PFPS: Priority-First Packet Scheduler for IEEE 802.15.4 Heterogeneous Wireless Sensor Networks

Sambhaji Sarode, Jagdish Bakal

Department of Computer Science & Engineering, G. H. Raisoni College of Engineering, Nagpur, RTM University Nagpur, MS, India

Abstract: This paper presents priority-first packet scheduling approach for heterogeneous traffic flows in low data rate heterogeneous wireless sensor networks (HWSNs). A delay sensitive or emergency event occurrence demands the data delivery on the priority basis over regular monitoring sensing applications. In addition, handling sudden multi-event data and achieving their reliability requirements distinctly becomes the challenge and necessity in the critical situations. To address this problem, this paper presents distributed approach of managing data transmission for simultaneous traffic flows over multi-hop topology, which reduces the load of a sink node; and helps to make a life of the network prolong. For this reason, heterogeneous traffic flows algorithm (CHTF) algorithm classifies the each incoming packets either from source nodes or downstream hop node based on the packet priority and stores them into the respective queues. The PFPS-Earliest Deadline First (PFPS-EDF) and PFPS- First Come First Serve (FCFS) algorithms present scheduling for each data packets using priority weight. Furthermore, reporting rate is timely updated based on the queue level considering their fairness index and processing rate. The reported work in this paper is validated in ns2 (ns2.32 allinone) simulator by putting the network into each distinct cases for validation of presented work and real time TestBed. The protocol evaluation presents that the distributed queue-based PFPS scheduling mechanism works efficiently using IEEE CSMA/CA.

Keywords: wireless sensor networks, priority-based data delivery, buffer management, packet scheduling, heterogeneous traffic flows.

1. Introduction & Background

The IEEE sensor network [1] is an emerging field and nowadays, it is being used widely for small scale applications due to its low resource needs and longer life features [2], and it approximately lasts up to 10 years using AA batteries. To name a few it covers process industry, healthcare [3], transportation, residential projects, tracking, monitoring [4-6] and much more. Thus it creates the scope for active researchers to design the flexible diversified communication network which can handle the multiple event data simultaneously dynamically. Generally, the occurrence of events in LR-WSNs is unpredictable; therefore, having the provision of data delivery mechanism with sensor MAC sublayer becomes an essential and necessary. But, developing a data carrier protocol to address such different aspects altogether is a truly challenging task in low data rate, low power, low processing capability, limited memory, and low transmission coverage network. The sensor network comprises the delay sensitive (for instance, body sensor networks, process assembly, etc.) and delays tolerant (for instance, monitoring, and tracking objects) applications. The existing contention-based protocols, namely S-MAC [7], T-MAC [8], B-MAC [9], X-MAC [10], and Wise-MAC [11] are developed to address the problem of data delivery; still undergoes from the collision, unstable behavior due to sudden traffic load, and topology deviation. In [12], [13], and [14]; the slotted CSMA/CA of beacon-enabled sensor network protocols are presented to mitigate delay of emergency applications. To address these types of applications simultaneously, the complexity level of data processing is handled at various data collection points in the distributed sensor networks using CSMA/CA. Therefore, there is need for improvising the provision of data delivery decision at various intermediate levels instead of at a sink node.

The scope of this paper covers following background cases for the PFPS using EDF (Earlier Deadline First) and FCFS (First-Come-First-Served) algorithm. *Case#1 (Classification of heterogeneous information):* In a mesh topology, many sensing devices are connected at various levels. The unique data is generated by each source node and delivers it via multiple hops. Here, the complexity of data transmission increases, therefore, the classification of data packets sent by networked source nodes to each hop becomes the necessity. Therefore, this case is designed as a part of the categorization of heterogeneous traffic flows algorithm (CHTF). For this reason, the dual queue is implemented to store priority traffic and regular traffic separately.

Case#2 (Priority Assignment): The impact of static priority assignment and dynamic priority assignment over underlying MAC protocol shall be taken into consideration for differentiating the traffics. In FCFS, the priority assignment is kept static which does not change over multiple hops. However, in EDF approach, the priority metric is designed to update priority based on hop distance and delay.

Case#3 (Queuing system for multi-traffic flows): A decentralization approach is the need of IEEE sensor networks which reduces the load on sink node. For this reason, considering middle-level processing nodes i.e. hop performs important job in the dense sensor environments. A packet level in each queue is the key parameter to prevent the buffer overflow. The reporting rate is updated time to time, based on the queue level. The prime objective is to prevent congestion so that a delay sensitive application in the multi-event environment does not suffer. The existing research focuses particularly on improving the packet delivery ratio; however, though it is important; still reducing the sensitive packet loss is also the necessity from the application context. This approach is incorporated at various actor points of the network to shrink weight of a sink.

Case #4 (Reporting rate): Managing the data reporting rate of each contributing source node is a significant topic of research since the inception of LR-WSNs. The problems like packet loss, congestion, an network transmission time, and excess power usage arise due to improper design of reporting rate mechanism. Therefore, to handle heterogeneous traffic flows, the flexible reporting rate mechanism is designed using a dual queue and their processing rate. The key objectives of PFPS protocol are: 1) to reduce end to end delay of long distance priority flows 2) to prevent bottleneck problem, and 3) to increase network life. Figure 1 shows network communication model consisting of multiple hops in-between sensors and the sink node. Hops are considered the additional capability of processing the data packets in addition to receiving and transmitting the packets.

The existing work covers mainly queue management, beacon-enabled slotted CSMA/CA, and beaconless CSMA/CA protocols for low rate IEEE 802.15.4 networks. In [15], congestion control and information prioritization approaches are presented for monitoring real-time data of the patient in wireless biosensor networks. The congestion control approach is applied at parent node whereas priority assignment of network bandwidth is applied over child nodes. The service differentiation is designed according to physical phenomena of a patient. The priority in node (PRIN) MAC protocol [16] is designed to prioritize the information using buffer management with one-hop network topology. The static priority is assigned to each node. RushNet [17] protocol presents traffic prioritization mechanisms for low priority (delay tolerant) and high priority (latency sensitive) types of applications. The throughput is improved using a token passing method to minimize the contention and avoid traffic jam, and multi-hop approach used to trim down the propagation delays.

In [19], the author proposes the packet allocation rate viz., traffic jam discovery and intimation, and congestion control to avoid the buffer overflow problem. ECODA [20] uses dual buffer management approach to achieve the data transmission requirement of transient traffic and locally sensed traffic at each hop level. The congestion problem is resolved using the weighted buffer and flexible queue scheduler to prioritize the information. The PCCP congestion avoidance protocol [21] discusses the node priority index for increasing its significance in the network. It detects traffic jam degree according to packet arrival period and processing rate. In [22], EDF and FP algorithm are presented for urban traffic application with considering the various intersection points of the road. The performance of both algorithms is compared against each other on isolated traffic intersection points. Analysis model illustrates that EDF algorithm performs well against FP algorithm in terms of delay, a number of stops, and means the trip time of priority vehicles. The shortest-first CSMA/CA [23] approach presents the solution for “energy hole problem” near to the sink. The length detection and anti-starvation mechanism are proposed. The nodes that are having the small data size packets are considered as high priority nodes whereas long size data packet holding nodes are defined with low priority nodes. To control periodic flows and network management control flows [24] management using guaranteed time slot approach. In [25], various MAC protocols have been surveyed to understand collision preventing techniques and achieving the greater reliability. A different synchronous, asynchronous, and hybrid protocols are thoroughly studied. This survey helps to design parameters of MAC protocols and existing state of the art work. At the end, authors have also put forth critical issues for open discussions. In [26], MMEDD presented for efficiently delivering the essential information in the wireless sensor networks for optimizing the power consumption. A hybrid operating system Contiki is used due to the low layer called Rime for reducing the energy consumption to the great extent. A pre-emptive multithreading module is applied for managing the multiple tasks parallels. Results are validated comparing with traditional approaches i.e. without multithreading mechanisms. Protothreads are used instead of threads. Authors have made claimed approximately around 9% higher than the classical approach.

The proposed architecture is based on EDF and shows considerable improvements over traditional CSMA/CA MAC protocol. The term sink instead of the base station and actor node instead of hop node are alternatively used in the further discussions.

The contributed strategies are summarized as follows.

- The CHTF algorithm presents the classification of heterogeneous traffic flows. It classifies the packets based on their priority level and stores either in the regular queue or in the priority queue.
- The PFPS proposes the priority first approach using dual queue management with preemptive strategy. The queue levels are defined according to their traffic type. The FCFS and EDF approaches are used for packet transmission to the next level.
- The priority metric is used to update the priority of a packet incrementally towards the base station to service long distance data-first over newly sensed flows at each actor node.
- The mathematical model is designed and developed to make it functional with respect to proposed operational steps of CHTF and PFPS algorithms in the network. Finally, the results are validated by performing various simulation cases in the ns2 (ns2.32allinone) discrete event simulator using CSMA/CA.
- Finally, PFPS is implemented over real time TestBed (6+1) with 24 sensors in total. The performance is examined and compared with the FCFS approach.

The residual sections of this paper are organized as follows. Chapter-2 describes about the proposed PFPS protocol description. Explanation of performance analysis is given in chapter 3. Furthermore, outcomes are concluded and present the future scope.

2. PFPS Protocol Description

2.1 Network Model and Assumptions

A communication model comprises source nodes, hop, and the base station. A source node is responsible for only sensing, delivering and receiving the information to and from its upstream node. A hop node and sink node are capable of sensing, processing, receiving, and transmitting the information. There are two main types of flows to be considered for protocol design, namely priority traffic flow (for e.g. O_2 saturation level) and regular traffic (for e.g. temperature). The size of data packets for both traffics is same. The nodes are placed randomly and AODV routing protocol is used for network formation. Each level i.e. at hop node, two queues is designed to store the regular and priority-based traffics. The incoming traffics are put in respective queues and are managed using First Come First Served (FCFS) mechanism or Earliest Deadline First (EDF) mechanism. A variable fairness index is achieved using PFPS algorithm. A classification of heterogeneous traffic flow (CHTF) algorithm performs filtration of incoming packets of different traffic flows and stores either in priority traffic queue or regular traffic queue. In overflow condition, data packets are not stored in the queue. In PFPS algorithm, transmission priority is given more to the priority-based traffic of queue-2 at each hop. Considering the sensitivity or criticality of a particular traffic flow, it is necessary to deliver at the earliest. For this reason, the decision of priority packet transmission is taken based on queue condition. However, if delay sensitive packets are not delivered within a deadline, then the data becomes useless or network usage is turn out and considered as wastage of resources. Therefore, PFPS algorithm is proposed to address the delay and deliver packets using effective use of queuing operations to the great extent. Descriptions of mathematical terms are explained in Table 1.

2.2 PFPS Protocol Implementation

In this section, two algorithms are discussed, namely CHTF and PFPS. In order to implement the priority based data transmission approach, the design of two queues is presented. The queues are priority queue and regular queue implemented on the hop. The regular queue is designed for regular traffic flow (for example, temperature) and priority queue is designed for priority traffic flow i.e. time constraint packets (for example, O_2 saturation level monitoring) as shown in algorithm-1. Based on different input flows; the fairness index is examined. If the applications are having hard timing constraints then queue would be developed from priority perspective which will be a better option to achieve the deadlines. Each queue is comprised of different traffic(s) at a given time at hop is described in equation (1). The total traffic load ($T_{f_{k,q_i}}$) at hop k, either q_1 or q_2

$$T_{f_{k,q_i}} = \sum_{\substack{type=reg,pri \\ i=1,2}} \left(T_{type}, q_i\right) \tag{1}$$

Where let q_i be a queue either type 1 (regular traffic) or 2 (priority traffic), $i = \{1, 2\}$.

The total incoming traffic load on any particular hop node ($T_{total,k}$) using both queues is as described in equation (2).

$$T_{in,k} = \lambda_k = \sum_{\substack{1 \le r \le m; q=1 \\ 1 \le p \le n; q=2}} T_{inf}\left(r_q; p_q\right)$$

$$= \sum_{q=1,2} \left(\sum_{r=1}^{m} (T_{inf_r}, 1), \sum_{p=1}^{n} (T_{inf_p}, 2)\right) \tag{2}$$

The quantity of packets delivered by a hop is expressed in equation (3).

$$T_{out,k} = \mu_k = \sum_{\substack{1 \le r \le m; q=1 \\ 1 \le p \le n; q=2}} T_{outf}\left(r_q; p_q\right)$$

$$= \sum_{q=1,2} \left(\sum_{r=1}^{m} (T_{outf_r}, 1), \sum_{p=1}^{n} (T_{outp}, 2)\right) \tag{3}$$

The remaining number packets in both queues are defined as T_{rem} at a particular instance as measured in equation (4).

$$T_{rem} = \lambda_k - \mu_k \tag{4}$$

The overall probability of packet processing of any particular hop is mentioned in equation (5).

Table 1. Summary of Mathematical Notations

Term	Definition	Term	Definition
T_{type}	flow type	T_{rem}	remaining packets in queues
T_{f_r}	regular traffic flow	p_k	priority of k^th hop
T_{f_p}	priority traffic flow	μ_{k,q_i}	average incoming packet rate in a queue i
q_i	queue includes 1 and 2	λ_{k,q_i}	average outgoing packet rate in a queue i
k	number of hops	q_i^l	lower limit of queue i
$T_{f_{k,q_i}}$	traffic flow at hop k in a type queue i	q_i^u	upper limit of queue i
$T_{in,k}$	incoming traffic at k^{th} hop	q_i^{max}	maximum limit of queue i
$T_{out,k}$	outgoing traffic at k^{th} hop	q_i^{size}	size of queue i
T_{inf_r}	incoming regular flow	R_r	reliability of regular traffic
T_{inf_p}	incoming priority flow	R_p	reliability of priority traffic
T_{outf_r}	outgoing regular flow	$\alpha, \beta, \gamma,$	queue processing tuning parameters
T_{outp}	outgoing priority flow	δ_{a_i}	additive & multiplicative increase tuning parameters
m	number of regular traffic nodes	δ_{b_i}	additive & multiplicative decrease tuning parameters
n	number of priority traffic nodes	η, η_1, η_2	packet count variables
r_q	regular traffic in queue-1	$\mathcal{n}$	range variable
p_q	priority traffic in queue-1	f_l	reporting frequency level
ω, σ	Priority weight parameters (0.5,0.05)	ε_{con}	Energy consumption for all control packets
		T_{proc}	Node processing time
ε_{cd}	Energy consumed for data & control packets	ε_{proc}	Energy for processing

$$P_k = \frac{\mu_k}{\lambda_k} \le 1 \tag{5}$$

The probability of each hop is computed individually to examine the affecting attributes of both queues separately. The probability of q_1 and q_2 for hops ($k = 1,2,3, \dots, n$); (P_k) are as explained in equation (6). The probability of processing packets at each stage of the hop is defined in decreasing order according to success rate. The values move from 1 towards 0, when the hop count goes higher because of traffic load for each flow. However, the decreasing factor is less in the case of priority traffic flows. The distance of one hop indicates that connected node to hop one is a one hop farthest from a sink node.

$$P_k \ge P_{k-1}, P_{k-2}, \dots, \ge P_2 \ge P_1;$$

$$P_k(hops) = \frac{\left(\frac{\mu_1}{\lambda_1} + \frac{\mu_2}{\lambda_2}, \dots + \frac{\mu_{k-1}}{\lambda_{k-1}} + \frac{\mu_k}{\lambda_k}\right)}{h_c} \tag{6}$$

The overall average probability of all contributing hops is stated in equation (7).

$$P_{hops} = \frac{\sum_{hops=1}^{k} \frac{\mu_{hops}}{\lambda_{hops}}}{k} \le 1 \tag{7}$$

The objective function is enhancing priority based traffic ratio simultaneously maintaining a fairness index at a reasonable level. This approach is designed in the viewpoint of heterogeneous nature of LR-WSNs. In order to handle them simultaneously, the queuing system plays a non-trivial role to attain a target of each specific event requirement. For that reason, dual queue model is designed which is based on number of packets in regular and priority queues, defined as η_1, η_2 respectively.

The frequency rate is updated based on the buffer level and processing rate, as expressed in equation (8).

$$\gamma_1 \le n \le 1; \left(\left(1 \le \frac{\mu_{k,q_1}}{\lambda_{k,q_1}} \le \alpha_1\right) || \left(1 \le \frac{\mu_{k,q_2}}{\lambda_{k,q_2}} \le \beta_1\right) || \left(1 \le \frac{\mu_{k,q_{1,2}}}{\lambda_{k,q_{1,2}}} \le \gamma_1\right) \wedge ((q_1^u \le \eta_1 < q_1^{max}) \; || \; (q_2^u \le \eta_2 < q_2^{max})) \right); (a1, b1)$$

$$\alpha_2 \le n \le \gamma_2; \left(\left(1 \le \frac{\mu_{k,q_1}}{\lambda_{k,q_1}} \le \alpha_2\right) || \left(1 \le \frac{\mu_{k,q_2}}{\lambda_{k,q_2}} \le \beta_2\right) || \left(1 \le \frac{\mu_{k,q_{1,2}}}{\lambda_{k,q_{1,2}}} \le \gamma_2\right) \wedge ((q_1^l \le \eta_1 < q_1^u) || (q_2^l \le \eta_2 < q_2^u)) \right); (a2, b2)$$

$$\alpha_3 \le n \le \gamma_3; \left(\left(1 \le \frac{\mu_{k,q_1}}{\lambda_{k,q_1}} \le \alpha_3\right) || \left(1 \le \frac{\mu_{k,q_2}}{\lambda_{k,q_2}} \le \beta_3\right) || \left(1 \le \frac{\mu_{k,q_{1,2}}}{\lambda_{k,q_{1,2}}} \le \gamma_3\right) \wedge ((0 \le \eta_1 < q_1^l) || (0 \le \eta_2 < q_2^l)) \right); (a3, b3)$$

$$otherwise; (b4) \quad (8)$$

The various conditions of queue level and processing rate are a1 to a3 as described below.

The additive increase (from case a1 to a3) is applied in the following cases.

a1: $f_{l+1} \leftarrow f_l * \delta_{a_1}, \gamma_1 \le n \le 1$;

a2: $f_{l+1} \leftarrow f_l * \delta_{a_2}, \alpha_2 \le n \le \gamma_2$;

a3: $f_{l+1} \leftarrow f_l * \delta_{a_3}, \alpha_3 \le n \le \gamma_3$

The multiplicative decrease is applied in the following cases from b_1 to b_4.

b1: $f_{l+1} \leftarrow f_l / \delta_{b_1}, n < \gamma_1$; b2: $f_{l+1} \leftarrow f_l / \delta_{b_2}, n < \gamma_2$;

b3: $f_{l+1} \leftarrow f_l / \delta_{b_3}, n < \gamma_2$; b4: $f_{l+1} \leftarrow f_l / \delta_{b_4}$

Let α, β, and γ be the tuning parameters for achieving the desired reliability of traffic flows. The values of α are 0.93, 0.66, and 0.33 of α_1, α_2, and α_3 respectively. The values of β are 0.96, 0.766, and 0.5 for β_1, β_2, and β_3; respectively. Let γ be processing tuning attribute with different values such as 0.945, 0.716, and 0.415 for γ_1, γ_2, and γ_3 respectively. Finally, the values of δ_a are 1.05, 1.10, 1.15 for $\delta_{a_1}, \delta_{a_2}$, and δ_{a_3}; respectively and the values of δ_b are 1.15, 1.10, 1.01 for $\delta_{a_1}, \delta_{a_2}$, and δ_{a_3}; respectively. However, the value of δ_{b_4} is 1.20.

The priority metric (p_{wt}) is used to compute the priority level of each outgoing packet at actor node. The static priority or previous priority is considered and its delay (d) from originating node to current node is taken into consideration. The hop count (h_c) indicates the number of hops away from the base station. It is expressed in equation 9.

$$p_{wt} = p_{wt} + \frac{\omega h_c}{\sigma d} \quad (9)$$

For example,

$p_{wt}(5) = 1 + \frac{0.5*5}{0.05*0.013} = 3.55$

$p_{wt}(4) = 3.55 + \frac{0.5*4}{0.05*0.017} = 5.81$ And so on.

Algorithm-1 (CHTF): It classifies all incoming packets according to their priority level and stores into respective queues. There are mainly two queues designed, the queue-1 is for regular traffics, for example, temperature and queue-2 are for priority traffic, for example, O_2 saturation level detection.

Algorithm-1 (CHTF): Classification of Heterogeneous Traffic Flows

Input: $(T_r, T_p) <: T_{type}$
Output: $q_{1,2} \leftarrow T_{type}$
Prerequisites: Priority Assignment to each packet of different traffic flows during packet formation at source node i.e. RFD
Begin

```
η ← 0; η1 ← 0; η2 ← 0;
do
 η = η + 1;
  If((Tr ∈ Ttype)∧(η1 < q1^max)) do
   q1 ← q1 + Tr; η1 = η1 + 1;
   elseif((Tp ∈ Ttype)∧(η2 < q2^max)) do
     q2 ← q2 + Tp; η2 = η2 + 1;//
  end if
while(Ttype! = NULL)
end do − while loop
```

End

They are categorized into two types of flows, namely priority traffic flow and regular traffic flow. The overall incoming rate η is maintained for various cases mentioned in PFPS algorithm as well as making the decision of delivery rate with respect to load on both queues. The individual packet level (η_1, η_2) for each queue computed separately in order to fasten the data transmission based on lower, upper, and maximum threshold levels. The packet delivery preference is given first to priority-based traffic i.e. O_2 saturation level data as it is considered to be an important and critical of queue-2.

However, while transmission of packets the fairness index is achieved at great extent by managing the queuing decision within threshold limits. Before storing into the respective queue, each packet and the queue limit is checked. This process is continued until packets are coming at each hop.

Algorithm-2 (PFPS): The various levels of regular and priority queues are expressed in point a1 and a2, respectively.The levels are the part of PFPS design in order to maintain every hop from congestion free with the priority-first approach. For this reason, the queue level differentiation is taken into account. The purpose is to serve the emergency traffic first or delay sensitive traffic-flow first instead of delay tolerant traffic. Moreover, the queue level thresholds are defined according to the type of flow. The more weight is given to high priority flow instead of regular traffic. The threshold limit is increased little over the limits of regular traffic queue just to get more time for data packet delivery. In addition, the one level up facility is also preferred to high priority traffic queue. Both queues are defined with three levels, namely lower limit, upper limit, and maximum limit.

Algorithm-2(PFPS): Priority First Packet Scheduler

Input: $(\boldsymbol{T_r} \in \boldsymbol{q_1})||(\boldsymbol{T_p} \in \boldsymbol{q_2})$

Output: traffic flow based reliability i.e. $(\boldsymbol{R_r}, \boldsymbol{R_p}) <: \boldsymbol{R_{type}}$

Prerequisites: Priority Assignment to each packet of different traffic flows during packet formation at source node i.e. RFD

Begin

do

$if\ (((\eta_1 \le q_1^l) \wedge ((\eta_2 \le q_2^l)||(q_2^l \le \eta_2 \le q_2^u)))\ do$

$\quad \text{transmit}(T_p) \leftarrow q_2;\ \text{dequeue}(T_p); \eta_2 = \eta_2 - 1;$

$elseif(((q_1^l < \eta_1 \le q_1^u)||\ (q_1^u < \eta_1 \le q_1^{max})) \wedge (\eta_2 \le q_1^l))do$

$\quad transmit(T_r) \leftarrow q_1;\ dequeue(T_r); \eta_1 = \eta_1 - 1;$

$elseif((q_1^u < \eta_1 \le q_1^{max}) \wedge ((q_2^l \le \eta_2 \le q_2^u)||(q_2^u < \eta_2 < q2max))$

$\quad drop(T_r) \leftarrow q_r; \eta_1 = \eta_1 - 1; //\ until\ it\ goes\ below\ q_1^u\ level$

$\quad transmit(T_p) \leftarrow q_2;\ dequeue(T_p); \eta_2 = \eta_2 - 1;$

$elseif(q_1 == empty \wedge q_2! = empty)\ do$

$\quad transmit(T_p) \leftarrow q_2;\ dequeue(T_p); \eta_2 = \eta_2 - 1;$

$elseif(q_1!! = empty \wedge q_2 == empty)$

$\quad transmit(T_r) \leftarrow q_1;\ dequeue(T_r); \eta_1 = \eta_1 - 1;$

$end\ if$

$while((q_1||q_2)! = empty)$

End

The decision is depended on the number of packets in each queue. However, the processing rate of the queue is also computed to ensure the transmission of data packets using CSMA/. The data transmission bandwidth limit is set to 250kbps according to standard in protocol configuration. The levels of the queue are defined as follows.

$$q_1^{max} = \left\lceil \frac{2.8}{3} q_1^{size} \right\rceil;\ q_1^u = \left\lceil \frac{2}{3} q_1^{size} \right\rceil;\ q_1^l = \left\lceil \frac{1}{3} q_1^{size} \right\rceil \quad (10)$$

$$q_2^{max} = \left\lceil \frac{2.9}{3} q_2^{size} \right\rceil;\ q_1^u = \left\lceil \frac{2.3}{3} q_1^{size} \right\rceil;\ q_1^l = \left\lceil \frac{1.5}{3} q_1^{size} \right\rceil \quad (11)$$

These various levels of the queue are used for transmitting the appropriate data packets.

The overall energy consumption (ε) is the sum of energy consumed in various steps involved during in-network processing, as described in equation (12). The energy consumption is directly proportional to energy consumed for transmission of data and control packets (ε_{cd}); and processing overheads (ε_{proc}) at a node.

$$\varepsilon_{total} = \varepsilon_{cd} + \varepsilon_{proc} \quad (12)$$

The energy consumed in waiting time (P_{wt}) is the time required to gain the channel access by performing the number of times backoff (T_{bckoff}) i.e. symbols used, as mentioned in equation (13).

$$\varepsilon_{wt} = T_{bckoff} * P_{wt} \quad (13)$$

The total power transmit of a node is the sum of total number of packet transmitted (D_{pkt}) multiplied by the power consumed for each outgoing data packet (P_{tx}), as expressed in equation (14).

$$\varepsilon_{tx} = D_{pkt} * P_{tx} \quad (14)$$

The total energy consumed for data packets at a node is computed using two parameters, namely power consumed (P_{rx}) for a single receiving packet and total number of data packets received (η_{pkt}), mentioned in equation (15).

$$\varepsilon_{rx} = D_{pkt} * P_{rx} \quad (15)$$

The total energy consumed for network control packets (ε_{ctrl}) of a node is the sum of number of packets (CP_{ctrl}) handled and power taken for receiving and transmitting each packets, as expressed in equation (16).

$$\varepsilon_{ctrl} = CP_{ctrl} * (P_{rx} + P_{tx}) \quad (16)$$

The overall energy consumed (ε) is the addition of energy consumed of data packets and control packets, as described in equation (17).

$$\varepsilon = \varepsilon_{tx} + \varepsilon_{rx} + \varepsilon_{ctrl} \quad (17)$$

The energy consumption for packet processing at a node depends on how much time it takes to process per unit time, as stated in equation (18).

$$\varepsilon_{proc} = \varepsilon_{con} + T_{proc} \quad (18)$$

3. Performance Analysis

3.1 Simulation Setup & Result Discussions

The simulation experimentations were conducted in the ns2 simulator (2.32 ns-allinone version). The network parameters ion and setting are summarized in Table 2. The simulations are performed by varying number of nodes, interval time, and simulation time. The each network performance metric is validated in different distinct cases. Figure 1-3 describes energy consumption over varying node densities, interval time, and simulation time period. It is observed that 18% less average energy is consumed compared with the FCFS approach, as shown in figure 1 , 12% less average energy is consumed over different time intervals as described in figure 2, and 9% less average power is utilized over different simulation time setup as depicted in figure 3.

Table 2. Network Attribute Summary

Attributes	Values
Sensing region	500x500m^2
Static Nodes	100,125,150,175
Simulation time	75-200 seconds
Transmission range	30m
Average hop count	5
Packet size	30byte
Transmit Power	0.6w
Receive power	0.3w
topology	flat grid
Node placement	Random
Antenna Type	Omni Antenna
Propagation type	Two Ray Ground
PHY Type	IEEE 802.15.4
MAC	CSMA/CA
Radio bandwidth	128kbps
Initial Energy	15J

It is achieved using efficient data transmission mechanism and observations state that the FCFS mechanism fails to attain target goals due to lacks in considering the hop count and delay attribute. The congestion is prevented using queuing operations effectively. As traffic load decreases with varying the interval period, it is noted that the both protocols consume less energy. Moreover, the maximum consumption is observed around 3 Joules over different simulation time, interval period, and node densities.

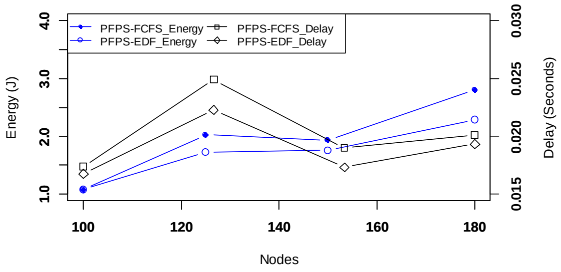


Figure 1. Analysis of energy and delay between PFPS-EDF and PFPS-FCFS algorithms over variable node densities

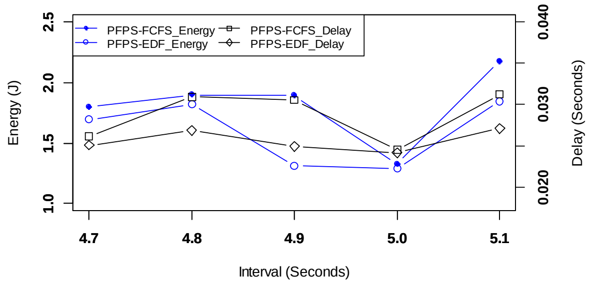


Figure 2. Analysis of energy and delay between PFPS-EDF and PFPS-FCFS algorithms over different time intervals

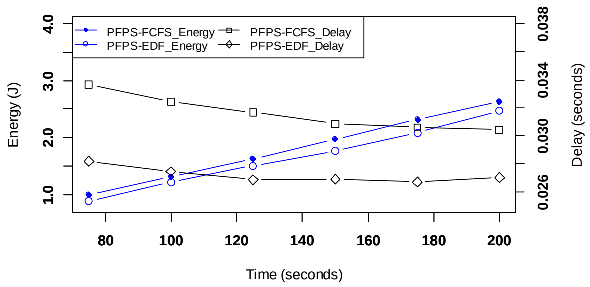


Figure 3. Analysis of energy and delay between PFPS-EDF and PFPS-FCFS algorithms over different simulation times

Figure 1 to3 plot variation of average delay of PFPS-EDF and PFPS-FCFS algorithms. We observed that less delay experienced in different period. Observations state that optimal rate of packet processing is necessary to address the packet propagation time. Due to effective queuing operations, overhead of packet retransmission is minimized. Moreover, though the delay gap is small still it is considerable from delay sensitive or critical application perspective. The difference is noted due to priority handler and queuing system for serving the long distance with high priority weight packets. This minimizes the extra packet processing overheads due to queue overflow situation. It is addressed to the great extent by dynamically handling the reporting rate. Thus results in less traffic and their collision too.

PFPS-FCFS mechanism does not have provision of consideration of different traffic with their weight factor. Thus our proposed PFPS mechanism performs greater in terms of higher PDR, less power usage and less transmission time. As compared with PFPS-FCFS, it can be noted in figure 1, 7% less delay over different node densities, in figure 2, 10% less delay over different time intervals, and in figure 3, 14% less delay over different simulation times.

Figure 4 to 6 explain analysis of PDR of PFPS-EDF over PFPS-FCFS algorithm. Figure 4 plots approximately average 5% higher than the PFPS-FCFS approach over varying number of nodes. The greater PDR ratio is achieved due to dynamism in packet delivery mechanism and handling the packet processing rate effectively. The observed difference illustrates that the packet drop ratio is reduced using earliest deadline approach. This approach is designed with priority metric which comprises mainly hop count and packet delay.

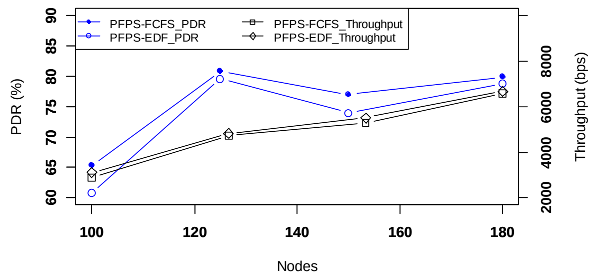


Figure 4. Analysis of packet delivery ratio and throughput between PFPS-EDF and PFPS-FCFS algorithms over different nodes

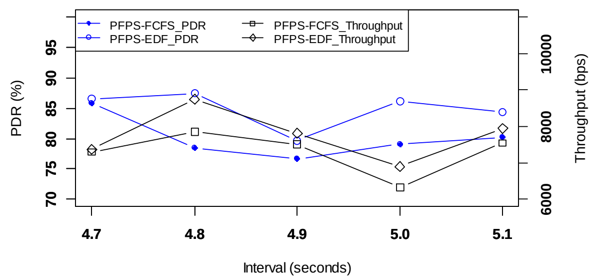


Figure 5. Analysis of packet delivery ratio and throughput between PFPS-EDF and PFPS-FCFS algorithms over time intervals

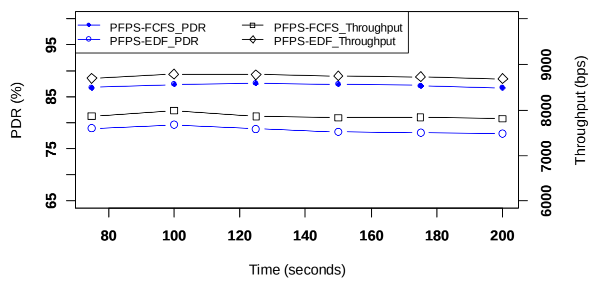


Figure 6. Analysis of packet delivery ratio and throughput between PFPS-EDF and PFPS-FCFS algorithms over different nodes

It reduces the packet drop ratio of long distance traveled packets otherwise newly sensed packets get an early chance for getting served than them. Thus it hampers the PDR ratio. This approach is designed with the consideration of sensitive traffic with more count, should not be hampered during in-network processing, however, FCFS mechanism lacks in packet categorization. Afterward, the protocol is tested by changing the interval period and still manages to show on an average 5% higher PDR ratio as shown in figure 5. The average PDR of PFPS-EDF over variable simulation time is 10% greater than PFPS-FCFS algorithm as depicted in figure 6.

As shown in fig. 4-6, PFPS-EDF achieves higher throughput than the PFPS-FCFS. The average throughput performance goes around 4% as illustrated in figure 4. The significant performance is shown due to optimal packet delivery is maintained throughout the simulation time. To validate its performance it is tested over different simulation time by keeping the same network setup of 101 nodes. In addition to that, it was shown noteworthy performance over different interval period too. It is observed that it performs 6% better over the FCFS mechanism as described in figure 5. Moreover, the proposed performance is tested over different simulation time period and it is noted around 10% greater than a PFPS-FCFS algorithm as shown in figure 6.

3.2 TestBed Setup & Result Discussions

The 2.4GHz RF of Nordic [26] is used for transmitting the data over the air and to process each incoming and outgoing packets, the Arduino Nano development board [27] is used. It operates over 2.4 – 2.4835GHz and maximum 2Mbps data rate it supports but however, considering the HWSNs data rate standard, we evaluated our protocol over the 250kbps data rate speed.

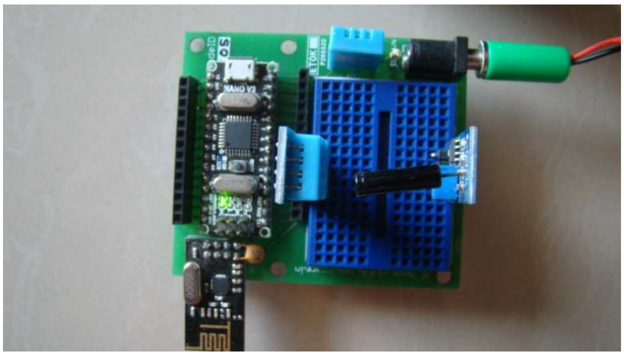


Figure 7. Top view of physical view of RF node which is used for experimentation

Furthermore, the nRF module has some inbuilt features such as automatic packet handling, selective retransmission, and auto acknowledgment. It has six logical data pipes. The modulation technique is GFSK. To manage the voltage level we used the 16MHz crystal. The packet size is 32 bytes out of which 25 bytes are used for payload.

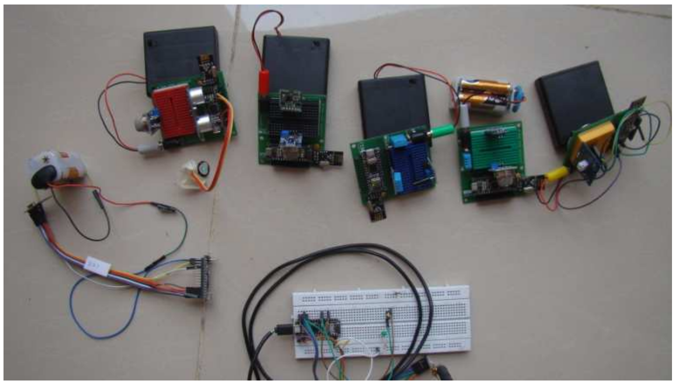


Figure 8. A top view of TestBed (used for experimentation)

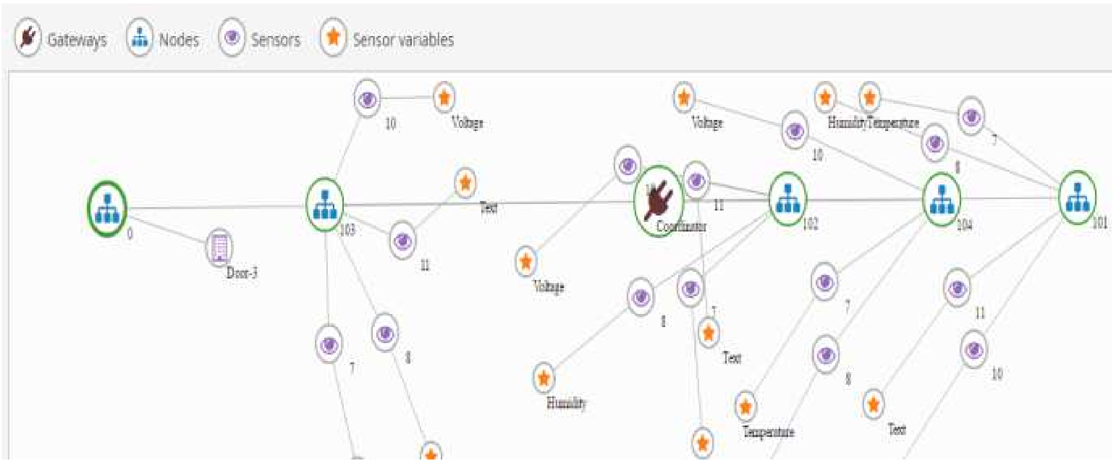


Figure 9. A view of dynamic topology formation at the run time

A delay bound is set to 200ms. The fundamental architecture uses the FIFO queue for scheduling the data packets. The RF node is depicted in figure 7.The TestBed setup includes 8 sensing nodes and one RF coordinator. In addition, the sensor cloud is setup to check the performance of each active node of the network. This online monitoring tool helps to check the packet delivery ratio, energy consumption, and throughput too. Furthermore, it gives the run time dynamic pictorial representation of the entire topology. It is easy to check, which node is connected with whom and how far it is from the base station. Any node can be set to the air by sending the appropriate command to it. Proposed algorithm is experimented and analyzed with the TestBed configuration as shown in figure 8. Furthermore, the dynamic view of the hop by hop topology is depicted in figure 9. Figure 10 and 11 depicts packet delivery ratio and throughput analysis for the PFPS-EDF algorithm against the PFPS-FCFS algorithm. It is observed that it performs well by incorporating the priority approach at various routing node to deliver the sensitive data first over the regular traffic.

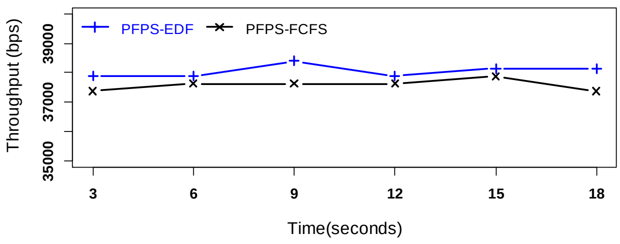


Figure 10. Comparison of network throughput over variable time period

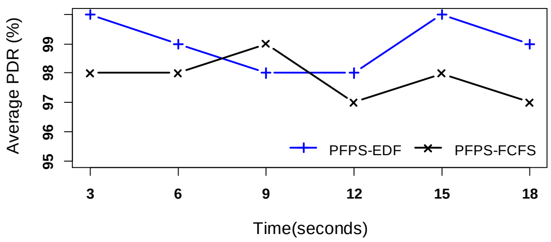


Figure 11. Analyzing of packet delivery ratio by varying experimentation time over average 3 hop topology

Furthermore, we tried to generate maximum traffic to test an outcome of proposed scheme over hop by hop mechanism. The distributed approach of PFPS-EDF has shown significant countable performance for the analysis though the TestBed setup was small in size. But we increased the number of sensing devices to each node. On an average, each node was equipped with 4 sensing devices which helped to generate the more traffic for data packet categorization at the various hop nodes. Hence we could able to end with the reasonable amount of heterogeneous traffic for examining the proposed work. The average packet delivery ratio is 99% which is greater than the PFPS-FCFS mechanism (97%) over different experimentation timing. Due to distributed approach, the less packet drop is observed. Thus throughput improvement is noted around 288bps which is higher as compared with the FCFS approach.

Figure 12 and 13 plots the energy consumption and delay of the network. We set up the cloud solution to maintain the track of battery level of each sensor node. The energy consumption is computed in terms of percentage (i.e. 1.9% which is lower than the 2.10% FCFS mechanism) dynamically during the experimentation as depicted in figure 12.

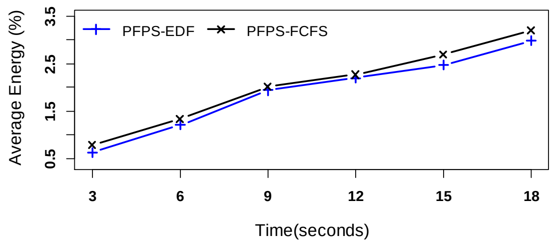


Figure 12. Analysis of average energy consumption over different experiment time

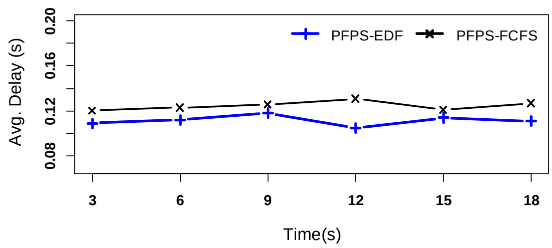
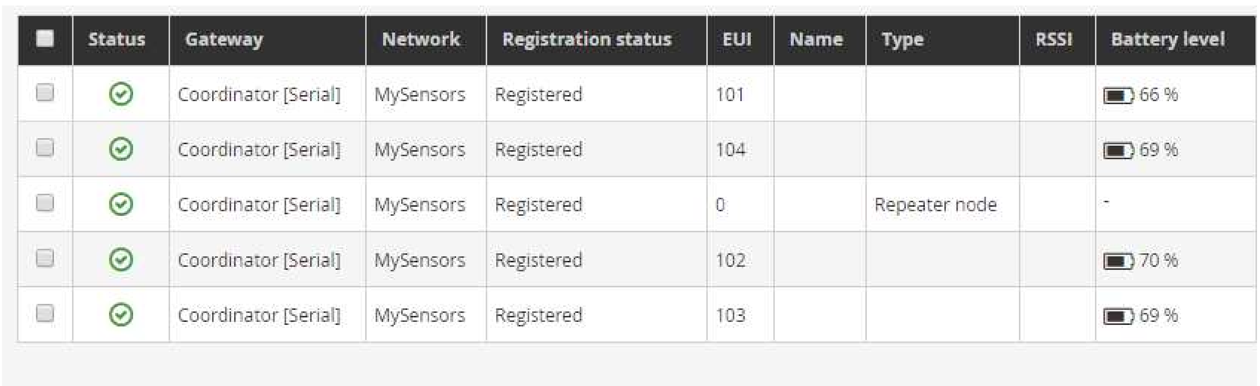


Figure 13. Analysis of average delay over different experiment time

It is observed that the less energy consumption due to less packet drop. Therefore, the retransmission overheads are greatly reduced. The long distance packets get higher priority as they travel toward the base station. Due to this efficient technique, the less delay is experienced. The variation in delay is noted around 0.0135 seconds over the FCFS approach. A cloud solution energy consumption at a glance as depicted in figure 14.



	Status	Gateway	Network	Registration status	EUI	Name	Type	RSSI	Battery level
		Coordinator [Serial]	MySensors	Registered	101				66 %
		Coordinator [Serial]	MySensors	Registered	104				69 %
		Coordinator [Serial]	MySensors	Registered	0		Repeater node		-
		Coordinator [Serial]	MySensors	Registered	102				70 %
		Coordinator [Serial]	MySensors	Registered	103				69 %

Figure 14. Energy consumption analysis view captured at the run time using cloud solution

4. Conclusion

The presented work is useful for multi-event sensor networks. The CHTF algorithm performs the job of data packet scrutinizing with respect to priority type and its distance travelled in terms of a number of hops crossed by the each traffic flow. The priority-first scheduling algorithms are examined using a dual queue, particularly for simultaneously heterogeneous traffic flows in the sensor network. The reported work proves that the designed algorithms over queuing system work well and is suitable for the prioritized data transmission applications in real time environments over regular traffic flow. The queuing system is designed a bit flexible for incorporating and maintaining the significance of regular data flow at earliest to a great extent. However, for delay sensitive applications the fairness index could be compromised in order to achieve the required data transmission within time window otherwise it becomes useless or harms the human if application type belongs to body sensor networks. In simulation setup, 5% to 10% PDR improvement is observed whereas in TestBed environment, 99% PDR. This problem would be taken into account using enhanced adaptive flexible queuing system with slotted CSMA/CA of LR-WSNs in future.

5. Acknowledgments

We wish to extend our thanks to all anonymous reviewers for the valuable constructive comments and their precious time.

References

[1] IEEE Standard 802.15.4. IEEE Standard 802.15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs).Available:http://http://standards.ieee.org/getieee 802 / download /802.15.4-2015.pdf.

[2] I. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, "A survey on sensor networks," IEEE Commun. Mag, Vol.40, No. 8, pp. 102–114, 2002.

[3] Y. Wang, L. Li, B. Wang, L. Wang, "A body sensor network platform for in-home health monitoring application," in: Proceedings of the 4th International Conference on Ubiquitous Information Technologies Applications (ICUT'09), pp.1–5, 2009.

[4] C., Deji, N., Mark, M., Aloysius, "WirelessHART Real-Time Mesh Network for Industrial Automation," Springer, 2010.

[5] W. Z. Song, B. Shirazi, R. Huang, M. Xu, N. Peterson, R. La Husen, J. Pal-lis er, D. Dzurisin, S. Moran, M. Lisowski, S. Kedar, S. Chien, F. Webb, A. Kiely, J. Doubleday, A. Davies, D. Pieri, "Optimized autonomous space in-situ sensor web for volcano monitoring," IEEE. SelectedTop. Appl. Earth Obs. Remote Sens, Vol.3, No.4, pp. 541–546, 2010.

[6] L. Rodriguez-Peralta, B. Teixeira Gouveia, D. J. Gomes de Sousa, C. DaSilva Alves, Enabling museum' environmental monitorization based on low cost wasns, in: Proceedings of 10th Annual International Conference on New Technologies of Distributed Systems (NOTERE), pp.227–234, 2010.

[7] W. Ye, J. Heidemann, D. Estrin, "An energy-efficient MAC protocol for wireless sensor networks," in Proc. 21st Ann. Joint Conf. IEEE Computer and Communications Societies (INFOCOM'02), pp. 1567–1576, 2002.

[8] T. van Dam, K. Langendoen, "An adaptive energy-efficient MAC protocol for wireless sensor networks," in Proc. 1st Int'l Conf. Embedded Networked Sensor Systems (SenSys'03), pp. 171–180, 2003.

[9] J. Polastre, J. Hill, D. Culler, "Versatile low power media access for wireless sensor networks," in Proc. 2nd Int'l Conf. Embedded Networked Sensor Systems (SenSys'04), pp. 95–107, 2004.

[10] M. Buettner, G.V. Yee, E. Anderson, R. Han, "X-MAC: a short preamble MAC protocol for duty-cycled wireless sensor networks," in Proc. 4th Int'l Conf. Embedded Networked Sensor Systems (SenSys'06), pp. 307–320, 2006.

[11] A. El-Hoiydi, and J. D. Decotignie, "Low power downlink MAC protocols for infrastructure wireless sensor networks", Mobile Networks and Applications, Vol. 10, No. 5, pp. 675-690, 2005.

[12] T. Kim, S. Choi, "Priority-Based Delay Mitigation for Event-Monitoring IEEE 802.15.4 LR-WPANs", IEEE Communications Letters, Vol. 10, No. 3, pp. 213-215, 2006.

[13] L. Sitanayah, C. J.. Sreenan, K. N.. Brown, "A hybrid MAC protocol for emergency response Wireless Sensor Networks", Ad Hoc Networks VOl.20, pp. 77–95, 2014.

[14] M. H.. Gilani, I. Sarrafi, M. Abbspour, "An adaptive CSMA/TDMA hybrid MAC for energy and throughput improvement of wireless sensor networks," Ad Hoc Networks 11, pp. 1297–1304, 2013.

[15] M. H.. Yaghmaee, N. F.. Bahalgardi, D. Adjeroh, "A Prioritization Based Congestion Control Protocol for Healthcare Monitoring Application in Wireless Sensor Networks," Wireless Personal Communications, Vol. 72, No. 4, pp. 2605–2631, 2013.

[16] A. Subramanian, I. Paramasivam, "PRIN: A Priority-Based Energy Efficient MAC Protocol for Wireless Sensor Networks Varying the Sample Inter-Arrival Time," Wireless Personal Communication, Vol. 92. No.3, pp. 863–881, 2017.

[17] C. J.. Liang, N. B.. Priyantha, J. Liu, F. Zhao, "RushNet: Practical Traffic Prioritization for Saturated Wireless Sensor Networks," SenSys '14 Proceedings of the 12th ACM Conference on Embedded Network Sensor Systems, pp. 105-118.

[18] A. Saifullah, Y Xu, C. Lu, and Y. Chen, "Priority Assignment for Real-Time Flows in WirelessHART Networks," 23rd Euromicro Conference on Real-Time Systems, pp. 35-44, 2011.

[19] R. S. Uppal, S. Kumar, and S. Singh, "A reliable and congestion control protocol for limited power wireless sensor networks," Int. J. Systems, Control, and Communications, Vol. 6, No. 2, pp. 153-166, 2014.

[20] L. Q.. Tao, F. Q.. Yu, "ECODA: Enhanced Congestion Detection and Avoidance for Multiple Class of Traffic in Sensor Networks," IEEE Transactions on Consumer Electronics, Vol. 56, No. 3, pp. 1387-1394, 2010.

[21] C. Wang, B. Li, K. Sohraby, M. Daneshmand, "Upstream Congestion Control in Wireless Sensor Networks Through Cross-Layer Optimization," IEEE Journal On Selected Areas In Communications, Vol. 25, No. 4, pp. 786-795, 2007.

[22] A. Ahmad, R. Arshad, S. A.. Mahmud, G. M.. Khan, H. S.. Al-Raweshidy, "Earliest-Deadline-Based Scheduling to ReduceUrban Traffic Congestion. IEEE Transactions On ntelligent Transportation Systems," Vol. 15. No. 4. pp. 1510-1526, 2014.

[23] W. Guanhua, W. Kaishun, M. Lionel, "CSMA/SF: Carrier Sense Multiple Access with Shortest First," IEEE Transactions on Wireless Communications, Vol. 13. No. 3, pp. 1692-1702, 2014.

[24] M. Colota, L. Gentile, G. Pau, G. Scata, "Flexible IEEE 802.15.4 deadline-aware scheduling for DPCSs using priority-based CSMA-CA," Computers in Industry 65, pp. 1181–1192, 2014.

[25] M. Guerroumi, A. K.. Pathan, N. Badache, S. Moussaoui, "On the Medium Access Control Protocols Suitable for Wireless Sensor Networks – A Survey," International Journal of

Communication Networks and Information Security (IJCNIS), Vol. 6, No. 2, pp. 89-103, 2014.
[26] MMEDD: Multithreading Model for an Efficient B. O.. Yenke, D. W. Sambo, A. A.. Ari, A. Gueroui, “Data Delivery in Wireless sensor networks,” International Journal of Communication Networks and Information Security (IJCNIS) Vol. 8, No. 3, pp. 179-186, 2016.
[27] Network Simulator 2 (NS2). http://www.isi.edu/nsnam/ns.
[28] http://www.nordicsemi.com/eng/Products/2.4GHz-RF
[29] https://www.arduino.cc/en/Guide/ArduinoNano