoT-assisted WSN applications that involve time-sensitive and high-priority information. IoT-assisted WSNs are required to prioritize data transmission based on criticality in order to ensure that information is transferred with minimized delay.

In this paper, we propose a dynamic TDMA protocol that allocates slot(s) based on priorities for heterogeneous IoT-assisted WSNs, optimizing slot utilization and reducing delay for high priority traffic. The proposed protocol allows the coordinator to assign time slots to these heterogeneous nodes based on pre-calculated priorities. Priorities are set as high, medium and low based on data criticality, traffic load and energy levels of the nodes. Nodes that are having critical data are considered high priority nodes. Nodes with high traffic load or low Residual Energy (RE) have medium priorities, while all other nodes

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have been categorized as low priority nodes. Unlike the conventional TDMA where slots are wasted if a node does not have pending packets, the proposed protocol allocates slots to nodes dynamically according to their requests. Thus, the proposed protocol addresses the limitations of both static and dynamic TDMA systems and offers an efficient and adaptable solution for IoT-assisted WSNs. The performance of the proposed protocol is evaluated using NS-3 and compared with the conventional TDMA in terms of throughput and delay for different node counts, packet sizes, and arrival rates. The main contributions of the paper are summarized as follows:

- Dynamic slot allocation to the IoT-assisted WSN nodes based on requested slot duration and nodes' priorities that incorporates data criticality, traffic load and RE.
- Detailed simulations and analysis of the proposed protocol using NS-3 across various scenarios and demonstrating its performance improvement over the conventional TDMA in terms of throughput and delay.

The rest of the paper is organized as follows: Section 2 provides an overview of existing literature on MAC protocols. Section 3 presents the design and architecture of the proposed protocol. Section 4 discusses the simulation results and performance metrics used for evaluation of the proposed protocol. Finally, Section 5 concludes the paper.

2 Related Works

In the conventional TDMA, nodes wake up and transmit data only in their allocated time slots and remain in the sleep state at other times. It is suitable for sensor networks with heavy traffic load [9]. But sometimes in sensor networks there are few nodes in a network which have little or no data to transmit to the coordinator or sink. In this case a slot allocated to such node is wasted and also the node is required to keep its radio on during the scheduled time that consumes extra energy. The coordinator has to keep its radio on all the times to receive the data from nodes even if a node does not have data to transmit. To solve this problem energy-efficient TDMA was developed that reduced energy consumption by enabling the nodes to keep their radios off when they have no data to send [11]. However, coordinator should keep its radio on during all the timeslots which may waste energy. A cluster and schedule-based protocol proposed in [9-10] known as Low-energy Adaptive Clustering Hierarchy (LEACH) integrated MAC and cluster-based routing protocols achieved low energy consumption and latency for micro sensor networks. LEACH was mainly based on cluster formation and TDMA MAC protocol. The drawback here is that the cluster heads are selected randomly and the cluster head with low RE values could die out soon, which could degrade the protocol's performance. J. Li proposed a schedule-based MAC protocol called Bit-map assisted (BMA) [11] that reduced energy wastage caused by collisions and idle listening. It had same cluster set-up phase as LEACH. The sensor nodes in BMA sends data to the cluster head in its allocated slot only when an event occurred and kept the radios off at other times. BMA has low energy consumption, complexity and latency. It outperformed TDMA and E-TDMA in low to medium network load, however, it is not suitable for high traffic loads. In [12], the authors proposed Energy-efficient adaptive TDMA (EA-TDMA) that used to monitor acceleration behavior of railway wagons. The application collected data from the sensors, placed inside the wagon that recorded the acceleration for investigating instability and irregularities in the train track. EA-TDMA ensures that each node wakes up in its scheduled slot if it has data to transmit to the cluster head, otherwise it remains in the sleep state, thus reducing energy consumption by minimizing idle-listening period. M. Xie and X. Wang [13] proposed an energy-efficient TDMA protocol for clustered WSN (EC-TDMA) for intra-cluster communication. EC-TDMA altered the TDMA frame length dynamically according to the number of member nodes and traffic load inside a cluster. It minimizes idle-listening and enhances channel utilization and thus extends network lifetime. EC-TDMA has overhead to make the schedule at the start of every frame that could create delays. An Energy-Efficient Dynamic Scheduling Algorithm (EEDS) [14] was proposed by S. C. Kim and H. J. Park that considered node's traffic load and priority for a clustered WSN. This technique reduced the TDMA frame size that resulted in minimized energy consumption and transmission delay. By performing mathematical analysis, it was shown that EEDS outperformed BMA and EC-TDMA in terms of energy consumption and delay. M. Wang and H. Li [15] developed an algorithm named as Node Priority-based Dynamic TDMA algorithm (NPB-DTDMA) that defined the node's priority based on the proportion of node's queue usage and facilitated the high-load nodes in obtaining the time slots. The simulation results showed that NPB-DTDMA achieved better performance in terms of throughput, packet loss rate, and end-to-end delay as compared to P-TDMA, E-ABROAD and fixed TDMA only when sending rate is lower than saturation capacity. The authors in [16] developed a context-aware MAC protocol that supported real-time transmission of critical data. Separate time slots were allocated to the sensor nodes using TDMA-based approach. In order to facilitate bursty traffic, extra slots were assigned to sensor nodes. Moreover, an innovative synchronization strategy was also proposed to minimize the overhead caused by traditional TDMA. The protocol performed well in terms of end-to-end delay but it did not respond to critical data immediately. In another protocol called as Heartbeat-Driven MAC Protocol (H-MAC) [17], the authors tried to enhance the efficiency by minimizing collisions and idle-listening by using the TDMA approach. The protocol exploited the human heart-beat rhythm information to perform synchronization for TDMA. Although it reduced the energy cost for synchronization, the TDMA slots are not adaptive to dynamic traffic. Anjum et al., [18] presented the traffic priority and load-adaptive MAC protocol, where the schedules of pending data packets were determined based on the priorities. In the proposed protocol the size of the super frame structure varied according to the traffic-load that could minimize energy consumption. In [19], the authors designed a traffic load aware sensor MAC for collaborative body area sensor networks. The protocol varied the super frame size dynamically according to the traffic load and a multi-hop communication pattern was included that prevented energy losses. Through extensive simulations the effectiveness of the protocol was demonstrated. However, the protocol did not include the priority information. A Cluster-Based Cross-Layer Multi-Slot MAC (CCM-MAC) developed in [20] for underwater optical wireless communication networks. CCM-MAC is a cluster-based protocol that assigns multiple slots to each node according to slot-occupying information. Collisions are detected and resolved dynamically by using updated information of routing. Simulations showed the improved throughput and collision-rate in contrast to existing contention-based MAC protocols. Atmaca in [21] proposed a MAC protocol named Low-Delay Hybrid Medium Access Control (LD-HMAC) for UAV-based data gathering in high density IoT networks. The protocol combined the strengths of CSMA/CA and TDMA to reduce delay and improve performance in time-sensitive applications. Simulation results showed that LD-HMAC outperformed MDCA and CCS in terms of delay. The authors in [22] proposed the Energy Efficient Group Priority MAC (EEGP-MAC) protocol for IoT networks that utilized a hybrid Q-Learning Honey Badger Algorithm to improve energy consumption and reduce delays. The protocol divided the network into groups according to energy levels, location, and traffic type. It assigned priorities to each group and selected contention nodes optimally within these groups. Simulation results showed that EEGP-MAC achieved better performance than QL-DGMAC in terms of delay, energy consumption, and throughput. Dutta et.al., [23] developed a TDMA-based MAC protocol that integrated Multi-Armed Bandit learning for collision-less slot allocation and a Decentralized Defragmented Slot Backshift technique to improve bandwidth efficiency. The protocol allowed the nodes to schedule their transmissions independently and adapt to topological changes without any centralized control. It is designed for IoT and WSN with low complexity. Extensive simulations showed that the protocol performed well in synchronized as well as in unsynchronized settings. Gul et.al., [24] proposed a traffic-aware and energy efficient routing protocol for IoT-Assisted WSN that integrated clustering with CSMA/CA MAC and selected a congestion less, energy efficient, and shortest path towards the BS. Simulation results showed that the protocol improved packet delivery ratio, end-to-end delay and energy consumption compared to LoRaWAN. Accelerated Particle Swarm Optimization (APSO) algorithm proposed in [25] presented a method for fair CH selection and improved the outcome of LEACH by choosing an optimal CH. APSO changed the LEACH protocol and improved the throughput, energy consumption, and network lifetime. The authors in [26] presented a novel hybrid switching mechanism for software-defined networks by exploiting reinforcement learning to facilitate dynamic and intelligent routing decisions. They focused on real-time network information for efficient resource utilization and improved adaptive decision-making, which improved the overall network performance. Anubha et. al., [27] proposed a routing algorithm for mobile ad hoc networks that used a reward and penalty system to examine the node behaviour and dynamically adjust the paths. It also considered parameters such as energy, mobility, distance, and the pheromone value. Simulation results showed that the protocol is efficient for selecting an optimal path. It also performed well in terms of energy consumption and packet drop. The authors in [28] proposed a protocol named Self-Arranged Ad Hoc Routing in Cluster Scenarios that focused on enabling strong node to node communication by adjusting the transmission power and creating logical clusters. This strategy improved network connectivity and lifetime by considering REs to restore links immediately after disruptions occur. Simulation results showed how traffic load, transmission power, and node longevity affected the performance and stability of the network.

Table 1 briefly summarizes existing TDMA-based MAC protocols.

These protocols were mainly designed for homogeneous networks, where nodes were almost similar in terms of power and traffic volume. Based on the limitations in the existing studies we propose a dynamic TDMA based MAC protocol that improves slot allocation by considering the priority levels of the heterogeneous nodes in order to achieve maximum network performance.

3 Proposed Protocol

This section provides details of the proposed protocol. The protocol is mainly designed for IoT-assisted WSN that consists of heterogeneous devices. These devices are different in terms of energy levels and traffic volume. The conventional TDMA based MAC protocols are not efficient for heterogeneous environments. One of the main objectives of the proposed protocol is to allocate TDMA slots dynamically to the heterogeneous nodes based on nodes' priorities while maintaining low latency and high throughput. Figure 1 shows the super frame structure of the proposed protocol where the transmission duration of the proposed protocol is divided into multiple timeslots of variable length such as T3 has more length as compared to T1 and T2 slots. The length of the frame significantly depends on total number of active nodes N. Each frame consists of allocation period represented by AP and data transfer period represented by DTP as shown in Figure 1. AP consists of slots for Control Packet (CP), Request Packet (RP) and slot announcement period. DTP is highly variable as it depends on the number of slots assigned to nodes N. Slots are assigned to nodes in the AP period while nodes transmit data in DTP. The flow chart and pseudocode of the proposed protocol are shown in Figure 2 and Algorithm 1, respectively. The parameters used in the pseudocode and flowchart are presented in Table 2. The following subsections explain operation of the proposed protocol.

Table 1. Summary of existing TDMA-based MAC protocols

Protocol	Contribution	Evaluation Metrics	Simulator Used
LEACH [9-10]	Low energy consumption and latency by integrating MAC and cluster-based routing protocols for micro-sensor networks.	• Network Lifetime • Throughput • Energy Dissipation	MATLAB
BMA [11]	Low energy consumption by minimizing idle listening and collisions and maintaining low latency.	• Average Delay • Energy Consumption	NS-2
EA-TDMA [12]	Low energy consumption and idle listening by minimizing the idle period when devices have no data to transmit.	• Energy Consumption	Rockwell's WINS Analytical model
NPB-DTDMA [15]	High throughput and less delay by dynamic slot allocation to nodes according to their requirements.	• Throughput • Packet loss rate • Average End-to-end Delay	NS-3
H-MAC [17]	Enhancing energy-efficiency by exploiting human heart-beat rhythm information to minimize energy costs for time synchronization for TDMA.	• Network Lifetime • Energy Cost	OMNet++
PLA-MAC [18]	Improving power consumption and packet delivery by prioritizing data packets and making super frame dynamic.	• Throughput • Delay • Power Consumption	Used C++
ATLAS [19]	Prevented energy losses associated with long-range communication by exploiting the super frame structure of IEEE 802.15.4.	• Average Duty-cycle • Energy Consumption • Throughput • PDR • Delay	NS2
DATBU [23]	Achieved collision-free transmission and reduced bandwidth utilization in IoT and WSN by using a decentralized TDMA slot scheduling and a defragmentation technique.	• Bandwidth Redundancy • Bandwidth Utilization Efficiency	Used MAC layer simulator with integrated learning modules

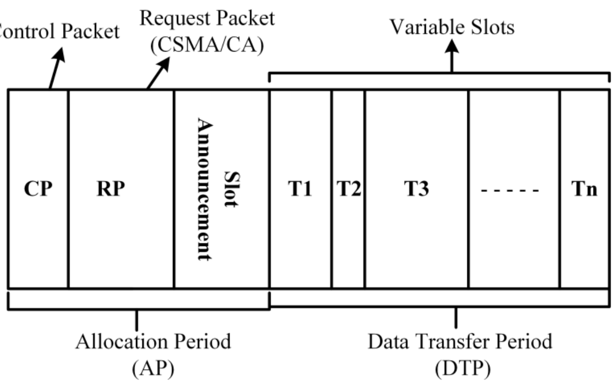

Figure 1. Super frame structure of the proposed protocol

3.1 Time Slot Allocation Mechanism

Assume that there are N active member nodes inside a heterogeneous network such as IoT-assisted WSN. Initially, the Coordinator (C) broadcasts CP to all nodes with high power, so that all nodes can receive it. Only active nodes N (that have pending packets) receive and respond. An active node that needs to send packets contends for the medium using CSMA/CA MAC to avoid collisions and packet loss. It first sends a request packet RP to C after receiving CP. RP consists of required slot duration, criticality bit, and priority information. C collects RP packets from N, processes and sorts the active nodes. Next, it prioritizes N with low, medium, and high priority levels. Critical nodes that need urgent transmissions are considered high priority nodes and are assigned slots first. The slots are dynamically assigned according to the requested slot duration unless and until the request doesn't exceed the DTP limit. These checks are considered and addressed in Algorithm 1 where remaining data transfer period represented by Tr is calculated and checked regularly.

Once high priority nodes are assigned slots the protocol checks medium priority nodes. Nodes that are either having high traffic load or having low RE are considered medium priority nodes. These nodes are assigned slots by the protocol according to their request, while keeping in view DTP's remaining duration. The remaining nodes are considered as low priority nodes as they do not have any critical data; neither have they had high traffic load nor low RE. These low priority nodes are assigned slots lastly in the slot announcement period of AP. Here, the remaining duration of DTP is checked again by the protocol as mentioned in Algorithm 1. If the DTP duration limit reaches and the nodes are left with unassigned slots, they are assigned high priority slots by C in the next super frame. It should be noted that nodes having the same priority are assigned slots on a First-Come-First-Serve basis. Moreover, the protocol is designed to handle changes in priorities dynamically. During each AP period of the frames, nodes send RPs to C that include the updated priority information that is based on real time factors such as traffic load, RE and criticality. C then uses this information to make slot allocations dynamically. After slots are scheduled by C, they are announced to N in the slot announcement period during AP as shown in Figure 1.

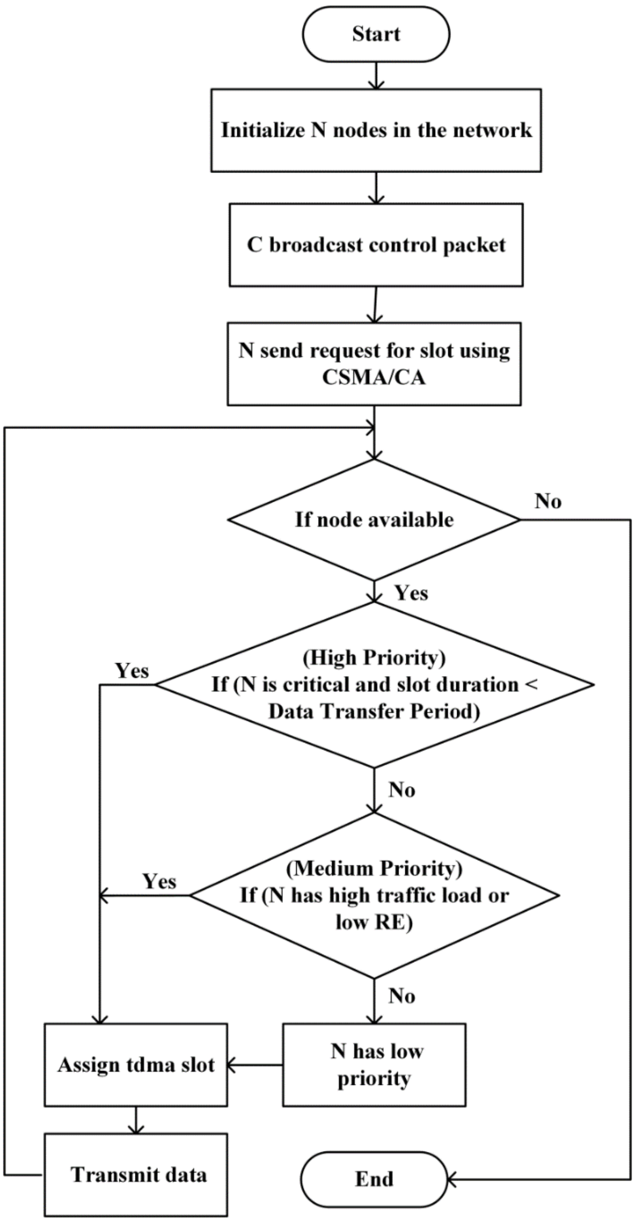

Figure 2. Flowchart of the proposed protocol

The nodes N transmit pending packets in assigned slots during the DTP of the next super frame. Slots are scheduled and announced by C to the nodes N in the current super frame and nodes transmit packets in the next super frame's DTP.

Table 2. Parameters with description

Parameter	Description
N	Set of active nodes
C	Coordinator
CP	Control Packet
AP	Allocation Period
RP	Request Packet
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
crit	criticality bit
S_t	Slot time
S_d	Slot duration
S_{dth}	Slot duration threshold
RE	Residual Energy
RE_{th}	Residual Energy threshold
DTP	Data Transfer Period
Tt	Total DTP
Ts	Sum of S_t and S_d
Tr	Remaining DTP

Since number of active nodes N is variable, the length of the super frame will vary accordingly. Unlike the conventional TDMA protocol where slots are wasted, the proposed protocol reduces wastage of slots which results in better delay and throughput performance.

Algorithm 1. Dynamic slot allocation

Input: N
Output: N with allocated slots
BEGIN
while true do
  for Each Frame do
    C Broadcast CP (High power)
    for all N
      N receives CP
      Request (Slot): N sends RP to C using CSMA/CA
    end for
    C receives RP from N
    C sorts N w.r.t Ascending_RP
    Ts ← 0
    //Dynamic slot allocation to high priority nodes
    for all N
      Tr ← Tt – Ts
      if (crit(N) ==1 and S_d(N) <= Tr)
        Assign Slot
        Ts ← $S_t + S_d$
      end if
    end for
    //Dynamic slot allocation to medium priority nodes
    for all N
      Tr ← Tt – Ts
      if (S_d(N) > S_{dth} || RE(N) < RE_{th})

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            if (S_d(N) <= Tr)
                Assign Slot
                Ts ← S_t + S_d
            end if
        end if
    end for
    //Dynamic slot allocation to low priority nodes
    for all N
        Tr ← Tt – Ts
        if !((crit(N) ==1 || S_d(N) > S_dth || RE(N) < RE_th))
            if (S_d(N) <= Tr)
                Assign Slot
                Ts ← S_t + S_d
            end if
        end if
    end for
    N transmit packets to C in DTP in their assign slots
  end for
end while
end BEGIN
```

4 Simulation Results and Discussion

This section presents the simulation results and discusses the performance of the proposed protocol. The protocol is thoroughly evaluated using state-of-the-art network simulator NS-3 and its performance is compared against the conventional TDMA. NS-3 is an open-source and discrete-event network simulator and provides built-in support for the simulation of numerous protocols including MAC and routing protocols. It is efficient in terms of memory usage and computation time. The simulation set-up consists of a network of stationary nodes that are randomly deployed within the field. The network consists of heterogeneous nodes with different energy levels and traffic loads. All nodes are connected to a central coordinator C in a star topology. C is node with high RE and is responsible for slot allocation and data gathering. Packet size, number of nodes, and packet arrival rate are varied for different scenarios in order to check the performance of the protocol in terms of delay and throughput inside the network. Simulation time is set as 50s and nodes are deployed in an area of 200 x 200 square meters. Table 3 presents the main simulation parameters.

Table 3. Simulation parameters

Parameter	Value
Network field	200 m x 200 m
Packet size	256 & 512 B
Simulation time	50 s
Number of nodes	5 to 30
Slots limit	20

The proposed protocol is evaluated by taking a number of simulations. The results are visualized in the following sections. The performance of the protocol is also compared with the conventional TDMA analyzing the metrics such as throughput and delay.

4.1 Throughput

Figure 3 to Figure 5 show various trends for throughput for both the proposed protocol and the conventional TDMA that is recorded in percentage values. The graph in Figure 3 shows that throughput increases steadily for both the protocols when nodes are added to the network. The conventional TDMA protocol has a slower throughput increase as compared to the proposed protocol and becomes less efficient when node count rises. At 30 nodes, the proposed protocol achieves 15.75% more throughput than the conventional TDMA. This suggests that the proposed protocol outperforms TDMA in handling larger networks by making better use of available bandwidth by dynamically allocating the slots. Moreover, an overall approximately 26% improvement is achieved by the proposed protocol as compared to the conventional TDMA. Similarly the pattern in Figure 4 depicts that the throughput is better for the proposed protocol than the conventional TDMA for increasing packet sizes. Static slot allocation of the conventional TDMA is the main cause of the decreased throughput. The slot size is designed fixed here, where a packet (of different size) may or may not fully utilize it. The unused slot portion is wasted which affects the throughput. On the other hand, the proposed protocol assigns dynamic slots to the nodes according to the packet size. This enhances bandwidth utilization and increases the throughput. The improvement can be observed from Figure 4, when packet size is maximum, that is, 300 bytes, where the proposed protocol achieves 17% more throughput than the conventional TDMA. The trend for throughput in Figure 5 shows that the proposed protocol outperforms the conventional TDMA in terms of increasing arrival rate. The reason is the static and predetermined slot allocation in the conventional TDMA protocol. Slots are allocated to each node regardless of the actual traffic demand. So, when packets are generated at a high rate and the arrival rate crosses the limit the slots can handle, the conventional TDMA can encounter saturation that can lead to queuing delay and packet loss, affecting the throughput. The proposed protocol achieves approximately 21% more throughput than the conventional TDMA when arrival rate increases to 120 packets per second. Figure 6 shows the throughput of the proposed protocol for increasing number of nodes for packet size of 256 bytes and 512 bytes. Here throughput for larger packet size increases at a faster rate, which indicates that more bits are transmitted and received in certain duration.

Network configured with 512 bytes packet size achieves 70% throughput when number of nodes is 20 while the same throughput is achieve by 30 nodes with 256 bytes packet size. This means that for 512 bytes packet size the throughput reaches 70% with 20 nodes configured in the network. While for 256 bytes packet size the value of throughput is 62.7% for the same number of nodes.

Therefore, larger packet size utilizes the bandwidth more efficiently compared to smaller packet size. However, when nodes' number reaches a certain value the throughput for both configurations shows less increase. It is because initially the channel passes fewer packets due to less traffic load.

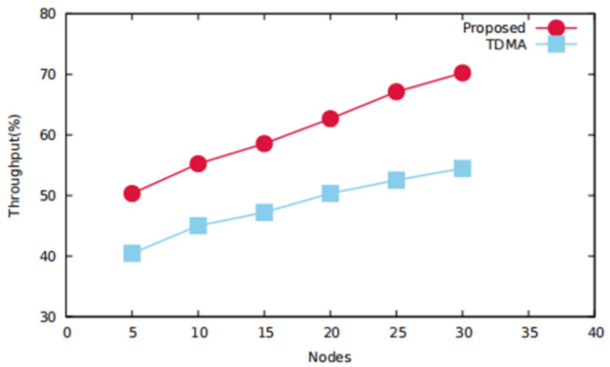

Figure 3. Throughput vs Nodes for proposed protocol and TDMA

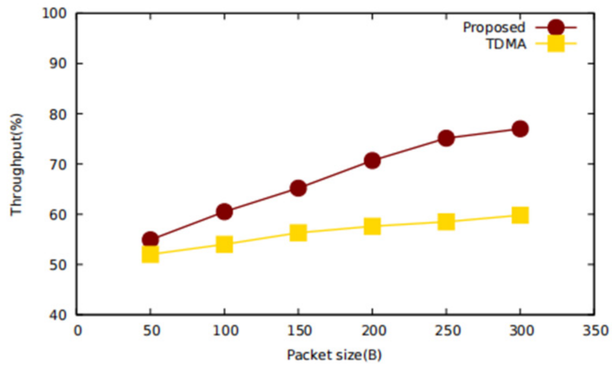

Figure 4. Throughput vs Packet size for proposed protocol and TDMA

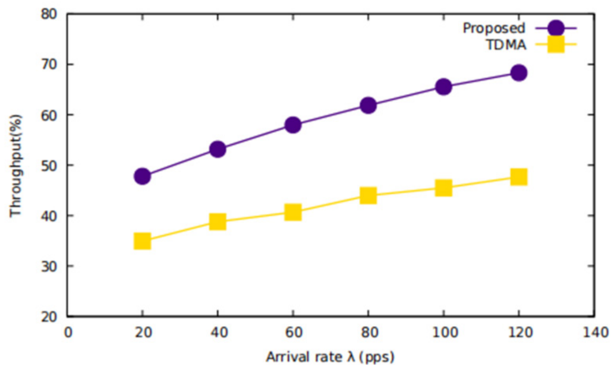

Figure 5. Throughput vs Arrival rate for proposed protocol and TDMA

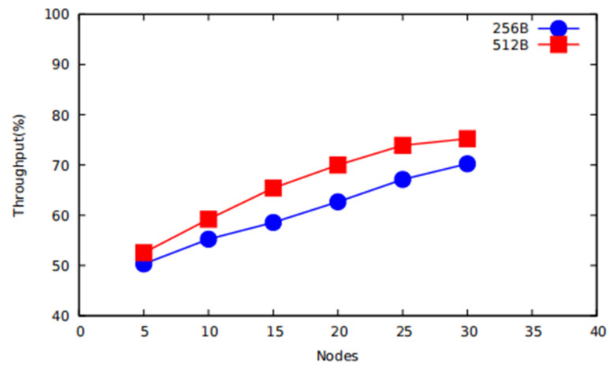

Figure 6. Throughput of the proposed protocol for varying number of nodes

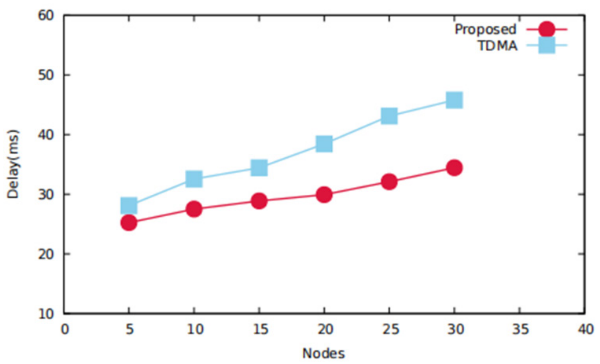

Figure 7. Delay vs Nodes for proposed protocol and TDMA

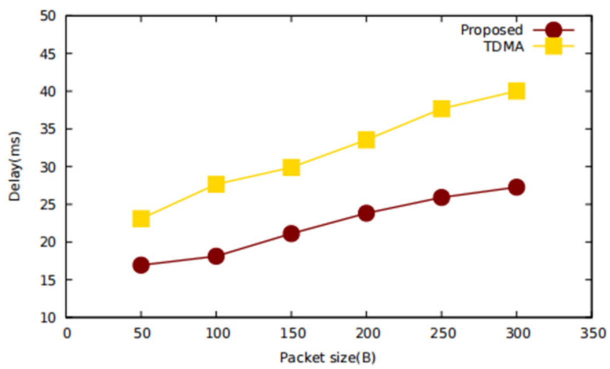

Figure 8. Delay vs Packet size for proposed protocol and TDMA

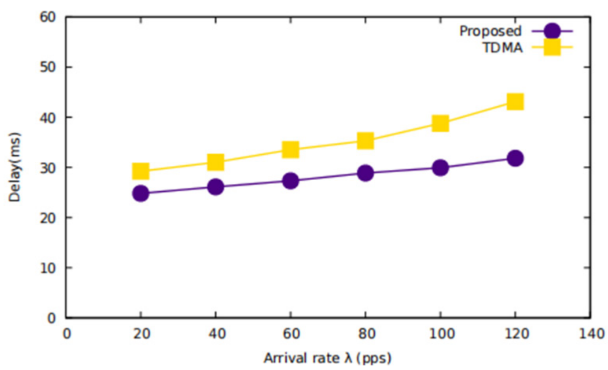

Figure 9. Delay vs Arrival rate for proposed protocol and TDMA

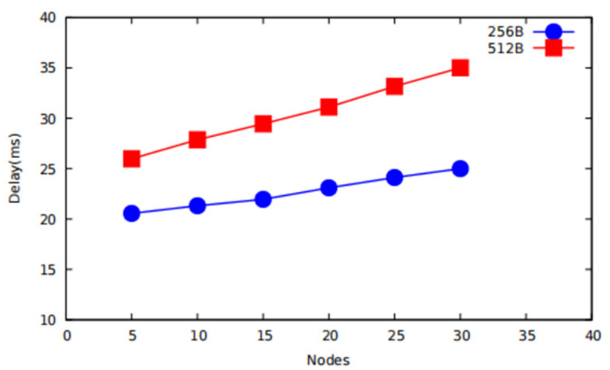

Figure 10. Delay of the proposed protocol for varying number of nodes

4.2 Delay

Delay is presented as a function of several parameters such as node counts, packet size and arrival rate. Figure 7 represents the delay taken against varying node counts where the nodes increase from 5 to 30 in number for both the protocols. The proposed protocol shows lower delay than the conventional TDMA across all node counts. The improvement is due to the dynamic nature of the proposed protocol, which, unlike the conventional TDMA, better allocates slots only to the active nodes that have pending packets. This minimizes the super frame size causing minimized delay. The proposed protocol shows 11 milliseconds less delay than the conventional TDMA when the number of nodes is 30. Figure 8 shows that delay increases with increasing packet size. However, the proposed protocol has lower delay than the conventional TDMA across all packet sizes. For 300 bytes packet size, the difference in delay between the two protocols is 12.8 milliseconds approximately. This is because the slots are assigned dynamically according to the packet size in the proposed protocol. This reduces the delay and on average 31% improvement is achieved by the proposed protocol compared to the conventional TDMA. Similarly, Figure 9 illustrates that the delay increases with increase in packet arrival rate. However, the proposed protocol outperforms TDMA for all values of arrival rates. It is again due to the dynamic slot allocation of the proposed protocol which assigns slots to the nodes on priority basis. Therefore, nodes that have high arrival rate are allocated slots first, so these nodes don't have to wait due to the inactive nodes that don't have packets to send. It can be seen in Figure 9 that when the arrival rate reaches 120 packets per second, the proposed protocol experiences approximately 4 milliseconds less delay than the conventional TDMA. The graph in Figure 10 shows that the delay increases as the number of nodes increases for packet size of 256 bytes and 512 bytes. Larger packets experience more delay compared to smaller packets, especially when the number of nodes is high. The delay for 256 bytes packet size at 30 nodes is 25 milliseconds approximately, while for 512 bytes packet size the delay is 35 milliseconds as can be observed from the figure. This is due to the increased time needed to transmit larger packets and the queuing effects of such packets.

5 Conclusion

We presented a priority-based dynamic TDMA MAC protocol that dynamically allocates slots to the nodes based on their priorities, traffic requirements and residual energies. Unlike the conventional TDMA, the proposed protocol adjusts super frame size by assigning slots according to the requested slot duration. This improves the overall performance of the network. Simulations demonstrated superiority of the proposed protocol over the conventional TDMA in terms of throughput and delay. It achieved approximately 25% and 26% improvement for delay and throughput, respectively, compared to that of the conventional TDMA for IoT-assisted WSN.

In future the proposed protocol can be improved by integrating it with reinforcement learning that can predict dynamic traffic patterns and assign slots intelligently. In addition, mobility can be added to the protocol to accommodate dynamic environments such as UAV-assisted IoT networks or vehicular networks.

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