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Prioritizing Information for Achieving QoS Control in WSN

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***Abstract*— Achieving QoS objective in Wireless Sensor Network (WSN) that deals with multimedia information is of paramount importance in the WSN research community. From the application point of view, meeting application specific QoS constraints is equally important as designing energy efficient embedded circuitry for WSN nodes. Among various WSN communication protocol stack, the transport layer functionality has gain fundamental fame lately in addressing the application specific QoS objectives by supporting Source prioritization besides the reliability and congestion control aspects of the design that helps in gaining high throughput with minimum end-to-end packet latency. This paper present the design of a new transport layer protocol that prioritizes sensed information based on its nature while simultaneously supporting the data reliability and congestion control features. The proposed transport protocol is tested in three possible scenarios i.e. with priority, without and distributed priority features. Simulation results reveal that by prioritizing the Source information and prioritized intermediate storage and forwarding reduces the End-to-End (E-2-E) latency of Source packets having <100 msec except for Source A where it is slightly higher than 400msec compared to non prioritized case where the E-2-E Source packet latency accounts to >400msec which is quite significant. Simulation test has been performed for distributed prioritized intermediate storage and forwarding among which the network distribution with node K as prioritized intermediate storage node (DIST-K) outperformed all of the mentioned cases by having 100% achieved Source priority,0% packet drop rate and 0.28Mbps achieved bit rate.**

Keywords- WSN, priority, QoS, transport protocol, congestion control, reliability.

I. INTRODUCTION

Wireless Sensor Network (WSN) gathers the intention of the research community from past few years in a variety of applications ranging from environmental monitoring to military by involving multiple disciplines of control, signal processing and embedded computing [1-3, 9]. WSN comprised of tiny pieces of hardware called “mote”, having inbuilt features of sensing, processing and communication over wireless channel, distributed randomly in space to form an ad-hoc network for communicating the sensed information from the region of interest to central control station also called “sink”. Energy is a primary concern while designing the WSN and achieving the objective of energy efficiency researchers are consistently engaged in designing the power efficient hardware and communication protocol stack for WSN. Being a network of energy hungry devices, energy efficient hardware and communication protocol stack design while simultaneously enabling the feature of energy scavenging is of paramount importance for longevity of the WSN.

In WSN, among various other layers of the communication protocol stack, transport layer is of fundamental importance for ensuring the E-2-E reliability of the sensed information as significant proportion of the overall mote’s energy budget is spent for this type of communication besides mote’s locally [1-3] sensing and processing the information of interest. The main causes of packet drop include:

- Congestion,
- Collisions due to hidden motes,
- Poor SNR due to bad channel quality,
- Link breakage due to mote failure.

Packet retransmission caused by packet drop due to poor channel conditions or network congestion considerably consumes mote’s power and therefore reduces the life of the WSN. Recently research community is trying to modify the existing WSN design (for fixed application) to target heterogeneous applications where the data is either scalar or multimedia by nature. For such applications data prioritization is also of significant importance for achieving the longevity of the WSN as the multimedia packet drop retransmissions occurs at considerable dispense of the mote’s power budget.

Transport layer of the WSN is responsible for communicating the sensed piece of information from the Source mote to sink [3]. Data information reliability either Hop-by-Hop (H-b-H) or E-2-E is of key importance from the application Quality of Service (QoS) point of view and transport layer is responsible for maintaining the application specific QoS [1]. The data packets fail to reach the sink can be retrieved by sink which sends the Negative Acknowledgement (NACK) to Source or some intermediate node (designated for temporary storage). The number and the arrangement of these storage nodes are highly depends upon the following:

- Required level of application specific QoS to be achieved,
- Network topology,

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- Level of congestion in the different parts of the network,
- Severity of interference that causes massive data packet loss.

We investigated the dependence of the WSN transport layer protocol on underlying MAC/Wireless-Phy layer where we concluded that for the longevity of the WSN the transport layer has a direct relationship with the underlying MAC/Wireless-Phy layer [11]. Based on the observations we had envisaged a transport protocol design based on stochastic control framework that manages congestion and E-2-E data reliability features of the WSN transport layer protocol [12]. In the following paper we are incorporating the priority feature in the existing stochastic control frame work based transport layer protocol design that enables prioritization of the Source information and prioritized intermediate storing and forwarding of the Source information towards sink in-order to ensure the application specific QoS.

The rest of the paper is organized as following. After introducing the related work is covered in Section II followed by the problem definition, system requirements and design considerations in section III. Section IV describes the proposed transport layer protocol. Section V describes the algorithm of the proposed transport layer protocol followed by section VI where we have describe the simulation setup used for observing its behavior and the simulation results we have taken. The discussion followed by the conclusions will be presented in the section VII.

II. Related Work

In this section we focus on the existing transport protocols used for WSN. We begin the discussion with TCP [13], UDP [14] and then extend it to various other WSN transport protocols like CODA [15], ESRT [16], RMST [17], PSFQ [18], RBC [19], GARUDA [20], DTC [21], STCP [22] and TCPWW [23]. Table 1 compares various WSN transport protocols like CODA, ESRT, RMST, PSFQ, RBC, GARUDA, DTC, STCP and TCPWW.

TCP [13] (connection oriented by nature) assumes congestion as the main cause of packet drop. It assures strict E-2-E reliability at very high energy cost, which is not acceptable in WSN because of its strict energy constraints. UDP [14] on the other hand, being connectionless by nature, offers significant throughput in comparison to TCP, but the packet drop rate is significantly higher during congestion [11]. Therefore the basic inference is that UDP offers extremely high throughput but minimum reliability, whereas TCP offers extremely high reliability but low throughput. Our literature study concludes that the existing research in the field of WSN transport protocol development exists in between these two extremes, which we now discuss in detail.

As show in Table 1, CODA (i.e. Congestion Detection and Avoidance) protocol [15] lacks reliability but provides excellent congestion control in the forward direction. This control is achieved by explicit notification of the congested scenario to the child motes. It utilizes wireless channel load and motes buffer occupancy for congestion detection and uses open-loop H-b-H back pressure and closed loop E-2-E multi-Source regulation for rate adjustment.

TABLE I. WSN Transport Protocols

Features **Protocol**	**Direction**	**Congestion Control Support**	**Reliability Management Support**
CODA	Upstream	Yes, Active control, Explicit Nototification	No
ESRT	Upstream	Passive Control, Implicit Notification	Yes, Event Based, Implicit loss detection and notification wit h E-2-E recovery
RMST	Upstream	No	Yes, Packet Based, NACK based loss detection and H-b-H recovery
PSFQ	Downstream	No	Yes, Packet Based, NACK based loss detection and H-b-H recovery
GARUD A	Downstream	No	Yes, Packet Based, NACK based loss detection and H-b-H recovery, Two-tier Two stage
STCP	Upstream	Passive Control, Implicit Notification	Yes, Packet Based and Event Based, NACK/ACK based loss detection and E-2-E recovery
TCPWW	Upstream	Yes	No

TCPWW [23] (TCP Westwood) is a sender based extension of the existing TCP protocol. It refines the window control and back-off process of the existing TCP design thereby achieving greater design efficiency under sporadic or random data losses. Under congested network conditions TCPWW uses the estimated value of the available channel bandwidth for properly setting the congestion window and slow start threshold limits. It also ensures rapid data retrieval, by avoiding excessively conservative reductions of congestion window and the slow start threshold limits.

Other than CODA and TCPWW, there are a number of other WSN transport protocols published in the literature like ESRT, RMST, PSFQ, RBC, GARUDA and DTC. These protocols only aim to provide reliability but completely lack congestion control feature. We now briefly explain this set of protocols.

Event-to-Sink Reliable Transport (ESRT) [16] aims to provide Event Based (EB) reliability support by employing implicit (Imp) loss detection and notification and E-2-E loss recovery mechanism. It also provides passive congestion control in the Forward (Fwd) direction by incorporating Imp congestion notification feature.

Reliable Multi-Segment Transport protocol (RMST) [17] offers Packet Based (PB) reliability support, H-b-H Loss

Recovery (LR) in the forward direction by incorporating "Not Acknowledge" (NACK) based loss detection and notification control. It uses timing information for data loss detection and once data loss is detected it sends a NACK to the Source mote or storage mote, which then retransmits the corresponding data packet upon receiving the NACK.

Pump Slowly Fetch Quickly (PSFQ) [18] aims to address the reliability support only in the reverse (Rev) direction from the sink motes to the Source motes. It uses NACK for data loss detection and is facilitated with rapid H-b-H loss recovery mechanism. However it is unable to detect the loss of a single packet when packets are transmitted in bulk. It also requires more buffer storage (being H-b-H nature) at the intermediate motes for data recovery.

Reliable Bursty Convergecast protocol (RBC) [19] offers E-2-E packet based reliability support in the Fwd direction. The level of reliability provided by RBC is comparatively higher than RMST and PSFQ because it incorporates Imp H-b-H loss detection, loss notification and loss recovery mechanism at MAC level. It uses NACK/ACK (Acknowledge) as a means for data loss notification and Implicit Acknowledgement (IACK) for loss notification at MAC level only.

GARUDA [20] provides reliability in the Rev direction, i.e., from the sink mote to the sensor motes. It uses core motes located at 3-hop distance apart for temporary sensed data storage, which could be retrieved in the event of loss. It uses NACK for data loss detection and two-tier two-stage loss recovery mechanism.

Distributed TCP cashing protocol (DTC) [21] aims to provide total packet driven reliability in both directions. It uses ACK and Selective ACK (SACK) for data loss detection. In DTC sink mote has the loss recovery control and uses H-b-H mechanism for possible loss recovery.

Sensor TCP (STCP) [22] is the only protocol so far that offers both congestion control and data reliability. It uses open-loop H-b-H rate control mechanism with Imp congestion notification. It uses packet processing and inter-arrival time for congestion detection. It offers both packet and event driven reliability and uses ACK and NACK to facilitate E-2-E reliability objective.

In this section we reviewed the existing transport protocol schemes for WSN. STCP is the closest work to what we are proposing, since it addresses congestion control as well as reliability. In the next section we give an overview of our proposed protocol.

III. Problem Definition

In WSN the factors like packet collisions at the receiving node due to transmissions from other nodes having the common destination (hidden node problem), congestion, route failure, crosstalk: resulting in high bit error rate (BER) etc contributes towards high power cost for per data packet communication, lower system throughput and increased E-2-E data packet latency.

So for enhancing the WSN energy efficiency transport layer protocol plays a vital role in increasing the network throughput and minimal E-2-E packet latency while maintaining the application specific QoS [11]. Also data information routing based on the nature of the packet information further elevates the energy efficiency of WSN. In this paper we present a light weight transport protocol that takes E-2-E packet delay information, intermediate node storage memory occupancy for evaluating the congestion index and packet information type for packet prioritization. The simulation of the envisaged transport layer protocol enable us in better understanding of the above mentioned performance limiting features and would open new dimensions in transport protocol designing for WSN.

A. *Requirements and Design Considerations*

The key requirement of the proposed transport protocol is as follows:

1. Congestion Control
2. Data Reliability
3. Heterogeneous Application Support
4. Sink Enabled Control

The first requirement for our proposed protocol is Congestion Control. To adhere to this requirement the protocol should be able to detect, notify and mitigate congestion in the network or at local hot-spots effectively. This is one of the main requirements because by adhering to this requirement packet drops can be reduced and hence the energy associated with packet retransmissions can be saved. To address this requirement the proposed protocol incorporates the following design consideration. The congestion control functionality in the proposed protocol employs end-to-end delay information of each packet at the sink mote for measuring the congestion state of the network (or link). The new rate value for future data packet is then estimated based on this end-to-end delay information or congestion state of the network.

The Second requirement for our proposed protocol is Data Reliability and can be met by the introduction of the temporary discrete data storage for possible data retrieval in event of packet drop either due to congestion or poor channel conditions. Any intermediate mote, located at bottleneck locations of the WSN (near sink or mote having large number of child motes), can serve the purpose of storage mote. In the proposed scheme the immediate child mote to sink and motes at locations that relays large amount of data (its own sensed data plus the data from large number of child motes) can serve the purpose of intermediate storage. In the proposed scheme the intermediate storage motes store data for predefined interval of time based on the apriori estimated value of total probability of data packet drop (P_f). However in order to conserve the energy spectrum of the WSN network we possibly in future incorporating the idea of variable reliability that ensures the retrieval of only high priority data packet (e.g. event based information if lost will be retrieved in comparison to less prior scalar information).

The data flow in the wireless network may be event driven, periodic or continuous of either multimedia or scalar by nature, so the proposed transport protocol should have the feature of Heterogeneous Application Support and is not limited to certain application scenarios. Such type of problem can be addressed by prioritizing the data based on its type. So the intermediate motes processes the incoming packets based on its priority/nature of data.

Presently the proposed transport protocol scheme works based on Sink Enabled Control [12], as sink has high computational power in comparison to Source and intermediate sensor motes. So majority of the computationally intensive tasks related to congestion control and reliability are being performed by the sink mote. In our case we have implemented a state machine, as described in the Section V, which predicts the congestion state of the network based on the delay T (i.e. packet E-2-E delay) and using this index to define a new Source rate plan.

IV. PROPOSED PRIORITY BASEDTRANSPORT PROTOCOL SCHEME

A. Proposed WSN Transport Protocol Scheme

The block diagram of the proposed scheme is shown in Figure 2. The proposed scheme comprised of following functional modules

- Congestion Control Module[χ]
- Prioritization and Reliability Module[Ψ]

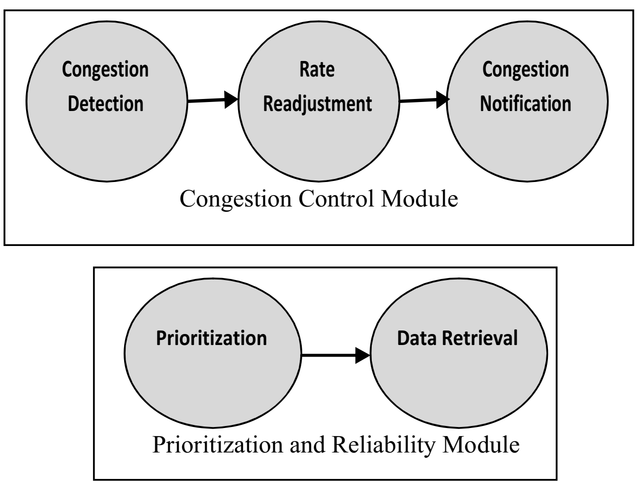

Figure 1. The Proposed Transport Layer Protocol

1) Congestion Control Module

Congestion control module [8] is used to detect, inform and mitigate the congestion in the network. Congestion in the network occurs when the data sending rate from multiple Sources exceeds the available channel bandwidth. Failure to prevent congestion in the network results in

1. Data packet drop and will considerably deplete network energy budget.
2. Increased E-2-E data packet latency.

Here the packet delay for single hop (1-hop) propagation is given by

$$T_{delay} = T_{pr} + T_Q + T_{pp} \quad (1)$$

where,

T_{delay} = average E-2-E packet delay in seconds,

T_{pr} = average packet processing time at node in seconds,

T_Q = average node queue delay in seconds,

T_{pp} = average 1-hop propagation time in seconds.

To effectively prevent congestion in the WSN we envisaged a prioritized transport layer protocol for WSN. The congestion index helps in identifying the level of congestion in the network and is given by the following equation:

$$C_i = n * m_i + T_{delay}\,(E-2-E) \quad (2)$$

where,

m_i= congestion level which is realized by the intermediate mote memory storage,

n= number of intermediate storage nodes,

$T_{delay}(E\text{-}2\text{-}E)$= E-2-E packet delay in seconds.

Now with Γ as time required to process one memory location/word then mi is given by:

$$m_i = \frac{\text{Total free spaces in the storage}}{\text{Total Memory space for storage}} * \Gamma \quad (3)$$

$$m_i = \frac{K}{M} * \Gamma \quad (4)$$

Also for 'N' number of hops between Source and sink with per mote and per link propagation delay of T_{pr} then $T_{delay}(E-2-E)$ is given by:

$$T_{delay}(E-2-E) = N * T_{pr} \quad (5)$$

where,

$$T_{pr} = T_Q + T_{MAC}\,. \quad (6)$$

T_Q = Queue delay at any intermediate mote and is given by

$$T_Q = Q_i * T_{1-p} \quad (7)$$

where,

Q_i = Current Queue index,

$T_{1\text{-}p}$= Time to execute one packet.

and T_{MAC} is given by:

$$T_{MAC} = T_{RTS/CTS} + T_{ch} \quad (8)$$

where,

T_{MAC} = MAC access delay,

$T_{RTS/CTS}$ = Delay due to ongoing transmission as indicated by RTS/CTS,

T_{ch} = Channel access delay.

So Eq.(2) i.e. congestion index, can now be given as:

$$C_i = n * \frac{K}{M} * \Gamma + N * \left((Q_i * T_{pp}) + T_{RTS/CTS} + T_{ch}\right) \quad (9)$$

[χ] For detailed mathematical understanding please refer to [12].

[Ψ] We incorporated Prioritized Source information forwarding including intermediate storage feature in the existing transport layer protocol [12] based on stochastic control framework.

Eq. (9) represents the congestion index or the congestion state of the network and is helpful in deciding the future rate plans for the Source motes. Based on this C_i the envisaged Transport Layer Protocol will then measure or estimate the new rate plan (based on the E-2-E data packet delay information $T_{delay}(E\text{-}2\text{-}E)$) for the Sources and notify them in order to mitigate congestion. The newly estimated $T_{delay}(E\text{-}2\text{-}E)$ involving C_i is given by [6]

$$\hat{T}_{delay}(c_i) = \overline{T_{delay} / C_i} \tag{10}$$

Hence the new estimated rate value $\hat{R}(c_i)$ comes to be:

$$\hat{R}(c_i) = \frac{\hat{T}_{delay}(c_i)}{N} \tag{11}$$

where,
N = total number of hops between Source and sink.

2) Prioritization and Reliability Module

The purpose of the Prioritization and Reliability module of the envisaged WSN transport layer protocol is to

- Retain the sensed information at selected intermediate motes [10] for some defined time interval.
- Resend the sensed information upon receiving the Negative Acknowledgement (NACK) from the sink.
- Receive the incoming packets from all possible Sources (Scalar and Multimedia sensor equipped) and rearrange the packets based on their information content priority.
- If the intermediate node receives data packets from multiple Sources having similar information priority then the packet with minimum E-2-E time to live value (TTL) will be served first.

V. PROPOSED PROTOCOL - ALGORITHM

In the previous section we discussed the main modules of our proposed transport protocol and also outlined how we calculate the key parameters used for congestion control and reliability. In this section we outline each step involved in computing the new rate information and the network congestion level as being proposed by our light weight transport protocol scheme meant for congestion detection and reliability assurance[Ђ]. The key steps are as follows:

Step1: Generation and transmission of the new packets at Source node

This is the first step in which the Source node sense the environment and start generating the data packets of size 1 KB and start sending this information at a rate $R(c_0)$ specified by the sink control.

Step2: Storage of the packets at the intermediate buffer node also being used for routing too

When the Source starts sending the data packets at some defined rate they are then stored at the intermediate storage node's buffer. At any particular storage node the packet's storage time is being dictated by the packet's probability of success i.e. $P_{success}$.

Step3: Data packets being received by the Sink node

The intermediate storage nodes prior for being used for storage can also be used for routing purposes, the routed Source information reaches the sink for post processing of the packet i.e. $\hat{T}_{delay}(c_i)$ (E-2-E).

Step4: Congestion Detection

After started receiving the data packets the sink controller starts computing the new rate value based on the existing congestion state of the network by looking at the E-2-E delay of each packet. Following steps are involved for the computation of the new estimated rate value

1. $f_{T_{delay}C_i}(t_{delay}, c_i)$ Joint density function that relates the E-2-E packet delay and congestion index C_i.
2. Posteriori estimate for received packets $\hat{T}_{delay}(c_i)$
3. Compare this posteriori estimate of $\hat{T}_{delay}(c_i)$ with threshold λ_{Thres} , if exceeds then congestion has been detected else no congestion.

Step5: Estimated error J computation

In this step the sink controller compares the estimated $\hat{T}_{delay}(c_i)$ of the received packet with the actual delay $T_{delay}(c_i)$ and based on this the sink controller computes the estimation error J.

Step6: Conditional mean-square error computation

Conditional mean-square error finding using helps in finding the means-square estimate of the new T_{delay} [6, 12]

Step7: Computation of new estimated rate value

Using equation $\hat{R}(c_i) = \frac{\hat{T}_{delay}(c_i)}{N}$, the sink controller starts computing the new rate value computed based on the estimated $\hat{T}_{delay}(c_i)$.

Step8: New rate notification to Source nodes

Finally the new estimated rate value is being communicated to the Source nodes by the sink including the level of congestion C_i .

VI. SIMULATION SETUP AND RESULTS

This section describes the simulation setup used for an extensive testing of the proposed transport layer protocol. The simulation setup is shown in the Figure 2 where Sources A, B and J are video sensor motes while Source C and H are generic scalar sensor motes. The priority of the video data packet is higher than the scalar data packet and follows the following priority rule:

$$Pr(A)=Pr(B)=Pr(J)>Pr(C)>Pr(H) \tag{12}$$

[Ђ] For detailed understanding of the proposed Transport Layer Algorithm refer [12] *where,*

Pr(A) = Priority of data packet from Source A,

Pr(B) = Priority of data packet from Source B,

Pr(C) = Priority of data packet from Source C,

Pr(H) = Priority of data packet from Source H,

Pr(J) = Priority of data packet from Source J.

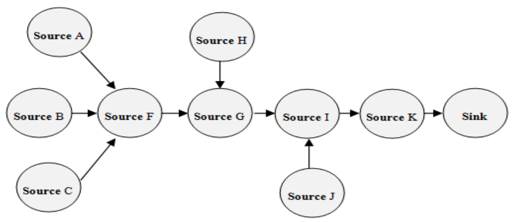

Figure 2. The Network Topology Used For Evaluation

In this simulation we have used Network Simulator NS-2 [16] and we consider that the entire multi-hop network is comprised of 10 nodes as an ad-hoc network for the case of IEEE 802.11[4]. For this wireless setup we performed the extensive analysis of E-2-E throughput, E-2-E packet latency and the average percentage priority achieved. The network parameters are listed in Table II.

In order to ensure the reliability in the results the simulations have been performed five times for the three possible cases of the proposed transport layer protocol and are:

- Proposed protocol without prioritized Source information storage and forwarding,
- Proposed protocol with complete prioritized Source information storage and forwarding,
- Proposed protocol with distributed prioritized Source information storage and forwarding.

A. *Performance metrics*

The extensive performance of the envisaged transport layer protocol is evaluated against the following performance metrics

1. Average E-2-E Packet Latency: It is defined as the total time a packet would take including all the delays resulting from queuing, retransmissions at the MAC layer, propagation delays and transfer time from the Source to sink (E-2-E).

2. Average E-2-E Throughput: It is defined as the number of data packets send by all the potential Sources to the data received by the sink corresponding to each Source.

3. Percentage Average Data Loss: It is defined as the percentage ratio of the data loss, difference of sent and received data, to the send data. The main contributors of data loss are collisions at the receiving end in the presence of blind nodes, congestion and link failure due to node energy depletion.

4. Average Percentage Priority Achieved: It is defined as the average number of specific Source data packets received at the sink to the number of data packets send by the same Source.

TABLE II. NETWORK PARAMETERS

Parameter	Values
Frequency	2.472e+9
Transport Protocols	1. Proposed protocol without prioritized Source information storage and forwarding 2. Proposed protocol with complete prioritized Source information storage and forwarding 3. Proposed protocol with distributed prioritized Source information storage and forwarding
MAC	IEEE802.11 [4]
RX and CS Threshold	9.32665e-10W 8.393985e-10 W
Routing agent	Ad hoc On-Demand Distance Vector (AODV) [7]
Ifqlen (Queue length at MAC level)	200 packets
Energy Model	Yes: NS-2 based Energy computation [5]
CP Threshold	10
Mote Initial power	100 W
Mote Idle power	712e-6 W
Mote Rx power	35.28e-3 W
Mote Tx power	31.32e-3W
Mote Sleep power	0.001W

B. *Simulation Results*

In the following section we will discuss the simulation results obtained. The simulation has been performed 5 times and the results mentioned here show the average values taken to ensure the reliability in the results.

1) Average E-2-E packet delay comparison of the proposed priority based transport protocol

Figure 3 shows the average E-2-E packet delay comparison of the proposed transport layer protocol for three possible cases. The results shown here represent the average E-2-E delay that a data packet suffers originated from various Sources. It would be obvious that for the first case where there has been no intermediate data packet storage and prioritized delivery of Source packets the average E-2-E latency of the Source data packet is quite significant and is above than 400 msec on average. Also except for the Source J whose priority is highest (same as Source A and B) as compared to Source C and H has suffered comparably less average E-2-E delay (being close to sink) which is approximately 368 msec. However, an improved response (less than 60 msec average E-2-E Source packet latency for Sources C, H and J) except for the Source A and B whose average E-2-E packet latency accounts to 431 and 116 msec has been observed in second case where the strict reliability and priority has been laid down in WSN. Lastly for third (distributed prioritized intermediate storage and forwarding) case we observed least E-2-E Source data packet delay for the following distributed network topology:

- DIST-K having average E-2-E Source packet latency is <40 msec, where the mote K is used for storage and prioritized data forwarding,

- DIST-I having average E-2-E Source packet latency is <52 msec, where the mote I is used for storage and prioritized data forwarding,
- DIST-F-K having average E-2-E Source packet latency is <40 msec, where the motes F and K is used for storage and prioritized data forwarding.

The worst performance is observed in case of network topology where the motes G and F are used for storage and prioritized data forwarding. For DIST–G case the average E-2-E latency for Source A packets is around 1.22 sec, 0.97 sec for Source B and C packets while 131 and 390 msec for Source H and J packets. For DIST-F case the average E-2-E latency for Source A, B, C, H and J packets is around 0.914 sec, 1.97 sec, 2.42 sec, 0.131 sec and 0.314 sec respectively. However, an acceptable result is observed (below 120 msec) in case of network topology where the motes combination F-I and F-G-I are used for storage and priority.

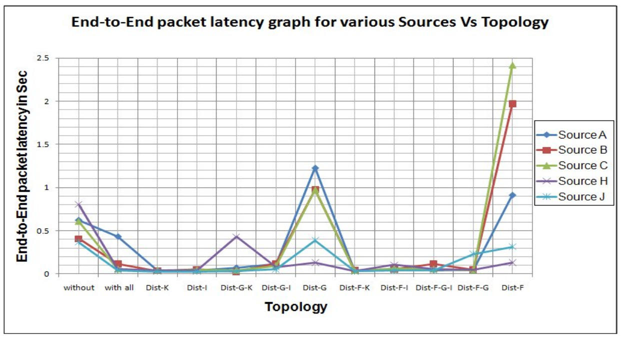

Figure 3. Average E-2-E packet Delay comparison

2) Average Throughput comparison of the proposed priority based transport protocol

The average throughput comparison of the proposed transport protocol for various possible network configurations is shown in Figure 4. From the result the configuration DIST-F-G-I has the highest possible throughput having a peak value of 0.4012 Mbps and is because of having three stage distributed prioritized storage and forwarding (so chances of packet drop reduces). Where as DIST-F shows the poorest response among all having average throughput of 0.15 Mbps this degradation is because of congestion and increased packet queue latency. Although F is receiving all the information packets from its child Sources A, B and C but still counters must be made to prevent congestion related packet drop due to information packets from Source H, J and possible relay information of G, I and K that will increase the queuing delay and thus results in poor E-2-E packet latency. Also the configurations like DIST-K and DIST-I achieve a fair average throughput level of 0.28 and 0.3 Mbps and the reason for this fairness is that these nodes are close to sink so they gather maximum packet information form the child Source and relay nodes and then based on prioritized storage and forwarding rule pass the information to sink. After DIST-F-G-I, DIST-F-I (which has an acceptable Source data packet E-2-E latency) shows better average throughput response of 0.34Mbps (here in addition to node F which gathers packet information from its child Source nodes A, B and C the node I also gathers the relay information from G, F and Source J so likely prevents the chances of packet drop to best possible).

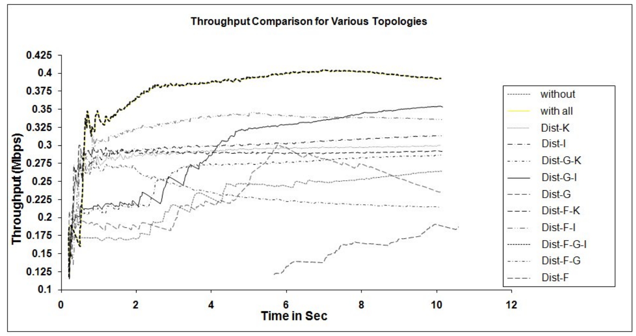

Figure 4. Average throughput comparison

3) Average Packet Drop comparison of the proposed priority based transport protocol

The average Source data packet drop comparison for various network configurations is shown in the Figure 5.

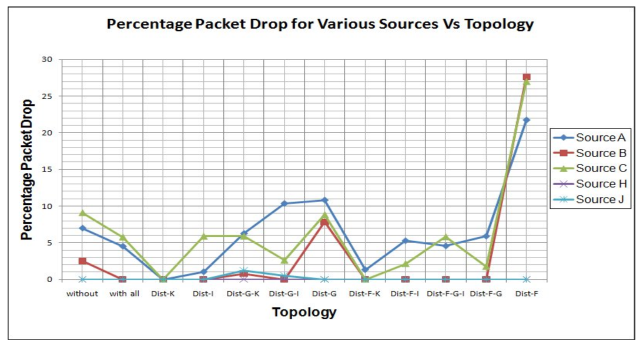

Figure 5. Average Percentage Packet Drop

From the results it would be obvious that highest possible data loss has been observed for the 'without' case (percentage data loss for Source B is 4%, percentage data loss for Source A is 7%, percentage data loss for Source C is 9% while for Source J and H is 0%) and is obvious because of having no prioritized intermediate storage and forwarding of the Source information which is quite vital for strict QoS oriented applications like Wireless Multimedia Sensor Networks (WMSNs). Significantly high loss has also been observed in case of DIST-F network configuration and the reason for this high data loss is that the node F is gathering information from Sources A, B and C at high rate but relaying the entire information on its output link which is shared by node G (that relay information of Source H) is quite difficult and also since this distributed storage node (node F) is at distant from the sink so the likely probability of packet drop due to large queuing delay at node F and at intermediate nodes and congestion at the later end (node K) which is close to sink is high. Among others The DIST-F-K (nodes F and K are storage nodes) and DIST-K (immediate to sink) shows better result where in DIST-K the percentage average data loss is 0% for all possible Sources while for DIST-F-K the percentage average data loss for all Sources is 0% while 1.5% for Source A.

4) Average Percentage priority achieved comparison of the proposed priority based transport protocol

Figure 6 shows the average percentage Source priority achieved for various possible network configurations the major reasoning involved for various cases under this section is already covered in the Average Packet Drop comparison section above (Section VI subsection B-3). Again for this case only DIST-K and DIST-F-K achieves the 100% Source priorities. Also for the 'without priority' network configuration case only the Sources H and J achieve the level of 100% while for Sources A, B and C the achieved priority level is 93.02%, 97.5% and 90.9% respectively. However for 'with complete priority' network configuration case only Sources B, H and J achieves the 100% level while for Source A and C the achieved priority level is 96.5% and 94.24%. Similarly for the 'distributed prioritized storage and forwarding' network configurations like DIST-F-G, DIST-F-G-I and DIST-I, where the Sources which failed to achieve 100% level are Source C and A (for DIST-F-G-I, DIST-F-G and DIST-I) respectively. The achieved priority level for Source A and C are 95.45% and 94.2% for DIST-F-G-I, 94.12% and 98.25% for DIST-F-G and 98.98% and 94.12% for DIST-I. Again the DIST-G network configuration which performed poorly for the cases of Average E-2-E data packet latency, Average data packet drop and throughput shows degraded results for Achieved average Source priority (achieved Source priority level of 89.19%, 92.16%, 91.18%, 100% &100% for Sources A, B, C, H and J).

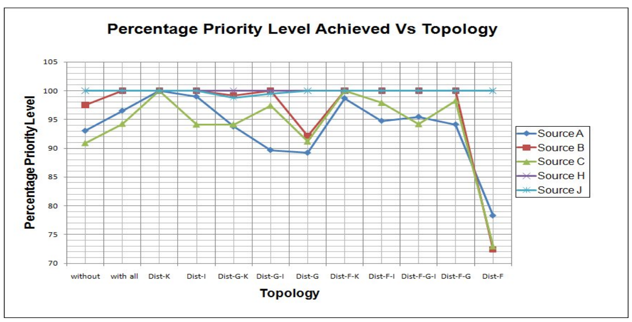

Figure 6. Average Percentage priority achieved

VII. DISCUSSIONS AND CONCLUSIONS

In the following paper we have presented a scheme for WSN transport layer which guarantees congestion control, reliability and Source priority. The congestion control has been achieved by taking into account the E-2-E delay of Source data packet at the sink. E-2-E reliability of the data packet has been achieved by employing the distributed memory concept in WSN which stores the data packet for some definite time frame and enables the prioritized forwarding of the Source data packet based on the set Source priority and TTL value for Source data packets. Results reveal that by employing the distributed memory and prioritized forwarding concept in WSN we can prevent the Source data packet drop and ensures the application specific QoS. DIST-K topology in comparison to all shows better result in terms of average percentage Source data packet drop, E-2-E data packet latency and achieved priority for various Sources having different priority levels. In the next step we will incorporate the cross layer feature to the existing design and this sets our future research direction.

REFERENCES

[1] I.F. Akyildiz, T. Melodia, and K.R. Chowdhury, "A Survey on wireless multimedia sensor networks,"Computer Networks (Elsevier) J., vol. 51, pp. 921-960, 2007.

[2] V. Potdar, A. Sharif, E. Chang, "Wireless Sensor Networks: A Survey," waina, International Conference on Advanced Information Networking and Applications Workshops, pp.636-641, UK, 2009

[3] V. Potdar, A. Sharif, E. Chang, "Wireless Multimedia Sensor Network Technology: A Survey," The 7th IEEE International Conference on Industrial Informatics (INDIN 2009), pp.606-613,UK, 2009

[4] IEEE P802.11, Main General Info Page, Aug 2008.

[5] The Network Simulator — NS-2, http://www.isi.edu/nsnam/ns/index.html, July 2008.

[6] F.L. Lewis, L. Xie and D. Popa, "Optimal and Robust Estimation with an introduction to Stochastic Control Theory", Second Edd, CRC Press, 6000 Broken Sound Parkway, NW (2008). ch 1-4, pp. 3-258.

[7] C.E. Perkins, E.B. Royer and S. Das, "Ad hoc On-Demand Distance Vector (AODV) Routing", RFC 3561, July 2003.

[8] B. Hull, K. Jamieson, H. Balakrishnan, "Mitigating Congestion in Wireless Sensor Networks", In Proceedings of the ACM Conference on Embedded Networked Sensor Systems (SenSys), pp. 134-147, 2004.

[9] D. Estrin, D. Culler, and M. Srivastava, "Overview of sensor networks," Computer, vol. 37, no. 8, pp.41–49, 2004

[10] S.-J. Park, R. Vedantham, R. Sivakumar, and I. F. Akyildiz, "A scalable approach for reliable downstream data delivery in wireless sensor networks," in Proc. ACM MobiHoc 2004, May 2004.

[11] A.Sharif, V.M. Potdar and A.J.D.Rathnayaka, "Performance Evaluation of different Transport layer protocols on the IEEE 802.11 and IEEE 802.15.4 MAC/PHY layers for WSN", 7th Int Conf MoMM , pp. 300-306, Malaysia, 2009.

[12] A.Sharif, V. Potdar, A.J.D Rathnayaka and T. Dillon, "Reliable Transport Protocol for WSN with Congestion Avoidance using Stochastic Control Framework", Submitted to ETRI Journal, Dec 2010.

[13] TCP, http://www.ibiblio.org/pub/docs/rfc/rfc793.txt, 2008.

[14] UDP, http://tools.ietf.org/html/rfc768, Aug 2008.

[15] C.Y. Wan, S.B. Eisenman, and A.T. Campbell, "CODA: Congestion detection and avoidance in sensor networks", Proc. ACM SenSys, pp.266–279, USA, Nov. 2003.

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

[17] F. Stann and J. Heideman, "RMST: Reliable Data Transport in Sensor Networks", In Proc. of the First IEEE Int. Workshop on Sensor Network Protocols and Applications, pp. 102-113, USA, 2003.

[18] C. Y. Wan, A. T. Campbell, and L. Krishnamurthy, "PSFQ: A Reliable Transport Protocol for Wireless Sensor Networks", ACM Int. Workshop on WSN and App, pp. 1-11, USA, 2002.

[19] H. Zhang, A. Arora, Y.R. Choi, M. G. Gouda, "Reliable Bursty Convergecast in Wireless Sensor Networks", ACM Mobihoc, pp. 266-276, USA, 2005.

[20] S.J. Park, R. Vedantham, R. Sivakumar, and I. F. Akyildiz, "A scalable approach for reliable downstream data delivery in wireless sensor networks," ACM MobiHoc, pp. 78–89, Japan, 2004.

[21] A. Dunkels, T. Voigt, H. Ritter, J. Alonso, "Distributed TCP Caching for Wireless Sensor Networks", Annual Mediterranean Ad Hoc Networking Workshop, Turkey, 2004.

[22] Y.G. Iyer, S. Gandham, S. Venkatesan, "STCP: a Generic Transport Layer Protocol for Wireless Sensor Networks", ICCCN, pp. 449–454, USA, 2005.

[23] S. Mascolo, C. Casetti, M. Gerla, M. Y. Sanadidi, and R. Wang "TCP Westwood: Bandwidth Estimation for Enhanced Transport over Wireless Links", ACM SIGMOBILE '01, Rome, Italy, 2001.