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Research Article

An Analysis of QoS in ZigBee Network Based on Deviated Node Priority

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ZigBee is an IEEE 802.15.4 standardized communication protocol. It forms a flawless Wireless Sensor Network (WSN) standard for interoperability at all levels of the network, particularly the application level which most closely touches the user. A large number of devices from different vendors can work seamlessly. These devices act as a network and send huge data traffic to the Coordinator. End devices at different zones have different roles in communication with each other. There has been a lack in executing their requests in a synchronized way based on task priority. This lack leads to massive data traffic loss and degrades the Quality of Service (QoS). One of the challenges is to analyze the QoS parameters in ZigBee network that help to detect the overall network performance. The contribution of this paper is twofold; first, a ZigBee Network is implemented based on node priority. It demonstrates a method to generate a new priority of devices with respect to their existing priority and zones' priority as well. Second, the QoS is analyzed based on the new priority status for tasks preference purposes. The outcome of this paper shows that the QoS of the network is more conspicuous than non-priority based network.

1. Introduction

ZigBee is a sensor based special network which pulls the trigger to establish it in wireless network standard. ZigBee was designed to provide high data throughput in applications where the lower duty cycle and power consumption are an important consideration. ZigBee specifications are maintained and updated by the ZigBee Alliance based on the Institute of Electrical and Electronics Engineers (IEEE) Standards Association's 802.15 specifications. It operates under the IEEE 802.15.4 physical radio frequency specification and in unlicensed radio frequency bands, including 2.4 GHz, 900 MHz, and 868 MHz. ZigBee Alliance states that it is often applied in industrial automation and physical plant operation, commercial building automation, home automation, personal, home and hospital care, smart energy, telecom applications, and so on [1–3]. It is frequently associated with machine-to-machine (M2M) communication and the Internet of Things. Internet of Things is the network in which objects are embedded with electronics, software, sensors, and connectivity to enable greater service by exchanging data with other connected devices. Each object is uniquely identifiable and able to interoperate within the existing Internet infrastructure via embedded computing system [1, 4].

However, the sequence of creating and forming a ZigBee network is simple as follows. The personal area network (PAN) Coordinator turns on a ZigBee network; it first looks for a suitable radio channel (usually the one which has the least activity) and then creates the network of self-assigning a PAN ID. When the network is formed, a router or terminal device can bring together the network through a nearby parent node (i.e., the Coordinator or another router) by sending a join request, and the parent can accept or decline the request based on its address space availability and other criteria [1, 5]. Due to ZigBee's network formation simplicity, a gigantic sum of devices can be connected together. The ZigBee Coordinator can conceal 65,535 devices in a single network [4]. The end devices are placed at diverse spots. The

Coordinator may be broken down to operate the network maintaining convenient QoS. The QoS maintenance and measurement are a challenging issue for ZigBee network. Mainly, it refers to the improvement of overall network performance.

Moreover, to increase the network performance a large network was partitioned into several zones or areas. Each zone has priority and containing devices have also local priorities in their corresponding zones. The priority indicates their task's importance. These devices send huge application traffic to the routers and Coordinator for processing. For QoS maintenance, this huge amount of traffic processing and end devices requests synchronization is needed. Priority scheduling is the promising mechanism in this regard. Beforehand, several strategic approaches had been adopted which worked on ZigBee network performance analysis in terms of routing performance and effective data flow and scheduling has been discussed [2, 6–9]. Yet, there is a lack in forming a ZigBee network efficiently. In that respect, further study is required for QoS analysis on ZigBee network as well as improvement of network performance.

This paper evolves new priority for each device considering local device and corresponding zone priority. To the best of our knowledge, this work has not been practiced yet. The goal of this paper is to construct a reliable ZigBee network for device synchronization using the node priority mechanism and study its QoS.

The paper is organized as follows. Section 2 describes the background and related works. In Section 3, the research methodology is described. In Section 4, proposed network simulation and implementation in Riverbed are illustrated. Section 5 evaluates the performance to show that results meet up with the designed objectives. Finally, Section 6 is a conclusion that presents the outcome of this work and suggests future work.

2. Background and Related Work

ZigBee is a sensible network. The ZigBee network gets worldwide popularity for its variety of usages. Since ZigBee is used in various automation system [10–12], therefore, an effective network formation is on demand. Moreover, reliability and effectiveness of a ZigBee network service are assessed based on QoS. QoS is the set of observations of ZigBee network characteristics. According to Chen et al., QoS analysis is the vital measurement of network performance. QoS in wireless sensor and actor networks in the context of critical infrastructure protection (CPI) was presented in the survey paper [13]. In this paper, the characteristics are classified into both user level and low-level specification in the context of the wireless network. The service ZigBee network mainly depends on its formation methods. Among the methods, priority is the most reliable for request scheduling purposes, event handling, synchronization, and so on. Priority based network construction is handy on the performance issue. Priority technique was applied to evaluate performance in terms of balancing energy in the study [1].

According to Islam et al., priority is an effective technique to synchronize requests from different regions. And the network performance is better than without-priority based ZigBee network with tree routing method [14]. The priority based scheme is used for event monitoring. Priority shows efficiency in handling related problematic delay and ensuring delivery of high priority packets analyzed in the article [15]. For home and M2M communication, the total home area is divided into subareas based on potential applications and radio services. And QoS improved in this strategy [10]. Again, QoS was enhanced for the smart grid. In the ZigBee-based smart grid, priority based differentiated traffic service was analyzed in the research [16]. In addition, different routing methods also play a vital role in the QoS issue. Tree, Mesh, and Ad Hoc On-Demand Distance Vector (AODV) had been used in ZigBee network. Besides, the research paper [17] describes an agent assisted routing to ensure better QoS in WSN. Localized routing for QoS of WSNs based on traffic differentiation is illustrated in the study [18]. Furthermore, QoS improvement for IEEE 802.15.4 based wireless body sensor network for health care is analyzed in the research article [19]. Moreover, room storage problem of tree based ZigBee network and neighbor table based shortcut tree routing is analyzed, respectively, in [20, 21].

In accordance with related works, priority is used for efficient network formation. And QoS is highly endorsed to analyze any network. From this context, a motivation comes to build a new priority calculation strategy for ZigBee devices where each device and zone have priority. This new priority is useful for synchronizing ZigBee devices from different zones. Since the new priority technique has not been practiced previously, QoS has been scrutinized to validate the performance of the prospective ZigBee network.

3. Methodology

A literature review is performed to find out the wide range use of wireless sensor network. Based on the literature review, ZigBee is selected to develop its versatile use of forming a smart network for home automation and office automation and performing Internet of Things concept. A careful study is done on how ZigBee performs Internet of Things and how to enhance its QoS. Afterward, an enhanced way has been found in the ZigBee network. In this study, zones and device request synchronization is performed based on the proposed priority method to construct an efficient ZigBee network.

A supported simulation tool was needed to design and implement a complete network model. A deep study has been performed on many simulation tools such as Network Simulator 2 (NS2), Network Simulator 3 (NS3), OMNET++, Riverbed [22], and MATLAB, which support ZigBee network development features. The Riverbed is chosen to design and implement ZigBee network as a simulator for its user-friendly interface and its wide range of acceptance. Moreover, Riverbed simulator provides the fastest discrete event simulation used to evaluate various parameters of network performance [23]. The selected tool is installed in an Intel Core i5 processor-based workstation.

Simulated data are collected properly and carefully from the different ZigBee protocol layer. After analyzing the simulated data, appropriate graphs are plotted. Careful study of the plots is expected to offer a quantitative measure of the effect of different network parameters. Finally, QoS has been measured of the designed ZigBee network analyzing various QoS parameters like end-to-end delays, MAC delay, MAC load, and MAC throughput.

4. Proposed Network Simulation

The section provides an overview of the proposed ZigBee network simulation configuration. Furthermore, it illustrates the analysis of QoS in this ZigBee network for the reliable and robust network.

4.1. Problem Formulation. In this subsection, formulation of the zone synchronization problem is conducted for competing for end devices. At the beginning, the ZigBee network has been marked in different zones. These zones have the same number of devices. In the ZigBee network, various types of end devices are set up in different ranges. All nodes are connected to several routers having a common central processor named ZigBee Coordinator. These nodes try to communicate with other nodes via Coordinator or routers. ZigBee end devices send a large number of requests to the routers or Coordinator and vice versa.

Each zone has a priority value. The higher priority value makes the devices of the zone executed first in the Coordinator. The zones' priority value and execution of these nodes according to the zone value are considered as global processing. On the other hand, every zone consists of numerous ZigBee nodes and each node has to adjust priority values for their local processing. The local processing concerns the end devices application traffic processing based on their respective priority values.

When two or more devices have same local priority how should the application traffic be treated? Moreover, Zone's priority values are different. How the application traffic of two different prioritized devices from two different zones will be processed? This is the primary concern. In this case, which requests are processed first before the others? The central goal of this research is to implement a method for application traffic synchronization of ZigBee nodes based on zone and individual priority and study its QoS.

4.2. Priority Implementation in ZigBee Network. A ZigBee Coordinator is responsible for forming a ZigBee network. End devices and routers have always a distance from ZigBee Coordinator. This distance around ZigBee Coordinator is defined as different area factors. The area factor is called a zone and each zone has many end devices under a router. Each zone has a set of priority attributes for defining its priority. In addition, the end nodes have also priority values in their zone. When nodes of different zones are trying to communicate via intermediate nodes, then routers or Coordinator always checks their priority values. In this mechanism, a child node (end node or router) connects to a parent node according to the child nodes willingness to pay for the connection. The paying preference is considered as a priority. We assume that each end device in the network has a certain willingness to pay and its zone has also a priority. End devices with higher priority zones have a higher willingness to pay and vice versa [1].

Table 1: Proposed zone payment scheme.

Zone name	Unit price	Available nodes
Zone_1	10	node_1, node_18, node_19, node_20, node_21
Zone_2	11	node_2, node_15, node_16, node_17, node_23
Zone_3	12	node_3, node_5, node_6, node_7, node_24
Zone_4	13	node_4, node_8, node_9, node_10, node_25
Zone_5	14	node_26, node_27, node_28, node_29, node_30
Zone_6	15	node_0, node_11, node_12, node_13, node_14

At first, the ZigBee network has been divided into six zones and set the priority values to the corresponding zones. The zones and participating nodes in these zones are listed in Table 1.

In Table 1, Zone_6 has the highest priority value 15 and lowest priority value 10 for Zone_1. The devices in the highest priority zones always get preference at the Coordinator for processing. The corresponding nodes in each zone have set priority value D_P (1, 2, 3, 4, and 5) according to their appearance on the table. This priority value is true for every zone and all participating nodes. Furthermore, a priority resolution technique is described in the following.

4.2.1. Priority Calculation. Locally, the higher prioritized nodes get a chance to send application traffic via a router to the other end devices. There are two sets of priority values. One is zone's priority and the other is an individual node's priority. When end nodes try to communicate beyond their respective zone at the same time, then priority resolution is needed in Coordinator for global access. As the two sets of priorities, a generalization has been done between the individual node and zone priorities. Standard deviation calculation is the process to find out general deviation from a set of values. In this context, standard deviation relates to this two-set priority with the same deviation value [24]. That paves the way for generating new priority for global device-to-device communication. Simply, in the global priority calculation is as follows.

The sum of all device priorities in each zone is

$$S_1 = \sum_{1}^{5} D_P = 15,$$
$$\text{average, } x_1 = \frac{S_1}{N}, \tag{1}$$
$$\text{so, } x_1 = 3,$$

where N is number of elements.

The standard deviation of the device priority values is

$$\sigma^2 = \left(\frac{1}{N}\sum_{i=1}^{N} x_i^2\right) - x_1^2. \tag{2}$$

Here, x_i represents individual node priority values.

The value of standard deviation of individual devices' priority is $\sigma = 1.41$.

The difference (D_i) between individual zone priorities and the sum of all device priorities (S_1) in each zone is as follows:

$$\begin{aligned} D_1 &= S_1 - \text{Zone\_1 priority value}, \\ D_2 &= S_1 - \text{Zone\_2 priority value}, \\ &\vdots \\ D_6 &= S_1 - \text{Zone\_6 priority value}, \\ \text{thus, } D_i &= S_1 - \text{Zone}_i \text{ priority value}. \end{aligned} \quad (3)$$

From the above, the difference is in each zone, respectively, $D_1 = 15 - 10 = 5$. Similarly, $D_2 = 4$, $D_3 = 3$, $D_4 = 2$, $D_5 = 1$, and $D_6 = 0$.

It is clear that Zone_6 has the always highest priority with no difference in total priority of the devices in this zone. As a result, all the devices in Zone_6 have the highest priority the same as the global zone priority value of Zone_6.

Now, consider the other five zones as follows: these zones have different zone values from their total sum-up of the values of corresponding devices. Now, the sum of priority values of Zone_1 to Zone_5 is given below:

$$S_2 = \sum_{1}^{5} \text{Zone}_i \text{ Priority Value}. \quad (4)$$

The sum of the zones priorities is $S_2 = 60$. Thus, the average is $x_2 = S_2/N = 12$.

Again, the standard deviation has been computed according to (2) for the corresponding zone values. Hence, the standard deviation of corresponding zones' priority is $\sigma = 1.41$.

The deviation is the same for both the devices' priority and zones' priority. The standard deviation method has been applied for the two sets of priorities in order to make it generalized for further calculation.

When a node tries to connect globally, then its possibility to be executed in the Coordinator depends on the node's respective priority value and its zone value. As its zone priority value is in a generalized form which is the standard deviation 1.41, it is quite easy to compute the new priority for different nodes in their global participation. The following equation generates new priority for all the participating devices, computing all the individual node priorities along with its corresponding zone priority:

$$N_p = D_P \times \sigma, \quad (5)$$

where N_p is new priority (per device), D_P is corresponding device priority, and σ is standard deviation.

This equation simplifies the early described problems.

4.2.2. New Priority Status. Equation (5) can change the existing priority status. In addition, it helps Coordinator to make the decision for request processing in terms of equal priority devices. Different observations are described below.

Observation 1 (different priority devices). During this observation, a lower priority (node_1) and a higher priority (node_10) device have been considered from Zone_1 and Zone_4, respectively. Initial priorities of node_1 and node_10 are 1 and 4 accordingly. After computing with (5), the new priority (N_p) values are 1.41 and 5.64 for node_1 and node_10, respectively. Therefore, node_10 gets the procession first in this case.

Again, the updated priority scenario has been observed for node_23 and node_29 from Zone_2 and Zone_6. The initial priorities are 5 and 4 for node_23 and node_29 sequentially. After computation, the new priority (N_p) figures have been found at 7.05 and 5.64 for node_23 and node_29, respectively. Though node_23 is from the lower priority zone, the new priority allocates it to get privilege for the first processing compared to node_29 to the Coordinator.

Observation 2 (the same priority devices). This observation mainly concerns the same prioritized devices which are from different zones. Here, both node_5 and node_8 have the same priority in their corresponding zone. The initial priority value is 2 for both the devices. The new priority (N_p) has been computed according to (5) and it has been found to be 2.82 for both node_5 and node_8.

Thus, the new priorities are also equal for both the devices. The Coordinator checks their priority and respective zone priority. Then, the Coordinator gives access to node_8 first because of its higher zone priority. All the zones and their nodes synchronize in this manner.

Equation (5) computes the new priority for every device. Based on these new priorities, ZigBee Coordinator makes a decision when certain conditions arise in synchronizing various device application traffic from diverse zone regarding the above two observations.

4.3. Simulation Configuration. According to the proposed implementation method, a simulation scenario has been created. The scenario consists of a ZigBee Coordinator, six routers, and several ZigBee end devices. After that, all the devices are organized into different zones. The proposed ZigBee network model scenario is organized on the basis of Table 2. The zones and their devices have set of predefined priorities according to Table 1. The new priority calculation has been performed using Riverbed's "Utility" service. The service sets new priority after analyzing communicating devices.

The synchronization of different proposed zones is done on the basis of priority values for processing their nodes request. According to Table 1, the priority values have been fixed for simulation in different zones and their corresponding devices. Almost all the devices were active in communication when Figure 1 had been captured. The node_0 is a central node which is ZigBee Coordinator whereas five routers (node_1, node_2, node_3, node_4, and node_5) are placed at a certain distance from the Coordinator. The routers are intermediary nodes and they hand over the application

Table 2: ZigBee network scenario overview.

Parameters	Descriptions
Number of nodes (overall)	30
Number of Coordinators	1
Number of routers	5
Number of end devices	24
Network dimension	300 m × 300 m
Simulation time	600 sec

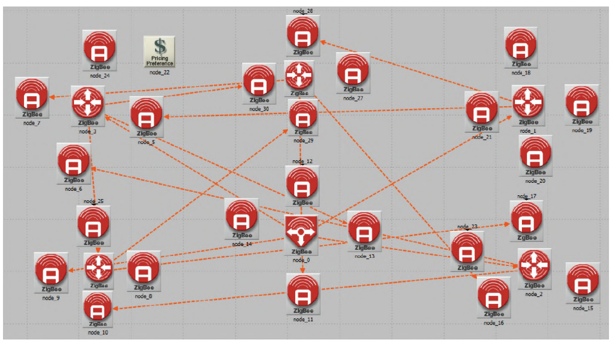

Figure 1: ZigBee network simulation scenario.

traffic to a particular destination. On the contrary, ZigBee Coordinator is a full-function device which is responsible for all functionalities as well as performance issues. After the 600 sec simulation, ZigBee nodes start communication as depicted in Figure 1.

5. Simulation Results

This section gives a detailed description of the analysis of the obtained simulation result. The result is prepared based on the ZigBee's (application and MAC) layer attainment analysis.

The graphs are generated by analyzing different QoS parameters (i.e., end-to-end delay in the application layer, MAC load, and MAC delay in MAC layer).

5.1. With versus without Priority. ZigBee network shows more efficiency on priority mechanism for setting up nodes in various zones of a home or office. If any zone has higher priority, then its activity will increase compared to zones with lower priority or without priority. The investigation of various QoS parameters is in progress for the proposed ZigBee network.

5.1.1. End-to-End Delay. End-to-end delay or one-way delay refers to the time taken for a packet to be transmitted across a network from source to destination.

Delay components are as follows:

$$D_{\text{end-end}} = N\left[D_{\text{trans}} + D_{\text{prop}} + D_{\text{proc}}\right], \quad (6)$$

where $D_{\text{end-end}}$ is end-to-end delay; D_{trans} is transmission delay; D_{prop} is propagation delay; D_{proc} is processing delay; and N is number of links (number of routers + 1).

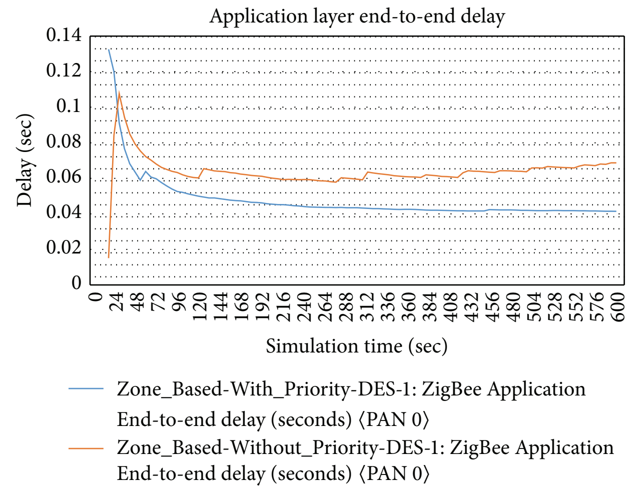

Figure 2: End-to-end delay (sec) for the global model.

Each router has its own D_{trans}, D_{prop}, and D_{proc}. Hence, this formula gives a rough estimate [25, 26].

It describes that when nodes try to communicate with other zones' node, then the request is processed on the priority based mechanism. In this sense, when one node communicates with a node in lower priority zone compared to its priority zone, then the total delay between creation and reception of application packets generated by this node increases.

Figure 2 represents that a global end-to-end delay is higher for network without priority compared to the priority based network. The priority based network faces on average 0.05 sec delay approximately. On the other hand, non-priority based network faces 0.07 sec delay approximately. The average end-to-end delay is slightly higher in the non-priority based network.

5.1.2. MAC Delay. Most of the requests are dropped on the basis of their priority and a limited delay occurs in accessing medium. It represents the total end-to-end delays (sec) of all the packets received by the 802.15.4 MACs of all WPAN nodes in the network and forwarded to the higher layer.

In Figure 3 (both for global network and for Coordinator), it is evident that without-priority based network has slightly higher MAC delay than the priority based network. The average MAC delay in ZigBee Coordinator (node_0) is about 0.12 sec and 0.14 sec for priority based network and without-priority based network, respectively. As a consequence, the average delay in the global network is 0.11 sec and 0.12 sec approximately for the prioritized and nonprioritized network, respectively.

5.1.3. MAC Load. It represents the total load (in bits/sec) submitted to the 802.15.4 MAC by all higher layers in all WPAN nodes in the network. Figure 4 points that without-priority based networks have higher global MAC load than the priority based network. In the priority based network, Coordinator (node_0) processes all the requests. For that

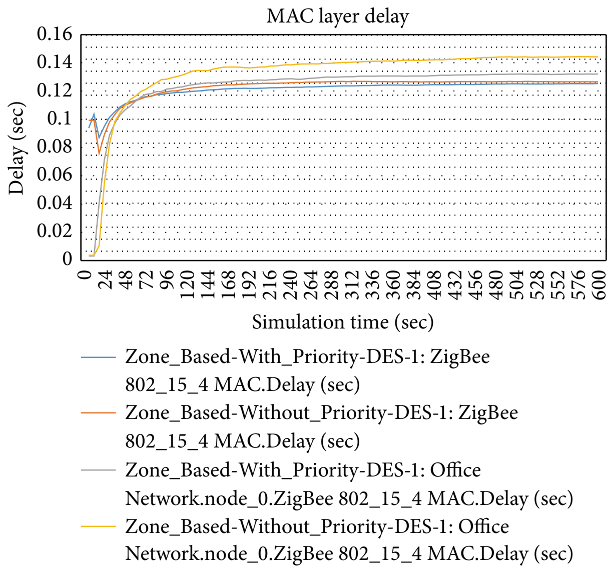

Figure 3: MAC delay (sec) for global model and Coordinator (node_0).

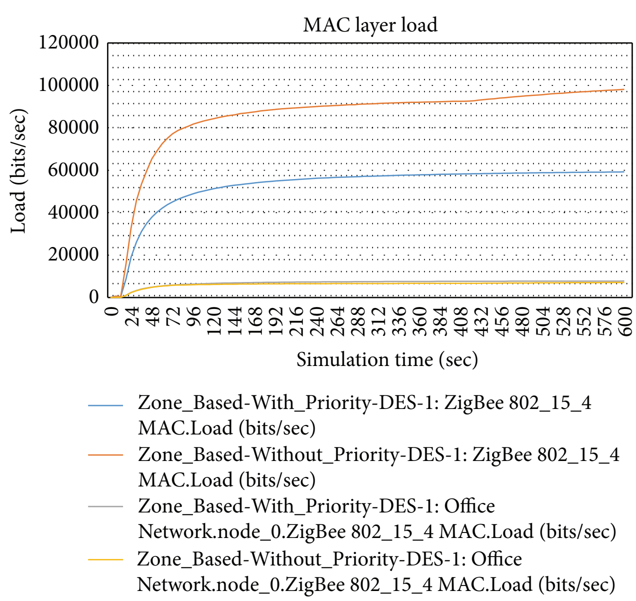

Figure 4: MAC load (bits/sec) for global model and Coordinator (node_0).

reason, priority based networks have more MAC load for Coordinator than without-priority based network as shown in Figure 4.

The MAC load in global network is roughly 9,000 bits/sec and 5,000 bits/sec for without-priority and priority based network. The without-priority networks carry a huge load for lack of node's request synchronization. But Coordinator faces almost similar load in both networks.

5.1.4. Throughput. In the context of a communication network, throughput is the rate of successful message delivery over the communication channel. The priority based network

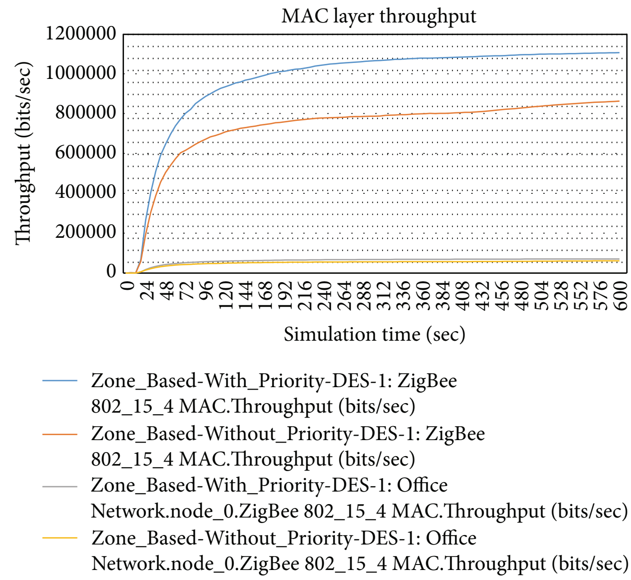

Figure 5: MAC throughput (bits/sec) for global model and Coordinator (node_0).

has high throughputs compared to without-priority based network.

Figure 5 represents throughput for both the global network and the ZigBee Coordinator (node_0) much higher for priority based network compared to without-priority based network.

The average throughput in a global network for the priority based network is almost 1100,000 bits/sec. On the other hand, for the without-priority based network it is only about 700,000 bits/sec. Throughput for the Coordinator (node_0) is relatively higher in the priority based network compared to the without-priority based network.

Various QoS characters of ZigBee network are observed for performance analysis of with-priority versus without-priority mode. Almost in all the statistics shown here, priority based network performance is going prominent compared to without-priority based network.

6. Conclusion and Outlook

This paper presented a set of observations with the emphasis on the priority of different zones and their nodes. The results were obtained by performing a simulation study. This research comes to several conclusions from ZigBee network along with its QoS parameters.

First, application layer's parameter (end-to-end delay) is considered for user level service performance measurement. About 14% less end-to-end delay has been found for the priority based network in the application layer. Second, MAC layer's parameters (MAC load, MAC delay, and throughput) have been considered in MAC performance measurement. In the global network perspective, the priority based network has almost 14% and 44% less MAC delay and load, respectively. Moreover, there was 36% higher throughput compared to the without-priority based network. All the QoS

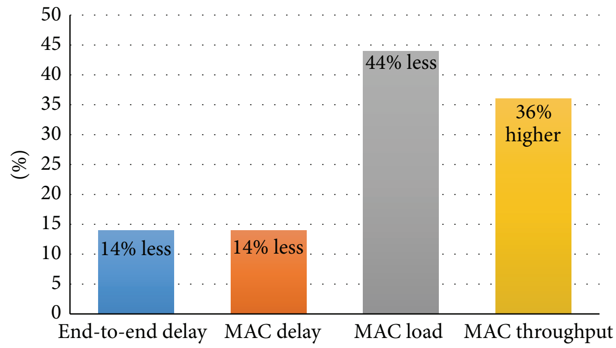

Figure 6: Overall QoS performance summary under proposed scheme.

parameters are shown in a percentage bar graph regarding their QoS improvement as shown in Figure 6.

The analysis of ZigBee layer's parameters contrasts significant response for QoS. After this study, the proposed priority based ZigBee network's performance is identified to be more effective than without-priority based ZigBee network with respect to these improved QoS parameters. The proposed approach is handy in differentiating or synchronizing different zones and their devices with different priorities in the ZigBee network.

The future work will address the ZigBee network performance analysis based on different queuing along with the mathematical model. This is ongoing work, including network latency and an efficient load balancing technique for ZigBee network. Moreover, this work intended to extend to security issue to model a reliable large scale ZigBee network.

Competing Interests

The authors declare that they have no competing interests.

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