SEMU - An Adaptive Policy - Control Based Routing Approach to Provide Effective QoS over Wireless Sensor Networks

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Abstract — Error control mechanism carries vital importance in research aspects of Wireless Sensor Networks (WSNs) due to its limited energy constraints and minimal support for power communication. The survey and analysis provides a comprehensive comparison of FEC / ARQ and hybrid ARQ schemes in WSN. This paper proposes an adaptive QoS routing scheme called SEMU, to support in routing for each variable service sessions based on policy-control rules in order to control transmission errors for different applications such as streaming content delivery over WSN networks using route metrics. A real time test bed approach along with a case study is adopted to test the data error during transmission along with its effective delay and latency. The test results show that SEMU performs to a scalable effective QoS compared to hybrid ARQ schemes and LEACH schemes with minimal latency and delay.

Keywords: SEMU, FEC, ARQ, LEACH, QoS, WSNs.

1.0 INTRODUCTION

Research aspects of Wireless sensor networks are multifold [14][16] as major new mission critical applications focus towards the area of monitoring and control which include intrusion detection, target tracking, wildlife habitat control and monitoring, disaster management and climate control.

The technology which drives the emergence of sensor applications is the rapid development in the integration of digital circuitry, which will brings small, cheap and autonomous sensor nodes into work. The rapid development of WSN though may offer new opportunities it also creates multiple challenges particularly in field of effective communication [2] and error control [19]. As collaboration between mobile nodes is highly required for effective communication, session management with optimal error control is on high priority. Such conflicting objectives provide unorthodox solutions for multiple situations.

Due to wireless nature of WSN, limited resource to be used such as power, memory processing, low node reliability and dynamic network topology [23] had added multiple research challenges. Hence developing real-time applications over WSN should consider available resource constraints, as well the node reliability and communication reliability along with the global time varying network performance. This research work is initially modeled as a non-convex mathematical programming problem whose primary objective is to identify and provide the optimal bandwidth in use. The proposed solution approach is based on data aggregation tree procedure in conjunction with a number of optimization-based heuristics to determine the QoS delay constraints. The objective function includes the "bandwidth in use" [8] of the transmission mode (data transmissions and data retransmissions) as well the bandwidth used by idle node or relay node (to wait for data from downstream nodes in data aggregation tree [4]).

Real time test bed is carried out to identify the behavior of proposed SEMU algorithm using computational experiments, which shows that SEMU outperforms existing heuristics that do not take MAC layer retransmissions and the bandwidth consumption in the idle node into account. In view of such challenges [21][17], it can be understood that error control is a major that enables us to provide robust multimedia communication and maintain Quality of Service (QoS). Despite the existence of some good research works on error control analysis in WSNs, none of them provides a thorough study of error control schemes for multimedia delivery.

SEMU proposes performance evaluation of Erasure Coding (EC), Automatic Repeat Request (ARQ), hybrid FEC/ARQ data link layer, Forward Error Correction (FEC) [16] and cross-layer hybrid error control schemes over Wireless Sensor Network (WSNs)[7][18][11] over streaming media services. Performance metrics of WSN include frame's Peak Signal-to-Noise Ratio (PSNR), energy efficiency [20], cumulative jitter [9], frame loss rate [1] and delay-constrained PSNR [3] which are investigated as part of this work. Analysis results demonstrate the identification of wireless channel errors which affect the performance of sensor networks and how different error control scenarios can be effective for such networks. The results also provide the required insights for efficient design of error control protocols in multimedia communications over WSNs [25].

1.1 MOTIVATION AND OBJECTIVE

The integrity of data being transmitted and fault-tolerance issues [4][10] in WSN has effect on the performance of any data acquisition system. Noise and other external network disturbances can often degrade the information or data transmitted by these systems. Hence the need for devising a fault tolerant communication mechanism in wireless sensor networks is a challenge [5].

As the construction and deployment characteristics of these low powered sensing devices are complex, due to low computation and communication abilities of sensor nodes [13]. Fault tolerant mechanism is inappropriate due to very low computation and overhead of nodes. Hence sensor nodes are highly vulnerable to failures. These sensors may lose functionalities at time instance due to energy depletion by harsh environment factors or malicious attack from enemies. Hence error handling and optimal QoS at any time period is important for input /output which also decides the survivability of sensor network [6].

In WSNs, any sensor node that is within another's interference range trying to transmit simultaneously would result in collisions [17]. When collisions occur, retransmissions are required to ensure that the data be successfully received. These retransmissions [12] result in additional energy consumption. Beside additional energy consumption, extra latency from retransmissions increases the link delay. Because of this extra latency for each link delay, the end-to-end delay from data source nodes back to the sink node will be increased.

1.2 SUPPORT FOR QOS IN MOBILE AND WSNS

QoS can be defined as: ''Totality of characteristics of a telecommunications service that bear on its ability to satisfy stated and implied needs of the user of the service'' E.800 (09/08) -ITU [2]. QoS refers to control mechanisms which monitor and control the resource reservation rather than the provided service quality itself.

In practical research aspects, QoS guarantees in WSN can be classified as hard real-time and soft real-time systems [14]. Hard Real Time system focuses on deterministic end-to-end delay bound where the arrival of a message after its defined deadline is considered as failure. A Soft Real Time system can support a probabilistic guarantee with an acceptable or tolerable delay. Hence, supporting the RT QoS in WSN should possess either a deterministic or probabilistic end-to-end delay guarantee in order for the system to function with an optimal QoS support [26].

2.0 LITERATURE SURVEY

Information routing [22] is a very challenging task in highly dense and distributed sensor networks due to its inherent characteristics that distinguish these networks from other wireless or adhoc networks [29]. The sensor nodes deployed in an adhoc manner need to be self-organizing [19] as this kind of deployment requires system to form connections and cope with the resultant nodal distribution. Another important design issue in sensor networks is that sensor networks are application specific. Hence the application scenario demands the protocol design in a sensor network.

The proposed routing protocols for sensor networks should consider all the above issues to be efficient and feasible for implementation. Table 1 classifies the WSN routing and QoS approaches. The algorithms developed need to be energy efficient, scalable for error handling as well increase the life of the network in the process. FEC [15] and LEACH [11] had been considered to be energy effective routing protocols, but neither of these protocols helps in controlling errors while supporting QoS. Both these protocols are better than conventional network protocols, which supports direct transmission adapting to minimum transmission energy with multi-hop routing are few major drawbacks which don't allow them to achieve all the desirable properties.

TABLE 1 CLASSIFICATION OF WSN ROUTING AND QOS APPROACHES

	Classification	Scalability	Mobility	Energy Usage	Location Aware	QoS	Multi-Hop	Data Aggregation
Flooding	Flat	Limited	No	High	No	No	Yes	No
FEC [15]	Data centric	Limited	Limited	Limited	Yes	No	Yes	No
LEACH[16]	Hierarchical	Good	Fixed BS	Limited	No	No	Yes	Yes
PEGASIS [16]	Hierarchical	Good	Fixed BS	High	No	No	Yes	Yes

3.0 SEMU MODEL AND FRAMEWORK

SEMU modeling framework adopts Markov deterministic framework architecture to predict the behaviour of network. Markov Deterministic Modeling Approach [MDMA] frame work works on function of MDP is to determine the optimal policy that will satisfy the current QoS of streaming media applications. The Markovian property [22] states that the occurrence of a future state in a Markov process depends on the immediately preceding state and only on it but does not depend on the past states. MDP helps in determining the optimal QoS for varying networks and applications. Hence based on the varying QoS parameters of WSN, optimal QoS service is provided to media applications. A single server queuing system with a finite buffer and heterogeneous arrival streams has been considered [31]. The arrival process is a Poisson or Markov Modulated Poisson Process (MMPP) while service times are with general distributions. In this classical problem of queuing theory [27], the probability of buffer over flow and packet dropping probability are computed. It also considers multiple transmission rates depending upon the channel conditions, distance and transmitting power. Each mobile station transmits data at an appropriate transmission rate using a particular modulation scheme based on the perceived signal to noise ratio [28]. The service provisioning is dynamically varied by selecting links that can use higher bandwidth modulation schemes. The main focus of this paper is integrated wireless channel modeling and data queuing analysis at the packet level to study the effect of physical layer link speed on high layer network performance. Assured forwarding (AF) in different server is used to provide differentiation service between traffic classes where the low priority class experiences higher loss rates and delays than the high priority class. Arrivals are modeled as a general batch Markov arrival process in which thresholds and packet dropping probabilities are selected so that real time and non real time traffic observe different QoS performance while considering the impact of varying the physical layer link speed in a realistic WSN environment.

3.1 SEMU ALGORITHM

SEMU algorithm work is based on three functions. Three major functions are carried out by any generic routing protocol – discovery of new route, selecting an optimal route among the several available routes and perform route maintenance and update for data transfer. Same functionalities are also incorporated in SEMU by implementing features like route reSEMUt, route reply, and reporting route errors. Figure 1 shows the message flow of SEMU which indicates the simplified execution flow of the algorithms. The SEMU_SREQ and SEMU_SRLY packet contains three more fields to accommodate QoS parameters such as bandwidth, delay and packet loss, in addition to the required fields for transferring data.

A source node initiates a route discovery to the destination by sending SEMU_SREQ packets towards its neighbors. As soon as the SEMU_SREQ packets are received, the neighbor or the destination will process those SEMU_SREQ packets. If the neighbor can satisfy the QoS requirements, it will forward the SEMU_SREQ packet to the next neighbor or destination. If the destination node has received the SEMU_SREQ, then it will send a SEMU_SRLY packet to the source.

When a node receive a SEMU_SRLY packet, if it still has the required resources available, it creates a forward route entry to the destination, reserves the required resources and then forwards the SEMU_SRLY packet to the upstream nodes using the reverse route. When the source receives the SEMU_SRLY packet from the destination, it will create a route to the destination in the routing table. Subsequently, the data transmission to the destination is initiated by the source.

On the other hand, a node that receives a SEMU_SRLY packet, and does not have enough resources to satisfy the data transfer, it drops the SEMU_SRLY packet, generates a SEMU_ERR packet, and sends it back to the node from where it received the SEMU_SRLY packet.

Procedure 1: SEMU_CreateRoute

{ (Route_ID, Route_Next, QoS_value) }

Route Request (SEMU_SREQ) and Route Reply (SEMU_SRLY) for any node Fi

Variables:

S, D : Identity of source and destination WSN nodes

Route [ ] : Array route consisting of all temporary WSN node

Route_OPT, TempRoute : Optimal route and temporary routes from S to D

η : WSN Node priority

| Hop_k |: 'k' number of hops between S to D, where 'k' being the radio propagation length

Ri (Li, Fi) : Route segment where neighboring WSN node Fi is located

τ: Route update : Time to Wait (TW) parameter

SEMU_BRoute : Route Broadcast

SEMU_SREQ: Route Request packet

SEMU_SRLY: Route Reply packet

SEMU_OPT: Optimal Route

Upon receiving SEMU_SREQ (S, D, TempRoute) from any Fi

```
1: if (S == D) & (|TempRoute| ∈ Route) then
2:     Route_OPT = TempRoute
3:     Send SEMU_SRLY( S, D, Route_OPT )
4:     Return (Route_OPT)
   else
5:     Send SEMU_RER ( 0 )
6: end if
7: if SEMU_SREQ ≠ θ
8:     if ( Ri ( Fi ) ≠ Ri ( Fj ) & ( Ri( Fi ) ⊂ TempRoute ) then
9:          add Ri ( Fi ) to TempRoute [ ]
10:    end if
11:    set Hop_k = distance( Fi , Fj) * τ
12:    increment Hop_k
13: endif
14: if Ri ( Si, Sj  ) == Rj( Di, Dk ) then /* If Si and Si are neighbours */
15:     stop Hop_k / * Fi is a better broadcast node */
16: end if
17: set η = 0
18: SEMU_BRoute ( S, D, TempRoute ) /* broadcast route */
19: receive SEMU_SRLY ( D, S, Route_RPL(Fj-1,Fi-1,-1)) from Fj
20: if η ≠ -1 then goto step 7
21: if ( Fi == S ) then
22:     Store Route_RPL in TempRoute
23:     Forward SEMU_SREQ (S, Fi, ROUTE_RPL(Fi+1, Fj+1,D, η))
24: end if
```

OPTIMAL ROUTE DISCOVERY AND ROUTE UPDATE

Identifying an optimal route for a service between source and destination defines the process of satisfying the QoS on demand as per SEMU metrics. Any service can be effectively accomplished if a best possible route or an optimal route among the available links is selected. The "capability" of defining an optimal route is based on the communication effectiveness for expected service in terms of logistic policy measure. Any node or link which is not "capable" to communicate as per optimality condition is defined as 'Worst'. Optimization helps in providing an adaptive service for services which demand QoS consistently such as streaming media delivery, content management feed, media conference. Optimization is provided to (a) assigning route with required bandwidth, (b) maintaining and monitoring SEMU metrics on delay, packet loss, no of hops, radio propagation range.

Procedure 2: Optimal Route

SEMU_ OptimalRoute (NodeID_send(j),NodeID_recv(j), SEMU_metric, Link_ID(j), β, μ)

where j is set of route links identified between 1 to n

Variables:

S, D : Identity of source and destination WSN nodes

Route [ ]: Array route consisting of all temporary WSN node

Route_OPT, TempRoute: Optimal route and temporary routes from S to D

μ: Service priority

| Hopk |: ‘k’ number of hops between S to D, where k being the radio propagation length

Ri (Li, Fi) : Route path where WSN node Fi is located

τ: Route update Time Wait (TW) parameter

SEMU_SREQ: Route reSEMUt packet

SEMU_SRLY: Route reply packet

SEMU_OPT: Optimal Route

Upon receiving SEMU_SREQ (S, D, TempRoute) from any Fi

1: if ((S == Fi) || (D==Fj)) & (|TempRoute| $\in$ Route [ ]) then

2: Route_OPT = TempRoute

3: send SEMU_SRLY(S, D, Route_OPT)

4: return

5: else

6: send SEMU_SREQ(S, D, TempRoute, μ,β)

7: set Hopk = distance (Fi, Fj) τ /* hop count between nodes */

8. set β = High || Low || Normal

9: set μ = High || Low || Normal

10: set $\tau = 0$

11: if SEMU_OPT = θ

12: if (Ri (Fi) $\neq$ Ri (Fj)&(Ri (Fi) $\subset$ TempRoute) &
SEMU_SREQ (Fi+1,Fj+1,μ) then

13: add Ri (Fi) to Route_OPT /* add the best route to Optimal Route */

14: end if

15: increment Hopk

16: if Ri (S) == Rj(D) then

17: stop Hopk / * Fi is a better broadcast node */

18: end if

19: send SEMU_OPT (S, D, TempRoute , β) /* Optimal route */

20: receive SEMU_SRLY (D, S, Route_RPL(Fj-1,Fi-1, -1)) from Fj

21: increment SEMU_OPT

22: if $\beta > 1$ then goto step 10

23: else

24: continue

25: endif

26: if (Fi == S) then

27: store SEMU_OPT in Ci and Ri

28: forward SEMU_SREQ (S, Fi, ROUTE_RPL(Fi+1, Fj+1,D, β))

29: end if

30: endif

The step by step explanation of the algorithm is discussed. Steps 1 to 6 explains the optimal route identified if the route is found to be shortest between the source and destination, with no other possible routes found in *TempRoute* list. Step 7 to 10, assigns default values for SEMU_OPT metrics, Step 11 checks whether an optimal route is available in list SEMU_OPT, else the process of adding the possible links based on the service request is added to SEMU_OPT as explained in Step 12 to 14.

4.0 EXPERIMENTAL TEST BED AND PERFORMANCE ANALYSIS

The parameters involved for simulation are lifetime, number of active nodes for communication, percentage of packet loss and end to end delay. MATLAB software [23] has been used for analysis purposes and evaluating node and route efficiency. The network test bed consists of random topology having desirable nodes with dynamic topology. N sensor nodes are located randomly within a square border of 10*10, where N is fixed as 20. The initial communication range of nodes is considered as 0.1cm. The connective range of nodes is 50 to 60 meters, which considers that each 2 nodes being located at a distance of less than 60 m are considered as neighbors hence can exchange data. Events are sensed periodically such that for each period an event occurrence is observed. Value of route selection for update of selection probability of a node is taken 0.001s. Table 2 shows the testbed properties

Multiple MamaBoard kits were used for carrying out real time testbed [36]. MamaBoard [32] combines a TinyNode Standard Extension Board (SED) [34][35][30]and a cellular GPRS module on a single device. The MamaBoard is intended to bridge a wireless sensor network to wireless LAN (WLAN) or GPRS. Each connectivity type is enabled by plugging an appropriate external module to the MamaBoard. The SD slot can be accessed both by the TinyNode [33] and the GPRS module. The Siemens TC65 [24] is the GPRS module which can be mounted on Mamaboard. This kit includes a simplified version of J2ME (Java 2 Mobile Environment) [24]. Hence, Java applications can be executed on the GPRS module. The TC65 comes with an integrated TCP/IP stack which allows us to establish standard Java socket connections to a server by using AT commands. The TC65 is connected to the MamaBoard through a 80 pin board-to-board connector.

The primary aim of this work is to ascertain the fixed value for aggregate background traffic and to continue with experimental test bed with the chosen value of 2.3 Mbits. This setup is maintained throughout the test run, as similar to tests to be conducted for bandwidth-constrained applications as well to maintain the delay bounded setting with different values for maximum end-to-end delay. In the experimental test bed, the network setup values vary between 10 and 100 ms. On analysis from the testbed results it can be observed that applying a maximum delay threshold of 20 ms for no video or voice traffic was accepted as cut-off value into the network.

TABLE 2 PROPERTY USED IN TEST-BED

Area of Test bed	10 x 10
N	20
Initial energy	0.01
Frequency	700
Connective range	60
Sensing range	30
Sink	300, 300

To understand and evaluate the average behavior of the protocol, SEMU protocol variant had been implemented in the test-bed framework. According to the test bed requirements, which focus adopting a simple star topology, 20 nodes are deployed in the field. All the nodes are randomly distributed with consistent mobility. The test run was performed for 5 iteration runs where each individual experiment, was executed for delay test results, while packet delay observed for number of WSN nodes in activity is shown in Figure 4. The curve relates to maximum channel utilization. Figure 2 demonstrates an end-to-end delay, which explains that the delay for the beacon tracking enabled mode ranges at slightly more than 4 ms on average, which is clearly below the worst case measure of roughly 8 ms. This observation shows that the channel clearly provides capacities that can be used for real-time traffic and non real time traffic. For a higher traffic load (for the packet interval shorter than 0.01 s), the end-to-end delay increases drastically due to buffering effects. The same trend can be observed for the beacon tracking disabled mode.

5.0 PERFORMANCE ANALYSIS

This work extends the performance evaluation of study and analysis of the protocol behavior using selected real time experimental run time functionality. The analysis of real-time capabilities of both the standard protocol ARQ scheme with FEC and SEMU (proposed protocol variant) is carried out as part of this research work. Analysis also investigates the packet loss rate and the possible throughput depending on the traffic load. The results being depicted in Figure 3, using relative experiments confirms the analytical evaluation of network traffic. Depending on the traffic load the optimal situation of delay bounds are controlled such that no packet loss occurs. However, at a defined throughput threshold of about 0.01s for the packet interval, the channel becomes densely saturated and delay increases based on buffering effects.

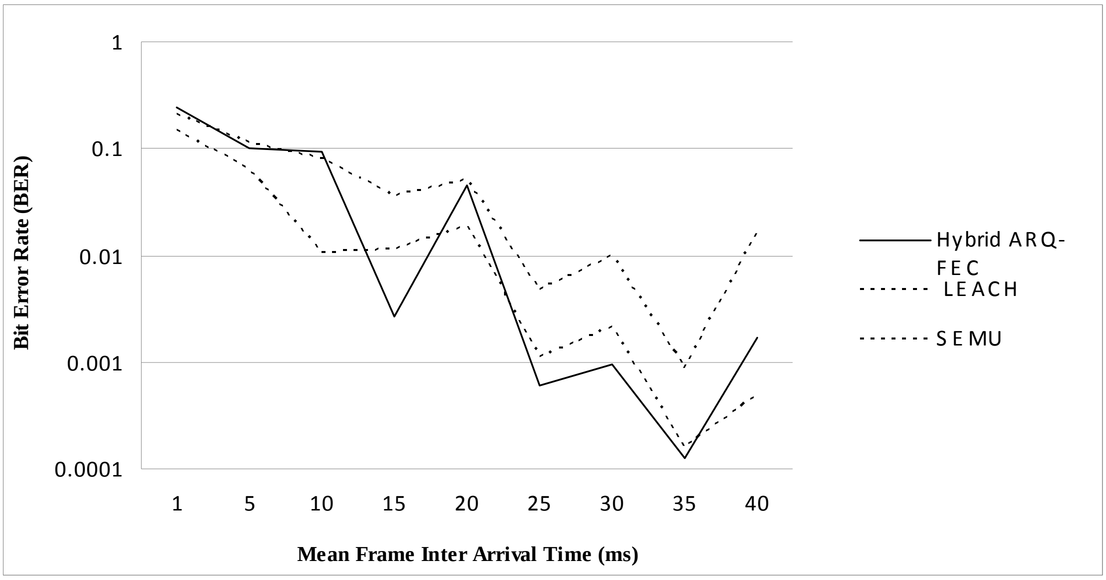

Figure 1. Bit Error Rate analysed over Mean Frame Interval Time

Figure 1 shows the Bit Error Rate analyzed over Mean Frame Interval Time (calculated during $15x10^3$ ms time slots) which is referred through the inferred network model and test-bed approach. Figure 3 presents the intensity of node traffic generated for increase in number of WSN nods. For this network, the mean percent errors are 9.01% and 18.0% for the average PDR and throughput respectively.

From the obtained results, it can be concluded that the SEMU model was able to predict adaptiveness as well provide QoS, with a high precision level, where the average PDR and delay variance behaviors in simulation test cases. This result is expected since the model was constructed using the first 60 minutes of data from the scenario of varying number of users.

This work can be summarized as the model was able to predict network behavior even when the number of users increased by a factor of 200%. Based on the obtained results, we can see that even for large increments in the number of users and network traffic the model was still able to produce very accurate predictions. This research work proposed a novel approach to modeling of WSN networks, which is based only on measurements (or simulations). Initially SEMU model work on set of simulated measurements of the inbound/outbound traffic and of the corresponding Quality of Service (QoS). The test bed works on relative set of real time measurements and updates such that finally the system converges to predict the QoS from the inbound/outbound traffic.

The model does not impose any restrictions to the type of metrics that characterize network QoS. The results obtained from applying the presented procedure to realistic network scenarios showed that this approach can achieve excellent performance in terms of predicting QoS of multiple network access points or gateways. The QoS prediction was accurate even when there were significant changes in the number of users.

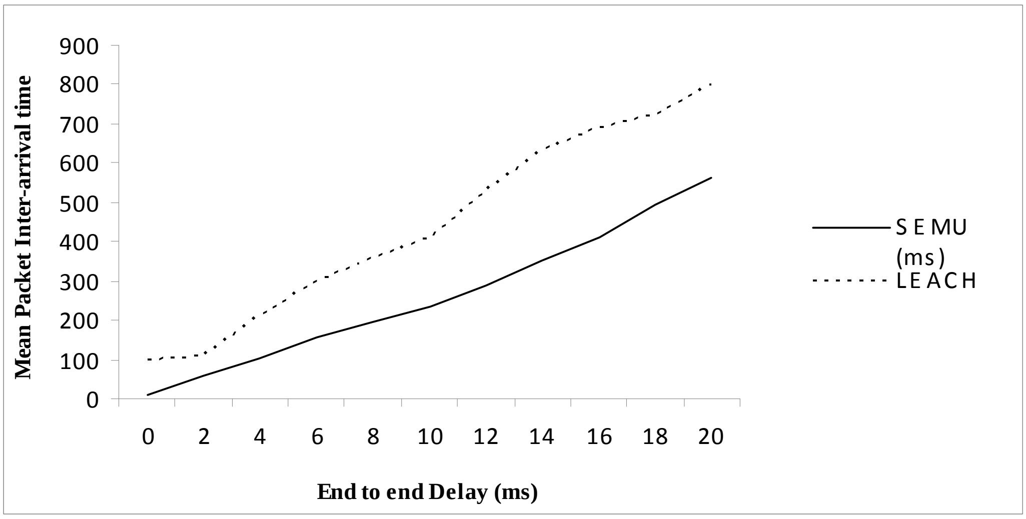

Figure 2. End-to-end delay observed for SEMU

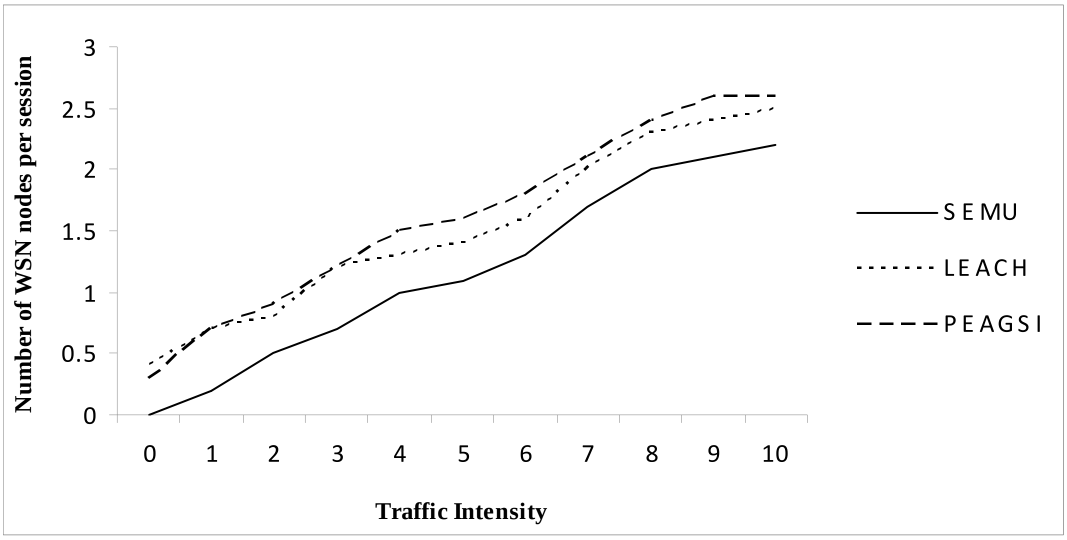

Figure 3. Intensity of node Traffic generated for increase in number of WSN nodes

Figure 4. Packet Delay observed for number of WSN nodes in activity

The graphs represent for the case of 54 Mbps data rate and 1000 bytes of data packet size. There is a significant improvement in the performance of SEMU's PDR in comparison with FEC. Moreover, SEMU follows a high throughput, minimal AEED, minimal NRL than FEC.

6.0 SUMMARY

The multimedia content in sensor networks should be delivered with predefined levels of Quality of Service (QoS) under resource and performance constraints such as bandwidth, energy, and delay. These constraints limit the extent to which QoS requirements can be guaranteed.

This paper discusses on the performance of QoS based routing approaches for WSN using scenario based test bed approach. It is identified from results that rule based priority routing helps in effective routing of packets and session handling with minimal loss and with less delay. In a real scenario network environment, where timely reception of each packet and session based routing plays crucial role, priority route scheduling helps in effective transmission of packets.

The study and analysis shows that the proposed SEMU packet scheduling and routing algorithm performs better when compared with the network performance such as FEC and ARQ incorporated routing approaches. The results are verified for WSN based multicast routing protocols, such as FEC, hybrid ARQ and FEC error control routing methods which are found to be encouraging.

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