VSRS: Variable Service Rate Scheduler for Low Rate Wireless Sensor Networks

Sambhaji Sarode[1,2], Jagdish Bakal[1]
[1]CSE, GHRCE, Nagpur, RTM University Nagpur, MS, India.
[2]Faculty at CE, MITCOE, SPPU, Pune, India.
{sambhajisarode, bakaljw}@gmail.com

***Abstract*— This paper proposes a variable service rate scheduler VSRS for heterogeneous wireless sensor and actuator networks (WSANs). Due to recent advancement, various applications are being upgraded using sensor networks. Generally, traffic consists of delay sensitive and delay tolerant applications. Handling such traffic simultaneously is a critical challenge in IEEE 802.15.4 sensor network. However, the standard CSMA/CA does not focus on traffic-based data delivery. Therefore, this paper presents a solution for priority-based traffic over no-priority i.e. regular traffic using CSMA/CA IEEE 802.15.4 MAC sublayer. The VSRS scheduler uses a queuing model for scheduling incoming traffic at an actor node using a dual queue. The scheduler updates priority of each incoming packet dynamically using network priority weight metric. The VSRS scheduler scans queues and picks the highest network priority packet. A packet weight is updated after selection from the respective queue. This core operation of an actor node offers good packet delivery ratio, throughput, and less delay experience of long distance traveled packets against no priority traffic. The work is validated using theoretical analysis and computer generated network simulators; proves that the priority based approach using weight factor works better over the First-Come-First-Serve (FCFS) mechanism.**

***Index Terms*— transport; scheduling; reliability; priority; wireless sensor networks; reliable data transmission; deadline**

I. INTRODUCTION

Gathering the accurate information from the supervised area is a non-trivial job for preserving an energy and data reliability in any industry. In particular, data delivery is a prime focus of any distributed wireless sensor network [1], [2]. Nowadays monitoring and controlling are two essential areas useful in daily life and industrial automation. The low information rate, low energy and low-budget Wireless Sensor and Actor Network (WSAN) play a vital role for short distance applications. However, multifunctional sensor nodes collect variety of data, e.g. temperature, location, speed, humidity, power consumption, etc., while actors perform various tasks like reporting rate, reprioritization of transient information, buffer specific decision for data collection and transmission, energy utilization in routing, and channel access [3]-[8]. Despite having many advantages, still, WSN technology is not used widely for many critical applications; due to less awareness or inherent limitations. Typically, WSN is preferred for monitoring the environmental conditions, in addition to this, it is self-configurable and self-adjustable, long life network, and low budget setup. IEEE 802.15.4 protocol suite supports collision-free environment [9]. The guaranteed time slot (GTS) is very useful for transmission the priority-based real-time traffic for the particular cause [10].

The dedicated slots assure less delay and high reliability in data delivery. Typically, star, mesh, cluster and tree-based topologies are mostly used [11]-[13] in wireless sensor network applications. However, the beacon-enabled and non-beacon network is configured according to the specific requirement of each application. For this reason, the un-slotted and slotted CSMA/CA mechanisms are used [14]-[15].The priority-based data acquisition approach is presented in this article for WSANs in a supervised area. It consists of information prioritization and scheduling over multiple-hop networks [10], therefore, we discuss few problem cases in succeeding section to understand the root causes in detail before we proceed towards the discussion of the reported solution.

A. Problem Discussions

Case#1: In event specific supervised sensor area, reporting sensor information to the desired location with minimum resource utilization is a crucial job. However, according to the type of task, procedures need to be incorporated into data transmission control protocol in heterogeneous sensor environment, sometimes performance of the network hinders due to bad link quality in an obstacle-real time environment. Reference protocols of data reporting approaches describe different ways of data delivery schemes namely, First-Come-First-Serve (FCFS), Earliest-Deadline-First (EDF) preemptive scheduling, and non-preemptive scheduling. In FCFS, a task which comes first gets served irrespective of its type, deadline, and priority. In EDF, the shortest-job is serviced first in preemptive priority scheduling. When the system is busy in executing the current task and at the same time if high priority task comes, then it schedules the new task. After successful execution of higher priority task, the control is resumed to low priority task. However, in non-preemptive scheduling approach, even if the current task is having lower priority and it is in process of execution still it is not interrupted by high priority. Many data carrier protocols have been invented to address the task specific needs. Recent work investigation and its target aware requirements have shown the augmentation into scheduling based data delivery schemes especially for time critical, emergency services, long lasting traffic, the physical condition of the human body, earthquake detection, fire detection, heartbeat counting, etc. Current research focus includes energy efficient scheduling techniques, scheduling of varied transient traffic, flexible priority based scheduler for real and non-real time data, and scheduling using routing technique. The scheduling process should be incorporated into the MAC protocol for proper functioning. The research work highlights two ways for handling the data transmission scheme which includes packet-level scheduling and queue management.

Case#2: Managing collaborative data gathering is a challenging job due to sudden bulk transmission, congestion, node failure, and unfairness contribution of nodes for packet injection into the network. Sometimes event specific reliability requirement gets hampered due to lack of packet transmission approaches to each individual event in the system design model. In the Industrial Wireless Sensor Network (IWSN) individual traffic generates its own requirement; therefore, common data delivery mechanism fails. Data delivery along with fulfillment of the constraints and transmission of actual payload at the same time becomes the primary focus of any data carrier protocol. The data carrier should have the provision of variable data transmission requirements in the emergency situation.

In IWSN, individual traffic has its own requirement; therefore, common data delivery mechanism fails to fulfill. Achieving data delivery with satisfying constraints is the prime focus of any data carrier protocol in industrial application. A data carrier should have the provision of variable data transmission requirements to handle an emergency situation.

Typically, scheduling includes periodic data scheduling and event-based data scheduling. In the event based network, sensor readings comprise emergency traffic, time-critical traffic, and collective traffic gathering.

Our strategies of priority are summarized as follows.

- The VSRS presents the packet scheduler which transmits the priority packet first over the regular traffic packets. As a result, priority event node experiences less delay against traditional approaches.
- The priority weight metric is designed to update the priority of packets dynamically on an actor node. It performs well over the fixed priority approaches.
- A mathematical model is designed and developed to regulate the network flow. Furthermore, the presented work is simulated and validated in various scenarios over multi-hop sensor topology using theoretical analysis and computer-generated simulations (ns2 simulator).

The objective of the VSRS algorithm is to provide service to long distance high priority events first, minimizing the energy utilization and improving the network life.

The residual sections of this research article are organized as follows: Section II gives the abstract view of the reference protocols providing the insights to all active researchers working at communication protocol level and investigated specific parameter. Section III describes the VSRS traffic scheduler and architectural overview of the algorithm. Section IV illustrates the performance analysis of proposed scheduler. And finally, work is summarized and presents the future directions. The actor word is used interchangeably for hop node and the base station is used for sink node.

II. Reference Protocols

This section describes various data scheduling approaches for delay sensitive, time critical events, and emergency events. Summary of comparative study is presented in table 1. This brief overview basically gives the insights of data scheduler in distinct cases for heterogeneous flows. The purpose of this study is to understand and apply the knowledge of scheduling mechanism in enormous industrial applications using RF based communication module. A study includes the working of buffer management and operations of GTS with CSMA/CA, un-slotted CSMA/CA, GTS-TDMA, cross-layer delay responsive and fairness approach. The earliest deadline first with fixed priority presents the traffic control at intersection point [16]. Proposed methodology contributes in reducing the mean trip time and average delay. It helps to calculate the number of stops. It is designed to make the transportation system intelligent. The idea is to collect the information of traffic condition time to time and takes the decision of changing signal timer. The traffic signal time is calculated at every moment according to the situation of traffic. This approach is developed to reduce the waiting time, unnecessary delays and delays for servicing the high priority vehicles. The variation [14] in data transmission is achieved by designing the scheduling mechanism to control the priority level and data rate. The scheduling mechanism is incorporated into MAC protocol to prevent the overhearing messages and unnecessary listening. The purpose is to reduce the delay while improvising the network life. However, priority weight is not addressed.

The MSS approach is configured in every cluster with different configurations of a Beacon Interval (BI) and Superframe Distribution (SD). For scheduling the Superframe, four different steps are followed namely cluster partitioning, scheduling in the first time slice, calculation of the time slice boundaries, and scheduling the cluster in ST_2. The time division and the multichannel approach are utilized for Schedulability and scalability of the network. Depending upon the time slices of different clusters the different channel allocations are considered. The IEEE 2006 version MAC 802.15.4 is modified. The modification mainly includes the radio with the multichannel approach.

The flow balanced schedule approach is presented in [16]. This approach is designed with the GTS-TDMA mechanism to address a problem of rate differentiation in the class of traffic. The transmission rate is different according to their priority level with respect to time criticalness and its severity. Typically with higher priority, higher rate delivery is observed in many communication protocol designs. The weighted tree is formed and proposed theorem gives the proof of congestion control. In every interval, relay node transmits the required number of packets in specified time interval irrespective of other quality parameters of the network. It has been observed that to achieve the desired target in each cycle, two times packets are held in a buffer which unnecessarily increases the overheads of the network and reduces overall network lifetime. Therefore, protocol rules are defined by considering the superframe duration, a number of cycles, and stride in every cycle and so on. The approach mainly measures the maximum number of SDs are required by every node. Using Poisson distribution GTS-CSMA/CA gives the better performance as compared to normal CSMA/CA mechanism. The analysis illustrates that the scheduling of SDs in parallel and alternation gives the better performance.

In [5], research focuses mainly on delay sensitive traffic and packet prioritization by proposing two approaches, namely delay responsive cross-layer (DRX) and Fair-delay aware cross-layer (FDRX). DRX method works with MAC basic operations and performs delay estimation and data prioritization functionalities for smart grid environment.

Table 1
Comparative study of reference work

Protocol Name	Network Evaluation Attributes	Methodology	Applications
PCS [4]	500x500m, 50 nodes, 50s, Mesh, PDR-91%, NS2-AODV	PCS	Surveillance/ emergency
DRX & FDRX [5]	Nodes-40, 300 seconds, Beacon – star, QualNet, Multi-event	DRX, FDRX	Delay sensitive
RPDT [6]	500m,50 nodes, 50s, Mesh, DDR-96%, NS2-AODV	RPDT	Critical events
MSS [14]	C6, Tslice- 251.3s, Beacon – PAN, DDR- App. 93%, ZigBee/ TinyOS platform, Multi-event network	Actor approach, Collision control	Emergency & Critical applications
GTS-TDMA [16]	40 nodes, 1ks-CSMA, 2ksec-traffic, Star, 10meter distance in-between nodes, High, 40-180 packets in each interval, ZigBee platform	Priority scheme, Collision approach	Time bounded applications
QPSM [18]	Class-10,8,6,4 & Channel-6, Grid topology, DDR-90%, Actor approach, MATLAB & OPNET	QPS	Critical events
MSRD [19]	Area-50x50m, Expt. time-100s, PAN-Mesh, ZigBee platform, Actor Approach	ABWC & VCA	Security/emergency
PPSM [20]	360x360m, 300 nodes, 600s, Mesh, Only for HPT, Actor approach, NS2-AODV	PPSM	Delay constraint events

Authors have proposed that FDRX method achieves fairness of information transmission to prevent unfairness to access channel. In DRX, when current delay exceeds the predefined limit of the application then it uses the CCA i.e. clear channel assessment method. In FDRX, fairness approach is incorporated to meet the delay and as soon as its current delay goes above the threshold variable then that particular event automatically becomes higher priority event to gain channel access. However, DRX and FDRX protocols assure the delay requirements of the target application. These two approaches are used for transformer screening, capacity bank control, and fault current indicator. The CSMA/CA protocol is used with exponential backoff to reduce collision. The delay estimation algorithm was introduced to reduce the in-network processing time of end to end packet transmission. In MAC sublayer, the CCA reduction technique is used. The analytical model for slotted CSMA-CA mechanism is enabled with beacon mode of the IEEE 802.15.4 described in [1]. The path loss models, namely, empirical model and deterministic path loss model are used. Two ray path loss model is used for outdoor environment especially for the transformer in a substation where two signal paths are used, one for "sensor to sink node" and another for "a metal object of the ground". The resulting analysis describes the DRX and FDRX schemes that reduce the latency in the network by negotiating the packet loss to some extent in real time scenarios.

In [18], authors have proposed the novel technique of packet scheduling for cognitive radio sensor network. Traditional traffic scheduling approaches fail to provide the guarantee to achieve the quality of services to diversified classes. Because of existing protocol design considerations are lagging to cover the diverse essential requirements of heterogamous data traffic. Therefore, prioritization model is designed for initial data classification. Two main challenges are taken into account for protocol design which consists of classification for heterogeneous services and routing strategies specifically for smart grid traffic. The communication constraints are considered in terms of delay, data rate, and reliability. The proposed channel quality evaluation method is used for frequency estimation by considering three aspects, namely, reliability, connectivity, and stability of the network. And the third scheme which is priority-based packet scheduling for different classes using dynamic channel selection to enhance the system utilization and service quality. The flexible priority adjustment strategy (FPAS) performs a priority assignment to every application. Initially, the default priority is assigned and during in-network processing, it is readjusted using priority function. However, to make interference free environment for a primary user, a preemptive technique is used.

In [19], un-slotted CSMA/CA based multi-rate based service differentiation (MRSD) proposed to support particularly for rate sensitive applications in wireless sensor networks. The main contribution is adaptive back-off window control (ABWC) and virtual collision avoidance (VCA) algorithms. The ABWC transmission technique is used to achieve the desired reporting rate of target application whereas VCA approach is applied to make the collision free environment to prevent the transmission rate degradation and preempts packets with a minimal utility. The packet preemption strategy works in two modes, namely, no packet preemption and packet preemption. In a case of no packet preemption, it does not guarantee to service high priority packet flow first. In the preemptive mode, even if low priority packet is being processed still it gets preempted when high priority packet comes in the network during execution.

Chen et al. proposed [12] ZigBee-based reliable data transmission protocol for wireless patient monitoring. The anycast multi-hop ZigBee-based network configuration is used to reduce the transmission delay and network overheads. The reliable transmission scheme is used for fall monitoring, fall detection, indoor positioning, and ECG monitoring. Due to anycast mechanism if the base station fails, then it automatically finds the nearest base station and rebuilds the new network path in an unreliable ZigBee-based network for emergency services. To improve the reliability the anycast procedure is incorporated in AODV protocol by introducing two additional messages, namely, DATA and ACK. Initially, control overheads are equal in three modes: multicast, broadcast and anycast mechanism but gradually with the increase in a data receiver, more control overheads are found in multicast and broadcast mode compared to anycast mode. When data receivers are 10 and 40 nodes then there is a difference of 20 control overheads. It is observed that difference in searching time is noted around 2ms between anycast and other routing procedures over 40 nodes experimentation setup. When it increases, suddenly it goes down rapidly. The energy utilization of each communication node is approximately 27mA (without LED light blinking). The packet delivery ratio is better in the early stage of experimentation. In case of anycast routing, it is up to 3 data receivers later, it becomes almost same for increasing number of data receivers. The end to end transmission delay of SMS for GSM; ECG for GPRS, UMTS, and WiMAX is approximately 40, 22, 8, and 5 seconds of 2G, 2.5G, 3G, and 4G cellular systems, respectively. Thus, 4G technology is better option to use for medical emergency services.

In [20], a priority based approach based on the signal strength and distance is proposed. The protocol is designed with consideration of important packets (high priority) and less important information (low priority). When events occur in a supervised area of the network, packets are prioritized according to their hop distance and delay. The event area is divided into smaller sections to assign the different priorities among them. The different priorities are assigned using mainly two methods namely, signal strength and time stamp. The priority approach produces the high PDR ratio irrespective of event location (30% variation noted) for high priority node whereas paper results show that nodes are having lowest priority produce less packet delivery ratio. However, lowest priority nodes show better results if packets are sent based on their arrival time. The packet delivery ratio difference is around 20% compared to priority approach at lowest priority end. The queue is managed for only prioritized traffic. Queue full event triggers and enables drop action for lower precedence data packets. This approach is focused on increasing PDR ratio instead of overall throughput of the network.

Precedence control scheme [4] achieves the maximum throughput, especially for high priority traffic. This protocol is designed to increase the packet delivery ratio against no priority traffic. The link quality indicator (LQI) is taken into consideration during the experimentation in real time environment. A reliable and prioritized data transmission protocol [6] describes two important application classifications, namely time constraint events and no time constraint events. The categorization is made due to the distinct need of each event in IWSN. The protocol algorithm mainly focuses on priority-based data transmission considering different types of classes. Multiple buffers are used for storing the different types of traffic. Priority scheduler is designed for filtered information to deliver the information to its destiny.

Two queue types are used, namely network queue, and local queue for long distance traveled i.e. high priority and short distance i.e. low priority, respectively. The priority scheduler functions over them. Furthermore, depending on the event type and hop count, the priority is updated after every periodic interval and the scheduler functions accordingly. However, this work is motivated and inspired by [13] and [15]; and differences are mentioned in table 2.

III. SYSTEM MODEL & ALGORITHM

A. *Network Model & Assumptions*

The multi-hop sensor network is configured for VSRS protocol evaluation. Queue management is the heart of priority-based scheduling approach as shown in figure 1. However, the queuing operations are functional over the multi-hop nodes. The purpose is to take the decision during data transmission in order to reduce the delay. The scheduler is designed for packet transmission based on their priority weight. The priority weight includes the hop count. The count is measured based on the number of actors crossed by the data packet. Initially, the priority bit is set to each packet either 1 or 0 (1 denotes high priority and 0 denotes low priority). The hop count in incremented by one at each actor node

.

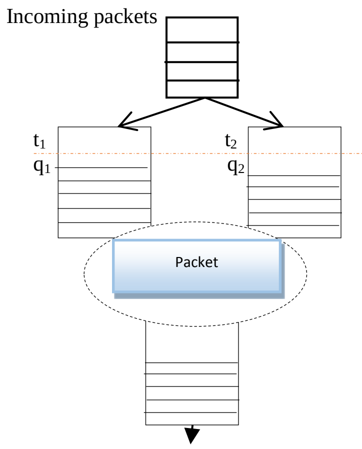

Figure 1: Priority based Queuing Model

When a packet travels from one hop to another, its priority gets updated as it goes to the next node distance. This approach becomes useful in a large network and high priority events occur far away from the sink node. Therefore, to serve those in time become the necessity. There may be the possibility that critical application does not tolerant the packet loss to some extent and it becomes purposeless though it has been successfully delivered by the underlying communication protocol. For example, fire or earthquake detection, early delivering of critical data is an important job within no time bound. A few seconds delay may harm to the great extent. Thus communication protocol plays the non-trivial role for delivering the required information within time. The VSRS addresses this problem by incorporating the buffer management over the multiple hops in order to serve the traffic at a run time. The network traffic classification and scheduling the data packets are two important operations of the priority scheduler.

Table 2
Summary of differences

Research Focus	ECODA [15]	ESRT [13]	PCS[4]	VSRS (proposed work)
Type of delivery	Rate-based	Rate-based	Rate-based	Rate-based
Traffic flows	Homogeneous	Heterogeneous	Heterogeneous	Heterogeneous
Decision window	Not addressed	Window-based	Not addressed	Not addressed
Priority	Hop count	Not addressed	Hop-count	Priority weight
Buffer	Dual buffer	Single buffer	Single buffer	dual buffer

The priority scheduler filters each incoming packet and enqueues into respective queues. Two queues are designed at every hop. The packets are stored and scanned during the transmission. When the packet is dequeued from the queue and transmits it to next node. The definitions of used notations are described in table 3.

Table 3
Glossary of Mathematical Terms

Term	Definition
q_1, q_2	queue types
t_1, t_2	threshold levels
P_{wt}	priority weight
h_c	hop count
d	delay
α,β	tuning parameters (1.1, 1.15)
p	Probability of priority packets
f_i	reporting frequency
n	source nodes
e_t	event time
l_1, l_2	current packet levels

A packet that has highest hop count and high priority bit get served first into the network. This strategy is applied for both the queues. However, the first preference is given to high priority packets of queue 2 instead of queue 1. Furthermore, if more than two packets have same hop count then they are selected based on their arrival rate into the respective queue. This queuing system is mainly designed for delay sensitive applications. Therefore, the fairness index is not taken into consideration over the no-priority traffic.

B. A VSRS Priority Approach

It focuses on long distance priority-based traffic over regular traffic by keeping the variable reporting rate. This is developed considering the view of emergency traffic over regular monitoring traffic. Typically, when an emergency event occurs at long distance then such event packets experience the long delay and packet loss. To prevent this; the mathematical model presents the solution of high preference to long distance prioritized packet over newly sensed packets at middle actor nodes. Initially, the static priority is assigned to each node as either 0 or 1 (0 indicates no priority and 1 indicates high priority). The packets are scanned on the priority queue based on two attributes, namely priority bit and network priority weight. The priority weight is computed at each actor node dynamically. It is expressed in equation (1).

$$p_{wt} = p_{wt} h_c + d^{\beta} \quad (1)$$

The equation (1) computes and updates the priority of each packet at each actor node. This uses the priority weight parameters in order to serve the long distance priority packets first. The β is the tuning parameter used to formulate incremental priority. The hop counter is decremented by at each hop node that indicates the distance to travel for reaching the base station. The delay is calculated from originating source node to current hop node.

The probability of high priority packets getting served first at some instance is as given in Equation 2.

$$p = (1 - p)^{n-1} \quad (2)$$

The reporting frequency is updated on low queue level. The additive increase method is described in Equation 3.

$$f_{i+1} = \alpha f_i \quad (3)$$

The packet transfer rate is reduced drastically when packet level is about to exceed the queue maximum level. The multiplicative decrease method for updating the reporting frequency is as follows.

$$f_{i+1} = f_i / \beta \quad (4)$$

Algorithm 1 shows the core operations which are aligned with the variable service rate reporting mechanism. When a node receives the control packet, it starts reporting the data packets to its upstream node with static priority bit assigned to the data packet which is being forwarded and continuously monitors the backward messages during data propagation period.

Algorithm (1): Data Forwarding Mechanism

Input: event sensing
Output: send data packets
Prerequisites: command from sink
Begin
1. do
2. Listen(cntrl_pkts);
3. response(update_info); // confirmation interest
4. update (f_{i+1});
5. transmit (data packets);
6. while (e_t!=0);

End

During data propagation, hop node sends the control packet of reporting rate to its downstream node in order to prevent the buffer overflow. The updated reporting rate is computed and then based on buffer occupancy level the decision of data delivery is taken. This dynamism in frequency changing rate makes the network more flexible and efficient for achieving the target reliability within the time period. This approach helps source node to understand their constant contribution to the network by following the decisions of actor node (hop node).

Algorithm 2 presents the data packet scheduler for heterogeneous event flows into the network. This scheduler comprises two main approaches for no-priority traffic and priority traffic. The first part of the algorithm does the classification of information wherein the incoming packets are given either to no-priority queue (q_1) or priority queue (q_2). Simultaneously, while packets are being queued the packet scheduler scans the queued packets. During the scanning process, it checks two attributes, priority bit and hop count number. The priority bit is assigned by the source nodes when it delivers to next actor node. The hop count is dynamic and is used for prioritizing the packets that have traveled long distance. The hop count (i.e. deadline) gets modified consistently when it crosses the hop node. Based on these attributes packets are chosen and are scheduled for transmission to MAC layers by incrementing its counter.

```
Algorithm (2): Variable Service Rate Scheduler Algorithm
Input: Data Packets
Output: Priority-First Scheduling
Begin
Do
Listen ();
If(p_in <: q1)
   q1 ← pr;
else
   q2 ← pp;
end if
if((q1 ∧ q2) !=empty)
   scan(qi);
   find p with highest priority weight;
   update(pwt)
   transmit(pp);//EDF approach or FCFS approach
end if
Buffer Operations:
Case1: Critical Situation
   if (l1 > t1) || (l2 > t2)
    drop (Pall)
    report rate refer equation-4
    Notify (f_{i+1}) ;//notification to regular sources;
   end if
 Case2: under control
 if (l1 < t1) ∧ (l2 < t2)
   Schedule (pckt); report rate; refer equation 3.
 end if
While (input buffer ≠ NULL)
end do-while loop
End
```

This procedure continues till 1/3 level of the priority queue is not reached. As soon as it goes below, it immediately switches to no priority queue. In no priority queue, it continues till the priority queue does not exceed ½ packets level. This has been included to improve the fairness index. Otherwise, every time only high priority packets will be injected and the probability of packet loss to low priority packets gets increased by close observation during experimentation. Therefore, the protocol is made little flexible for data transmission by considering the other traffic contribution into the network. However, less weight is given to serve the low priority packets because of protocol focus towards high priority packets. The reason is to meet the deadline of the long routed packet. Typically these types of packets get lost though they are defined with high priority. The distributed approach of scheduling the packets at actor node achieves the better reliability over multi-hop networks. The reporting frequency is varied due to the prediction of buffer level at hop node. A mathematical model using additive increase multiplicative decrease (AIMD) is presented for reporting mechanism to bring dynamism into the network. On or before buffer overflow, it immediately reports to source node via downstream node. This reduces the probability of packet loss at the great extent and related to effective network utilization.

The load of the base station is distributed among the actor nodes in the multi-hop topology. It focuses on only data packet collection approach for heterogeneous flows.

IV. Performance Evaluation

The proposed VSRS algorithm is simulated in a 1000x1000m^2 network area over the underlying CSMA/CA MAC protocol. The common network parameters [21] are shown in Table 4. In addition, other specific network parameters are described detail in various scenarios elaborated in the proceeding sections. The nodes are arranged in multi-hop fashion in order to test the presented scheduler for categorization and transmission of different types of packets at each actor routing node. The setup information is shown in Table 2. The remaining part of this section elaborates assessment of QoS parameters of setup network for the proposed work.

Scenario-1: The experiments are performed over 75, 100, 125, 150, and 175 nodes with the maximum retry limit of 3, the interval is set to 5 milliseconds, the queue length is 50 bytes, packet size is set to 30 bytes, and initially 128kbps data rate.

Table 4
Experiment Setup

Attributes	Values
Sensing field area	1000x1000m^2
Transmission range	30m
Packet size	63byte
Transmit Power	0.660w
Receive power	0.395w
MAC	CSMA/CA
Initial Energy	15J

The flat grid topology is used for experimental setup in order to forward the traffic hop-by-hop. The simulation time is 190 seconds. The various performance metrics have been applied in order to evaluate the reported work in this paper. Figure 2 shows the analysis of delay with varying number of nodes in 190 milliseconds time period in each.

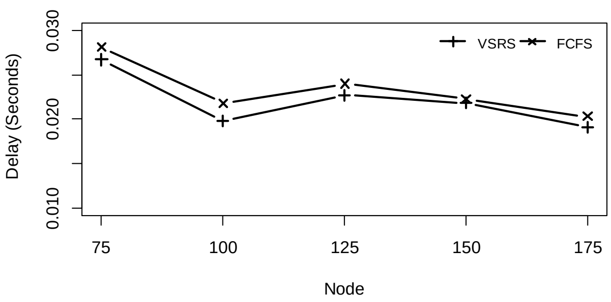

Figure 2: The average delay performance of VSRS and FCFS.

The figure shows the superior results of VSRS approach over the traditional FCFS approach. It can be seen that the VSRS algorithm shows very little delay, with the performance enhancement of 6% over FCFS mechanism for forwarding the data packets in multi-hop topology. The VSRS shows strong performance due to consideration of delay aware strategy for long distance traveled packets at each actor node.

The actor node filters each incoming packet and delivers them to next upstream node. The delay is considered in computation at the decision during data transmission particularly during priority metric computation; hence VSRS minimizes delay in the hop by hop network. The multi-hop priority metric function helps to reduce the control overheads and minimizes the queuing delay of long and delay sensitive information during in-network processing decisions.

Figure 3 plots the average energy consumption, which increases with node count. There is an increase in energy consumption with the sudden increase of network traffic. The performance improvements of VSRS is approximately average 10% better than the FCFS mechanism, which is depicted in Fig. 3 and compared with a traditional FCFS mechanism to validate the projected figures of VSRS priority approach. Typically packet loss occurs due to TTL expiration of long distance traveled packets, therefore, the priority metric is designed with a consideration of delay factor. This approach significantly reduces the network delay which results in less energy consumption. This increases the network life of the network. Queuing delay is reduced by handling the high hop count packet and greater delay packet first.

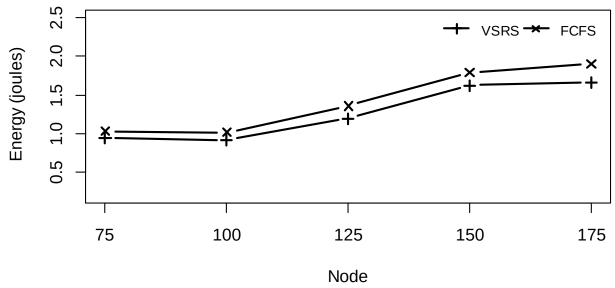

Figure 3: The average energy consumption over different node densities

Figure 4 illustrates a comparison of the average throughput for different node densities. The analysis shows that VSRS is better than the FCFS with the enhancement averages around 6%. This is achieved with distributed intelligent filtering and priority updating metric at various actor nodes using queuing operations efficiently. In addition, it should be noted that the irrespective of energy it delivers the long distance packet first. However, power aware approach is out of the scope of protocol operational flow. This approach brings the less data packet drop during in-network processing. Thus it performs well against the first-in-first-out mechanism. The packet delivery ratio is improved due to efficient data reporting mechanism as shown in figure 5. However, the PDR is indirectly proportional when the number of nodes increases. The queuing system of VSRS manages to keep the PDR ratio above 70% on an average up to 150 nodes and a little declination can be seen afterward. As compared with FCFS mechanism, the change is less but FCFS mechanism shows sharp decline PDR ratio.

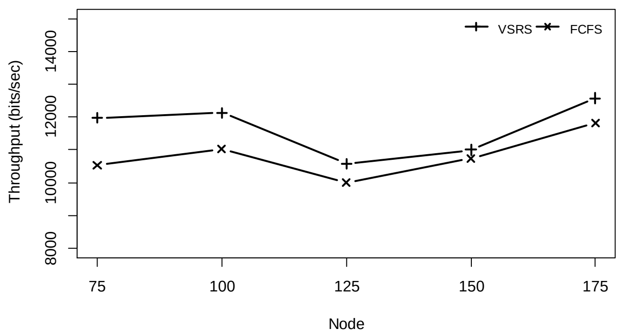

Figure 4: The analysis of average throughput over different node densities

The VSRS algorithm shows average 6% better performance over FCFS mechanism. The reason behind the strong performance is a delay and hop aware distributed scheduling mechanism in the hop by the hop multi-event sensor network.

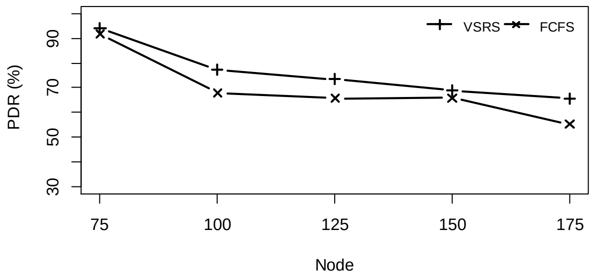

Figure 5: The average packet delivery ratio over different node densities.

Scenario-2: To verify the packet delivery and energy consumption ratio, we simulated over different node densities. It has been observed packet delivery ratio decreases marginally.

Figure 6 illustrates that packet delivery ratio is indirectly proportional to the node densities.

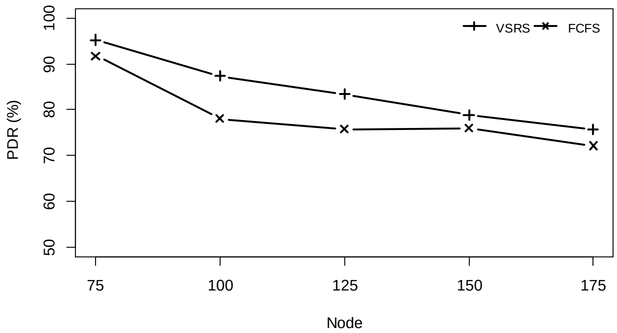

Figure 6: The analysis of packet delivery ratio over different node densities

The VSRS proves that it performs well with variable node densities over same simulation setup. In 190 second period, the graph illustrates good packet delivery ratio approximately on an average 5% (VSRS mechanism) better as compared with the FCFS mechanism. Graph plots PDR ratio in decreasing order due to a large amount of traffic gets generated during simulation time. Handling such huge traffic sometimes results into buffer loss that affects the overall PDR ratio marginally.

The average energy consumption increases with the increase in a number of nodes as shown in figure 7.

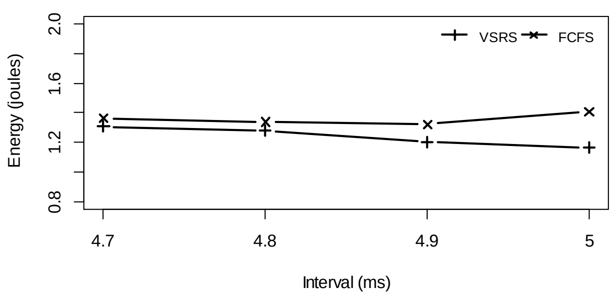

Figure 7: The analysis of average energy consumption over different

time intervals

Moreover, it significantly shows that it performs well in each experimental setup. It shall be noted that the classification of packets and handling their severity becomes a necessity in delay sensitive application in a multi-event sensor network when they occur simultaneously. The 7% energy saving improvement is noted against FCFS mechanism. This significant achievement is possible with less long distance packet retransmission. Considering delay and hop count, fewer packets are dropped. Thus, this approach reduces the retransmission overhead over the network which in turn minimizes the wastage of energy.

V. CONCLUSION AND FUTURE WORK

In this work, we have discussed two-phase protocol to address the problems of flexible prioritization and variable rate differentiation. The priority is updated at various levels in order to reduce the packet loss of short deadline packets and schedule higher priority packet-first. VSRS helps in updating service rate differentiation. The analysis shows that there is an approximate hike of 5-8% PDR ratio against the FCFS mechanism. However, indirectly it contributes to reduce the delay of high priority traffic. As a result, the variable rate algorithm helps to achieve the desired reliability as well as prevents the traffic jam in the successive interval of the network which results in less power utilization. In future, we plan to investigate the optimal operating frequency for higher and lower priority classes to function effectively.

ACKNOWLEDGMENT

We would like thank to reviewers for their valuable time and constructive suggestions for enhancing the reported research work in this article.

.

REFERENCES

[1] K. M. Thotahewa, J. Y. Khan, and M. R. Yuce, "Power efficient ultra-wide band based wireless body area networks with a narrowband feedback path," IEEE Transactions on Mobile Computing, vol. 13, No. 8, 2014, pp.1829-1842.

[2] K. A. Al-Saud, M. Mahmuddin, and A. Mohamed, "Wireless body area sensor networks signal processing and communication framework: a survey on sensing, communication technologies, delivery, and feedback," Journal of Computer Science 8 (1), 2012, pp.121-132.

[3] C. Buratti, "Performance Analysis of IEEE 802.15.4 Beacon-Enabled Mode, IEEE Transactions on Vehicular Technology", Vol. 59, No. 4, May 2010, pp.2031-2045.

[4] S. Sarode, J. Bakal, "Precedence Control Scheme for WSNs", Pervasive Computing (ICPC), 2015 International Conference on, IEEE ICPC, 2015, pp.1-5.

[5] I. Al-Anbagi et al., "Priority- and Delay-Aware Medium Access for Wireless Sensor Networks in the Smart Grid", IEEE Systems Journal, Jan 23, 2013, pp.1-11.

[6] S. Sarode, J. Bakal, L.G.Malik, "Reliable and Prioritized Data Transmission Protocol for Wireless Sensor Networks", Proceedings of the International Congress on Information and Communication Technology, Volume 439 of the series Advances in Intelligent Systems and Computing, 2016, pp.535-544.

[7] M. Khanafer, M. Guennoun, and H. T. Mouftah, "A survey of beacon-enabled IEEE 802.15. 4 MAC protocols in wireless sensor networks," IEEE Communications Surveys & Tutorials, Vol.16, No. 2, 2014, pp.856-876.

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

[9] 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/getieee802/download/802.15.4-2015.pdf.

[10] M. H. Yaghmaee, N. F. Bahalgardi and 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.

[11] 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, 2014, pp.1181–1192.

[12] S. k. Chen, T. Kao, S. T. Chan, C. N. Huang, C. Y. Chiang, C. Y. Lai, T. H. Tung and P. C. Wang, "A Reliable Transmission Protocol for ZigBee-Based Wireless Patient Monitoring", IEEE Transactions On Information Technology In Biomedicine, Vol. 16, No.1, January 2012, pp.6-16.

[13] Y. Sankarasubramaniam, O. B. Akam and I. F. Akyildiz "ESRT: Event to Sink Reliable Transport in Wireless Sensor Networks", MobiHoc'03, ACM, 2003, pp.177-188.

[14] T. Emanuele and L. L. Bello, "Multichannel Superframe Scheduling for IEEE 802.15.4 Industrial Wireless Sensor Networks", Ieee Transactions On Industrial Informatics, Vol.8, No.2, May 2012, pp.337-350.

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

[16] A. Ahmad, R. Arshad, S. A. Mahamud, G. M. khan and H. S. Al-Raweshidy, "Earliest-Deadline-Based Scheduling to Reduce Urban Traffic Congestion. IEEE Transactions On Intelligent Transportation Systems", Vol.15, No.4, AUGUST 2014, pp.1510-1526.

[17] M. Takaffoli, E. Elmallah, W. Moussa, "Scheduled Access Using the IEEE 802.15.4 Guaranteed Time Slots", IEEE ICC 2010 proceedings

[18] X. Siya, W. Lei, L. Zhu, G. Shaoyong, Q. Xuesong and M. Luoming, "A QoS-Aware Packet Scheduling Mechanism in Cognitive Radio Networks for Smart Grid Applications", Communications System Design, china communication, 2006, pp.68-78.

[19] Chewoo Na and Yaling Yang , "MRSD: Multirate-based Service Differentiation for the IEEE 802.15.4 Wireless Sensor Network", IEEE "GLOBECOM" 2009.

[20] X. Yin et al., "A priority-based Packet Scheduling Methodology Wireless Sensor Networks", of the 2006 IEEE International Conference on Information Acquisition August 20 -23, 2006, Weihai, Shandong, China

[21] Network Simulator2 (NS2). http://www.isi.edu/nsnam/ns.