On the Design of MAC Protocol and Transmission Scheduling for Internet of Things

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Abstract

With the ubiquitous sensing enabled by wireless sensor network technologies, Internet of Things (IoT) is developed to many areas of modern day living. The inexpensive IoT devices and platforms capable of wireless communications enable the ability to measure, infer and understand environmental indicators, from delicate ecologies and natural resources to urban environments. In this paper, we firstly investigate a scalable multimode-based MAC protocol, IoT-MAC, which consists of a channel contention period and a data transmission period, to reduce contention of channel access due to coexist of many IoT devices. Secondly, we study a data transmission scheduling algorithm to maximise data collection under the constraints of radio link quality and remaining energy of the IoT node, while ensuring a fair access to the radio channel. To study the performance of data reception rate, packet loss rate and latency, we evaluate the IoT-MAC and scheduling algorithm with varying data rate and different network scale.

Keywords: Internet of Things; MAC protocol; scheduling; packet reception rate; fairness

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1. Introduction

The emergence of Internet of Things (IoT) and the availability of sensing devices capable of wireless communications enable a wide range of applications in various fields such as smart home [1], smart grids [2, 3], smart city [4, 5], and public transportation monitoring [6, 7]. Figure 1 presents the IoT network structure with the four typical applications. Generally, IoT network consists of a large number of nodes attached to everyday objects, which are connected and managed through wireless communication networks, and cloud-based servers. The distributed IoT nodes self-organise and transmit the sensory data towards one or more base stations (BS) through the wireless channel [8]. A meticulous design of the medium access control (MAC) protocol is key to reach a successful data collection without transmission collision.

Three critical challenges arise in the data collection of IoT networks. The first challenge is a large number of channel accesses from massive amount of sensor nodes in service coverage of a base station (BS). Therefore, a MAC protocol that performs minimum transmission collision and adaptive contending priorities is a key requirement for successful deployment of IoT networks. The second critical challenge is from scheduling data transmission of the nodes since heterogeneous quality of service (QoS) in the network re-
quires the node to obtain hierarchical performances. The link quality of the wireless channel between each node and the BS may vary with time. Having a node transmit during instances when the channel quality is poor is likely to result in packet reception errors, which in turn would require retransmissions and thus increased data collection delay. The third challenge is to guarantee a fair channel access and data collection from the nodes. In particular, the MAC protocol is required to provide the access fairness of devices that failed to compete the transmission opportunities over time. Furthermore, the amount of data collected from each node should be greater than a certain application-specific threshold. This is important to maximise the accuracy of data analysis, for example, in the context of people mobility modelling and population characteristics in smart city.

Random channel access allows the sensor node to transmit data when channel is free, however, there is a high chance of transmission collision and data lost when multiple nodes transmit at the same time. The data collection based on TDMA has a collision-free channel access where each time slot is statically allocated to one specific node. However, TDMA protocol causes a long delay on data collection where the data packet could be dropped due to time sensitivity of the data readings. Conventional transmission scheduling such as the one employed in IEEE 802.15.4 are based on First Come First Served (FCFS), which we refer to as batch processing. Batch processing has limited performance in real-world conditions with irregular radio channels and limited bandwidth. Any node with poor link quality occupies the channel due to retransmissions, while the nodes with higher link quality have to wait. Finally, batch processing does not support data collection fairness, potentially downloading a large amount of data from a small subset of nodes.

In this paper, we propose IoT-MAC, a MAC protocol to maximise packet reception rate and achieve a fair data collection in IoT network. Specifically, a super frame structure of IoT-MAC is designed to utilise a 2-stage communication model, with $p$-persistent Channel Access Period ($p$-CAP) and Scheduled Data Transmission Period (SDTP). The two periods interchange periodically and are synchronised by the BS. $p$-CAP allows the IoT nodes to contend transmission slots with their own priorities, i.e., the contending probabilities. Moreover, to ensure the fairness, if the devices failed in contention at the previous frame, their contending priorities will be raised by increasing the contending probabilities at the next frame. Only successful contending nodes are allowed to transmit data during SDTP that provides TDMA type of data communication. Furthermore, a data trans-
mission scheduling algorithm that schedules transmissions based on both the link quality and the residual energy of each node is implemented in IoT-MAC so that the nodes find their transmission slot within the super frame and only transmit during their scheduled time to prevent interference [10]. Especially, the mobile IoT nodes with mobility do not keep track of the schedule while away from the BS, they only participate when in the range of the BS. We target at single-hop data collection network, where a central node is deployed in a specific area to collect data from the nodes within its radio coverage. Moreover, many recent works have addressed network coverage by optimal nodes placement so that the wireless connection is guaranteed [11, 12]. Finally, we quantify and explain the impact of realistic conditions and standard IoT-MAC configurations on network performances. We also evaluate our enhancements of IoT-MAC by emphasising the gains in terms of data packet reception rate, overall latency of the data collection, and utilisation of time slots.

The remaining of the paper is organised as follows: Section 2 reviews the literature on MAC protocol and transmission scheduling. Network configuration is presented in Section 3. IoT-MAC is described in Section 4. Its performance is analysed in Section 5 considering a star topology with different network scale and various data traffic. Finally, Section 6 gives concluding remarks.

2. Related Work

In this section, we review the literature on MAC protocol and transmission scheduling in wireless sensor network (WSN) and IoT system. We classify MAC protocols into three categories based on channel access mechanism of the sensor nodes: contention-based, reservation-based, and multimode-based protocols.

2.1. Contention-based Protocol

Thanks to the requirement of scalability and simplicity on IoT system, X-MAC that is a preamble-sampling protocol based on Low-Power-Listening (LPL) mechanism was performed over a large scale IoT testbed [13]. LPL reduces energy consumption through duty-cycling, by putting the radio in sleep mode as often as possible and for long periods of time. Therefore, the preamble in X-MAC is split into small strobes, and the sensor nodes decide their schedule independently from their neighbours. Yan, H., et al. presented
a superframe structure of the slotted MAC [14] in IoT environment. A mathematical model first estimates the median access latency of the whole network based on the queue theory. Furthermore, a superframes’ allocation strategy was proposed to minimise the latency while satisfying QoS requirements of the network.

In the context of WSN, to indicate that there is an impending data transmission, a sensor node precedes its data with a preamble that is long enough to be detected by all potential receivers [15]. However, it was known that contention-based MAC protocols with preamble sampling, such as B-MAC and X-MAC, cause significant overheads due to their preambles, and the achievable throughput is limited since the preamble transmission occupies the channel and prevents neighbouring nodes from transmission. Therefore, an asynchronous scheduled MAC (AS-MAC) protocol was proposed in [16]. AS-MAC employs duty cycling to avoid idle listening and uses LPL to minimise the periodic wakeup time. In [17], a duty-cycle MAC protocol (RL-MAC) was presented to analyse and overcome the mismatches between the fair medium access and the un-uniform payload distribution feature in data gathering WSNs among nodes in different position. RL-MAC enhances node-level channel access fairness, and avoids packet loss and buffer overflow incurred by un-uniform payloads, without degrading energy efficiency.

2.2. Reservation-based Protocol

In order to minimise the channel access collision in contention-based protocol, a self-scheduled TDMA MAC protocol, Low-Power Distributed Queuing (LPDQ), for one-hop IoT system was studied in [18]. In LPDQ, LPL is used for network synchronisation, and distributed queuing is used as the channel access mechanism. Moreover, there is no collisions during data packet transmission, and link resources are evenly distributed among nodes in LPDQ due to the TDMA slots allocation. A CCA-Embedded TDMA MAC protocol was proposed to improve the transmission efficiency and system stability in IoT [19]. By adding the CCA slots into a shared transaction slot, CCA-Embedded TDMA reduces the channel access collision of the IoT nodes who are competing for a shared transaction slot. Additionally, a Markov model was proposed to evaluate the efficiency of system throughput and expected delay of CCA-Embedded TDMA.

A correlation-based collaborative MAC protocol (CC-MAC) was investigated for energy conservation and low data collection latency [20]. A centralised node selection algorithm was implemented in CC-MAC to regulate
medium access and prevent the transmission of redundant information from the closely located nodes due to high location correlation. To achieve further energy conservation and faster reporting latency than CC-MAC, a distributed Spatial-Correlation MAC protocol (SC-MAC) was proposed by Bouabdallah, F., et al. [21]. SC-MAC calculates the data amount required from the selected nodes to achieve an information reliability. SC-MAC schedules the selected nodes to stop the data transmission in order to avoid unnecessary energy wastage when the BS receives enough data to attain the required information reliability.

An energy-efficient dynamic TDMA protocol, TRACE, was designed for real-time data broadcasting [22]. TRACE uses dynamic controller switching and schedule updating to adapt to a changing environment and reduce energy dissipation in the nodes. Network lifetime is maximised and different QoS levels are also supported via priority levels. In [23], a MAC protocol that satisfies the time-varying QoS and security requirements was studied. Different from the original TRACE protocol where nodes transmit only their source ID during contention slots, in the MAC protocol, the nodes also upload their remaining battery level during contention period.

2.3. Multimode-based Protocol

A generalised and configurable MAC protocol for WSN, C-MAC, was presented based on a decomposition of traditional protocols of the three major categories, i.e., channel polling, scheduled contention, and TDMA [24]. Given that most of WSNs are event-driven, a MAC protocol, Sift, was proposed to handle spatially-correlated contention, where multiple nodes in the same neighbourhood sense a similar event. Sift uses a geometrically-increasing probability distribution within a fixed-size contention window to schedule slot allocation [25].

A scalable hybrid MAC protocol was proposed for heterogeneous IoT systems in [9]. The hybrid MAC protocol consists of a contention period and a transmission period. The IoT nodes with preset priorities that are given by hierarchical contending probabilities first contend the transmission opportunities with a $p$-persistent CSMA mechanism. The successful nodes are assigned a time slot for data transmission with a TDMA mechanism. The hybrid MAC protocol reduces channel access collision, however, it does not consider to optimise data collection with the constraints in real-world application.
In [10], a scheduling scheme \(\kappa\)-FSOM was investigated for data collection from a continental-scale network of sensor nodes. \(\kappa\)-FSOM maximises the amount of collected data under the constraints of radio link quality and remaining energy of the node, while ensuring a fair access to the radio channel. The data transmission of nodes are scheduled based on a ratio of the link quality and residual energy. This enables the nodes with the lowest energy reserves and the best chance of achieving successful transmissions to transfer their data first. However, the node competes the channel randomly in \(\kappa\)-FSOM causes a large number of channel access collisions.

In this paper, we leverage the complimentary properties of the hybrid MAC protocol (the convention-based \(p\)-persistent CSMA) and the \(\kappa\)-FSOM (data collection maximisation), and propose the design of a novel MAC protocol in IoT system. In particular, our MAC protocol ensures the fairness of both channel access and collected data among all the IoT nodes.

### 3. Network Configuration

We consider a set of IoT nodes \(N\) distributed over a two-dimensional area. They all collect data and transmit the data to a central BS according to a transmission priority. Priority awareness is a significant matter in IoT network as the various data collected by the nodes can have different degree of importance and the resources are limited; so, emergency and highly important data packets should get a better chance to be transmitted. Therefore, we primarily perform a priority classification on the nodes based on the delay and reliability constraints of data packets.

In our network, \(N\) number of IoT nodes are classified to \(G\) groups with appropriate priority \(\{C_1, C_2, \cdots, C_G\}\). Each group of IoT nodes, \(C_i\), is given a probability \(p_i\) which denotes the probability of the nodes contending the channel in RCAP, i.e., the group \(C_i\) with higher \(p_i\) contends the channel in a higher probability. Additionally, the nodes with higher priority has higher \(p_i\) than that with lower priority. The BS calculates contention probabilities \(\{p_1, p_2, \cdots, p_G\}\) for each group. Each node is assigned to one of the \(G\) groups with \(p_i \in [p_1, p_G]\) and \(0 \leq p_i \leq 1\). Moreover, the number of nodes in each group is denoted as \(N_c\) where \(c \in [1, G]\). The residual energy of individual node \(i\) \((i \in [1, N])\) is denoted by \(E_i^0\). In order to prevent a node from completely depleting its battery, we assume that a node powers down if the residual energy goes below a certain threshold \(E^-\). The data payload stored on each node is represented by \(\lambda_i\). In addition, data should be downloaded
from the nodes in a fair way, i.e., the amount of data collected from each node should be greater than a certain application-specific threshold. We define the fairness coefficient as \( k \), \( 0 \leq k \leq 100\% \). Generally, the value of \( k \) is determined by the application, e.g., for the application requiring various sensor data, the amount of data collected from individual IoT node increases with increase in \( k \). Therefore, the data reception fairness is presented by a constraint that the number of data packets the BS collects from each node is not less than \( k \cdot \lambda_i \).

4. IoT-MAC Protocol

In this section, we start by describing the frame structure of IoT-MAC protocol. Then, we develop a channel access control mechanism which considers the operation of the network on a frame-by-frame basis. A data transmission scheduling algorithm is proposed to maximise the collected data with the fairness constraint.

4.1. Superframe Structure

The frame structure in IoT-MAC Protocol utilises a 2-stage communication model, with priority-based channel access period (PCAP) followed by scheduled data transmission period (SDTP). Figure 2 illustrates the proposed superframe structure for the nodes to access the channel, and for the BS to schedule their data transmissions. Specifically, at the beginning of the superframe, a beacon message is broadcasted to the network by the BS. PCAP is based on \( p \)-persistent CSMA mechanism which allows different nodes to contend the channel with their own priorities, i.e., the contending probabilities. The node competes for the channel by broadcasting a \textit{HELLO} message. When multiple nodes send out the message at the same time, a collision occurs. If \textit{HELLO} packets collision happen, the senders have to back off a random time to access the channel again.

BS calculates the transmission schedule at the end of PCAP by running the data collection algorithm that we illustrate in Section 4.3. BS informs all sensor nodes the optimal schedule by broadcasting a special (S) packet, at the end of the PCAP. The S packet provides the time slots that are allocated to the node. Each node only transmits data in the specific \textit{DATA} slots to prevent interference. The length of the \textit{DATA} slots is selected by the scheduler and will typically allow for multiple packet transmissions.
4.2. Channel Access Control Mechanism

Given by $p$-persistent CSMA, if the node with a static contention probability fails to access the channel during PCAP, it loses the transmission opportunities at SDTP since the contention probability does not change. The data of this node is not able to be collected. Therefore, an incremental contention probability for the fairness on channel access is investigated to increase the contending probability of the node frame-by-frame if it failed to access the channel at previous frames. Specifically, a preliminary contending probability $p'_i$ is initialised for each node $i$. If the node $i$ fails to access the channel at previous frames, its contending probability at current frame is increased by Equation (1).

$$p_{i,f} = \max\{1, (1 + \omega)^f p'_i\}$$  

where $\omega$ denotes an incremental indicator. $f$ ($f \in [1, F]$) is the number of frames during which the devices failed in contention. When the node successfully access the channel in a superframe, the contending probability is decreased to $p'_i$ to prevent the node occupies the contention probability.
Figure 3 presents the details of the channel access control in the individual superframe.

![Diagram of channel access control mechanism]

Figure 3: The channel access control mechanism of IoT-MAC protocol.

4.3. Data Transmission Scheduling Algorithm

The energy consumption of nodes arises from the transmissions in PCAP and SDTP. We define $e_{txHELLO}$ and $e_{rxS}$ as the energy consumption of transmitting one HELLO packet, and receiving one S packet of the nodes, respectively. Due to the tiny energy consumption of carrier sensing compared to transmitting and receiving packets, we neglect the same in this paper. The energy consumption of node $i$ in the PCAP is given by

$$E_{PCAP} = e_{txHELLO} + e_{rxS}$$

(2)
We next define $E_{SDTP}$ as the energy that node $i$ consumes on data transmission in all superframes,

$$E_{SDTP} = \sum_{f=1}^{F} \sum_{j=1}^{J} x_{ij}^f \cdot e_{tx}, (i \in [1, N])$$  

(3)

where the $e_{tx}$ represents energy consumption of transmitting one data packet, and $J$ is the number of DATA slots in one superframe. A boolean variable $x_{ij}^f$ is defined as a transmission indicator for node $i \in [1, N]$ associated with the time slot $j \in [1, J]$ in the super frame $f \in [1, F]$. We assume the residual energy of node $i$ at the first superframe is $E_0^i (i \in [1, N])$. Therefore, the residual energy of node $i$ at superframe $f$ is obtained,

$$E_i^f = E_0^i - \sum_{f'=1}^{f} (E_A^i \cdot \varphi_{i}^{f'} + \Delta E_{i,f'}) - \sum_{f'=1}^{f} \sum_{j=1}^{J} x_{ij}^{f'} \cdot e_{tx}$$  

(4)

Due to the prominent effect of residual energy and link quality on the scheduling, IoT-MAC prioritises the nodes for scheduling based on a ratio of the link quality and residual energy, which is given by

$$\eta_i^f = \frac{q_i^f}{E_i^f}, \forall i \in [1, N], \forall f \in [1, F]$$  

(5)

where $q_i^f$ denotes the Packet Reception Ratio (PRR), $q_i^f \in [0, 1]$. Additionally, $q_i^f$ may change from one superframe to the next due to the time-varying channel. We assume $q_i^f$ does not change during the superframe due to block fading.

The scheduling algorithm of IoT-MAC gives a high transmission priority to the node with a large $\eta_i^f$. This method achieves large data reception because for the nodes with the same $q_i^f$, the node with the smallest $E_i^f$ gets higher transmitting priority. Similarly, for the nodes with the same $E_i^f$, one with higher $q_i^f$ has higher priority. Moreover, an energy threshold $E_{id}$ enables the node to stop channel access and data transmission when its residual energy is low. We denote the amount of data collected from node $i$ as $\alpha_i$, and total data volume is $\lambda_i$. The implementation is shown in Algorithm 1. Specifically, at the end of RCAP, the BS is aware of $E_i^f$ and $q_i^f$ of the nodes contending channel. The BS first calculates $\eta_i^f$ for individual node so that the node with the largest $\eta_i^f$ value has the highest priority to transmit data in
SDTP. Next, the BS schedules the node to transmit according to the priority. We denote $\alpha_i$ as amount of data collected from node $i$. If $\alpha_i$ is greater than $(\kappa \cdot \lambda_i)$. The BS does not schedule node $i$ to transmit and allocates slots to other nodes, which ensures a fair data collection. Eventually, when all the nodes in the network fulfil $\alpha_i \geq (\kappa \cdot \lambda_i)$, the BS schedules the node with the highest priority to transmit until its residual energy is below the $E_{td}$. In addition, node $i$ will not be scheduled to transmit once all its data packets have been collected.

**Algorithm 1** Data transmission scheduling algorithm of IoT-MAC protocol

1: The BS calculates $\eta_i^f$ for the node $i$, $\forall f \in [1, F]$
2: The BS sorts the nodes by $\eta_i^f$, then $\eta_i^f \geq \eta_i^{f'}$, ($i \neq i', i', i' \in [1, N]$)
3: if $\alpha_i \geq (\kappa \cdot \lambda_i)$ then
4: The node $i$ is not scheduled to transmit
5: The BS schedules the next one to transmit
6: else
7: The BS schedules the node $i$ to transmit
8: end if
9: if every node has $\alpha_i \geq (\kappa \cdot \lambda_i)$ $\forall i \in [1, N]$ then
10: The BS calculates $\eta_i^f$ for each node
11: The BS sorts the nodes by $\eta_i^f$, then $\eta_i^f \geq \eta_i^{f'}$, ($i \neq i', i' \in [1, N]$)
12: if $E_i \geq E_{td}$ then
13: The BS schedules the node $i$ to transmit
14: else
15: The node $i$ does not access the channel until $E_i \geq E_{td}$
16: The BS schedules the next one to transmit
17: end if
18: if $\alpha_i < \lambda_i$ then
19: The node $i$ is scheduled to transmit
20: else
21: The node $i$ is not scheduled
22: end if
23: end if
5. Performance Evaluation

This section first presents the implementation of our hardware setup. Then, we conduct an experiment to obtain how the contending probability effects on the performance in a small-scale network. To show the network performance, IoT-MAC protocol is further evaluated in a large-scale network by simulations.

5.1. Contending Probability Measurement

We set up a testbed that consists 10 sensor nodes and 1 BS for the experiments, which is shown in Figure 4. Moreover, our BS has two antennas, one for Beacon and S packet’s transmission (Tx) and the other for data reception (Rx). The length of one superframe is 250ms, which means one Beacon message is broadcasted by the BS to the network every 250ms.

We build the node based on a seeeduino microprocessor and a RFBee wireless transceiver. RFBee works in 868MHz and its Baud rate is 9600bps. The transmit power of the node is 10dBm. The length of data payload is 4 bytes, which contains sender address, receiver address, sensory data, and length of payload. Each node has 1000 packets in the buffer to transmit. Note that the data collection experiment stops until all the nodes complete data transmission. The data transmission rate is set to 4.8kbps. The initial contending probability of each node is set to 80%, which indicates the channel access probability.

Figure 5 presents the performance of node’s throughput when we apply \( p = \{0.2, 0.5, 0.7, 0.8, 0.9\} \) for the channel access control. Specifically, the network throughput decreases with a growth of the \( p \) value. The reason is that a large \( p \) value indicates more nodes have the chance to access the channel in PCAP, which increases the channel access collision. Therefore, the number of nodes that are scheduled to transmit data in SDTP is reduced. Moreover, it is observed that upper bound of the network throughput is the total data packets of one node. The reason is that only one node is scheduled to transmit data in SDTP of the superframe due to a small number of nodes communicating with the BS in the experiment.

5.2. Simulations on DATA Scheduling

Extensive MATLAB simulations are carried out to compare the performance of our IoT-MAC protocol with the TDMA protocol and CSMA/CA protocol. In TDMA protocol, DATA slots allocation is static, i.e., the BS
reserves $DATA$ slots for all the nodes in each superframe to ensure every node has the chance to transmit data. Therefore, there is no channel competition in TDMA. However, the nodes in CSMA/CA protocol compete the channel with carrier sensing, i.e., the node transmits data packet to the BS if the channel is sensed as idle.

The length of $Hello$ message and $S$ packet is 10 bytes, and the data payload has 32 bytes. The total number of superframes is 1200, and there are $N$ number of $DATA$ slots in SDTP of each frame ($N \in [5, 30]$). We set that the IoT node has more than $N \times F$ data packets in data buffer so that the node can contend for channel in each superframe during the simulation. The sensor nodes and the BS work in the same frequency band. Moreover, RTS/CTS is used to prevent hidden node. We assume the link quality does not change during the superframe, but may change from one superframe to the next due to the time-varying channel. Therefore, block fading channels with path loss is applied, which is related to the distance between the node and the BS. The nodes are uniformly distributed around the BS within one hop.

We evaluate three performance metrics: network throughput, data collection latency and $DATA$ slots utilisation ($U_{DATA}$). Specifically, data collection latency is the duration from the start of data collection to the end. The maximum value of network latency in our network is set to 100 seconds.
Figure 5: The throughput of the node when $p = \{0.2, 0.5, 0.7, 0.8, 0.9\}$. The total data packets one node transmits is set to 66.

$U_{\text{DATA}}$ denotes the amount of DATA slots used for the data transmission, which is given by

$$U_{\text{DATA}} = \frac{\sum_i^N \sum_{f=1}^F \sum_{j=1}^J x_{ij}}{J \cdot F} \quad (6)$$

Figure 6 shows a comparison of the network throughput. The throughput of IoT-MAC, TDMA, and CSMA/CA increases with increase in the number of nodes. Specifically, the three protocols perform similar throughput when $N = 10$. However, IoT-MAC achieves 28% and 87.9% more data packets than TDMA and CSMA/CA when $N = 30$. This is because IoT-MAC schedules the transmission priority to the node with a large ratio of link quality and residual energy, which gains more data reception. In addition, the data transmission of CSMA/CA is completely distributed, which causes much higher collisions than the other two.

Figure 7 depicts the performance of data collection latency. The network latency of IoT-MAC, TDMA, and CSMA/CA grows with an increase in number of nodes. IoT-MAC achieves 72 seconds less latency than CSMA/CA when $N = 15$. The first reason is that the channel access control of IoT-MAC is based on $p$-persistent CSMA (shown in Equation (1)), where each node has the probability to contend channel for data transmission. The second reason is the data transmission scheduling, which allocates the DATA slots to the
node with high PRR value. Therefore, the retransmission of data packet caused by link failure is reduced. In addition, when $N \geq 15$ (for CSMA/CA) and $N \geq 20$ (for TDMA), latency of the protocols is limited to 100 seconds due to the configuration of the maximum delay.

A comparison of $U_{DATA}$ is shown in Figure 8. The $DATA$ utilisation of the proposed IoT-MAC protocol outperforms TDMA output for 41%. Multiple factors contribute to this behaviour. Firstly, in IoT-MAC, the BS schedules $DATA$ slots in SDTP to the nodes with the packet arrival since they contend for the channel in PCAP. Moreover, the node with high residual energy has priority to transmit, i.e., more slots are allocated to the node who transmits more data. However, TDMA allocates the $DATA$ slots to all the nodes in each superframe. Some slots are wasted since the scheduled node does not transmit data due to no packet arrival or low residual energy. Secondly, IoT-MAC schedules the slots based on $\eta_i$ value, i.e., only the node with high PRR is scheduled. This scheduling algorithm ensures that the BS collects data successfully in each slot in SDTP. However, TDMA reserves $DATA$ slots for all the nodes even when the PRR of some node is low. Moreover, it can also observed that CSMA/CA protocol performs better utilisation than TDMA when $N \leq 10$, because the nodes are able to access the channel successfully. However, the utilisation of time slots in CSMA/CA
drops with an increase of nodes due to more transmission collisions.

6. Conclusion

In this paper, we consider the data collection in IoT network that consists of a large number of sensor nodes and a BS. We have proposed and evaluated a scalable multimode-based MAC protocol, IoT-MAC to control the channel access and schedule the sensory data transmission. The sensor nodes with different contending probability contend for the channel with $p$-persistent CSMA during PCAP, and the successful nodes of channel contention is allocated to transmit in SDTP. Moreover, we investigate a data transmission scheduling algorithm to allocate DATA slots. The algorithm gives the transmission priority to the node based on its residual energy and link quality ratio. We build the sensor node and conduct a experiment for the channel access measurement in a small-scale network. Extensive simulations are carried out to show the network throughput, data collection latency and DATA slots utilisation in a large-scale network.

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Figure 8: The performance of $U_{DATA}$.

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