Performance of Transport Protocols for Multimedia Communications in Wireless Sensor Networks

Özgür B. Akan, *Senior Member, IEEE*

***Abstract*— Many wireless sensor network (WSN) applications require efficient multimedia communication capabilities. However, the existing communication protocols in the literature mainly aim to achieve energy efficiency and reliability objectives and do not address multimedia communication challenges in WSN. In this paper, comprehensive performance evaluation of the existing transport protocols is performed for multimedia communication in WSN. Performance metrics such as packet delivery rate, end-to-end packet delay, bandwidth and energy efficiency, frame peak signal-to-noise ratio (PSNR), delay-bounded frame PSNR, frame delivery probability, frame end-to-end delay and jitter are investigated. The results clearly show that the existing transport protocols are far from satisfying the requirements of multimedia communication in WSN and hence there is a need for new effective multimedia delivery protocols for WSN.**

***Index Terms*— Multimedia communications, transport protocol, congestion control, rate control, sensor networks.**

I. Introduction

Wireless Sensor Networks (WSN) are multi-hop ad hoc networks composed of small sensor nodes with limited capabilities in terms of power, processing, memory and communication. Recently, considerable amount of research efforts have yielded many promising communication protocols to address the challenges posed by the WSN paradigm. These results mainly address the reliable and energy-efficient communication problems of the WSN applications, which primarily require conventional data communications. Nevertheless, there exist many proposed WSN applications such as real-time target tracking, source localization, discovering and following rare animal species which may also involve in collecting information in the form of multimedia such as audio, image, and video; and hence necessitate efficient multimedia communication in WSN [1], [2].

The main focus of this paper is to comprehensively evaluate the performance of the existing WSN transport layer protocols in multimedia communication scenarios. To this end, we perform a wide range of simulations and present the results in this letter to clearly assess the performance and point out the shortcomings of these currently proposed protocols for multimedia communication in WSN.

II. Existing Transport Protocols and Multimedia Challenges

Main properties of the existing protocols are summarized in Table I. Although these protocols provide congestion detection or reliable transport functionalities, none of them supports real-time (RT) communication or provides multimedia quality-of-service (QoS) guarantees. RMST [6] performs strict (i.e., 100%) packet-based reliability, which is not needed in multimedia communication. ESRT provides reliable event detection, however, it does not consider the requirements of multimedia delivery. On the other hand, GARUDA [8] and PSFQ [7] provide reliability on the reverse path, i.e., from the sink to the sensor nodes, which is irrelevant to the problem of multimedia communication from the sensor field to the sink[1].

TABLE I
Summary of Existing Transport Protocols for WSN

Name	*Direction*	*Congestion Detection*	*Reliability Support*	*QoS or RT Support*
ESRT [3]	Forward	Passive	Event	-
CODA [4]	Forward	Active	-	-
SenTCP [5]	Forward	Active	-	-
RMST [6]	Forward	-	Packet	-
PSFQ [7]	Reverse	-	Packet	-
GARUDA [8]	Reverse	-	Packet	-

Clearly, the existing transport protocols are not specifically designed for multimedia delivery in WSN. Next, we perform a wide range of simulation experiments and provide the results to assess their performance in multimedia communications.

III. Performance Evaluation

Simulation experiments are performed using ns-2 [12]. 50 nodes are randomly placed in 200m X 200m field. 4 source nodes are randomly selected within an event area of radius 70 m. Sink is randomly located within the field. End-to-end hop-count changes between 2 and 8 with an average of 6. Each node has a queue size of 50, radio range of 40m, 2Mbps 802.11 MAC where link layer ARQ and RTS/CTS exchange mechanisms are disabled. Directed Diffusion [10] is used as the routing protocol. Simulations are performed for 25 times using random deployment and the results are averaged. ESRT [3], CODA [4], SenTCP [5], and RMST[2] [6] are included in the experiments.

A. Data Traffic With High Load in WSN

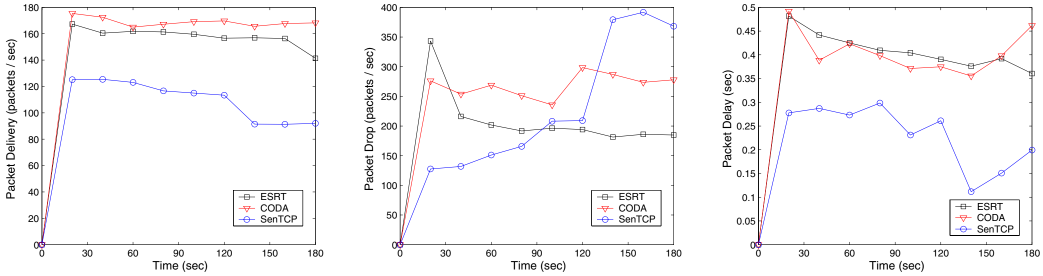
Traffic originating by a multimedia event occurring in a densely deployed sensor field yields high network load. Here, each source is assumed to start transmission with the initial sending rate of 200 packets/sec and a packet size of 200 Bytes. Note that this corresponds to a multimedia delivery scenario where the generated traffic rate is 320 Kbits/sec.

[1]Thus, GARUDA [8] and PSFQ [7] are not included in the experiments.
[2]RMST is only included in video streaming simulations.

Manuscript received November 4, 2006. The associate editor coordinating the review of this letter and approving it for publication was Dr. Luiz Dasilva. This work was supported by the Turkish Scientific and Technical Research Council Career Award under grant 104E043.

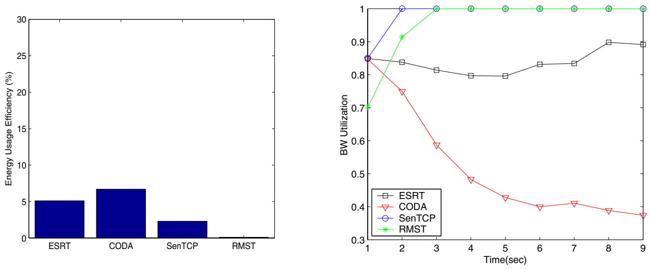
The author is with the Next Generation Wireless Communications Laboratory, Department of Electrical and Electronics Engineering, Middle East Technical University, Ankara, 06531, Turkey (e-mail: akan@eee.metu.edu.tr).

Digital Object Identifier 10.1109/LCOMM.2007.061811.



(a) (b) (c)

Fig. 1. High load data traffic experiments (a) Packet delivery rate, (b) Packet drop rate, (c) End-to-end packet delay.



(a) (b)

Fig. 2. Energy usage efficiency (a) and normalized bandwidth utilization (b).

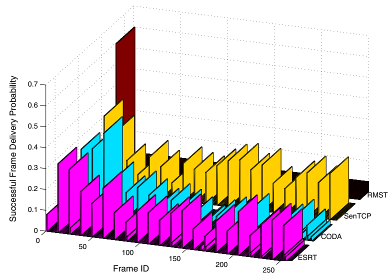


Fig. 3. Successful frame delivery probability.

As shown in Fig. 1, network is congested and works at the full capacity when the data traffic load is high as will be the case with multimedia delivery. In Fig. 1(a) and Fig. 1(b), it is observed that the number of dropped packets are significantly greater than the received packets for all protocols. This shows that sensor nodes waste most of their power in the scenarios where the data delivery requires high bandwidth. As in Fig. 1(c), end-to-end packet delay performances are not satisfactory especially for WSN applications that require effective interaction of sink and sources.

Consequently, the results obtained indicate that these protocols do not achieve efficient communication when the offered network load is high which will be the case in multimedia communication scenarios.

B. Real-time Video (MPEG-4) Streaming in WSN

A sample MPEG-4 stream of 8.6 seconds, i.e., sufficient duration to observe the complete operation of each protocol, (30 fps, 1850 Bytes average frame length, 38 dB average frame PSNR) is used for the simulations. In [11], it is shown that for a given bit error probability, energy efficiency decreases when packet size exceeds a threshold which is nearly 100 Bytes. Hence, the frames are packetized into 100 Bytes for energy efficiency proposes. When any protocol reduces the sending rate, source omits the frame which has a sending time less than that of the next frame to maintain the real-time delivery goals. Results are extracted using a video quality evaluation tool named Evalvid [9]. Lost packets are zero padded for the received video, however, lost sections are extrapolated from the previously reconstructed frames during decoding phase.

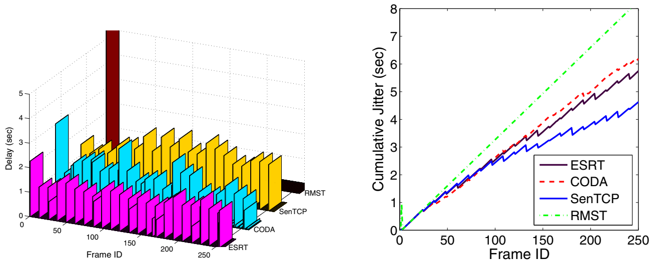
1) Energy and Bandwidth Efficiency: Fraction of lost packets is an indication of waste of energy in WSN. Energy efficiency can be obtained at the sink as the fraction of number of packets received to the total number of dropped and received packets as shown in Fig. 2(a). The energy efficiency of protocols is very low due to huge amount of packet loss under such high load.

The normalized bandwidth utilization, i.e., the ratio of source sending rate to the required sending (initial) rate, is shown in Fig. 2(b). SenTCP and RMST preserve the initial source sending rates while ESRT and CODA try to regulate the source sending rates to decrease the congestion level. However, congestion control schemes of ESRT, CODA and SenTCP do not consider the multimedia requirements and hence cannot meet the expected delivery rate.

2) Probability of Successful Frame Delivery: The probability of successful frame delivery is shown in Fig. 3 for each protocol. None of the transport protocols provide a reasonable frame delivery rate. RMST can only get the first frame across the sink, since it loses the remaining frames while trying to recover all of the lost packets of the first frame with retransmissions. Note also that for all protocols, the probability of successful delivery for initial frames is greater than the others since the network becomes severely congested as more frames are injected to the network.

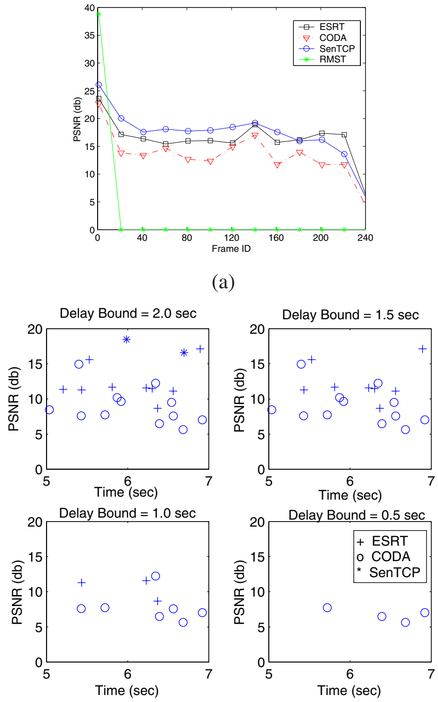
3) Frame End-to-End Delay and Jitter: Frame end-to-end delay results in Fig. 4(a) indicate that the observed delay for successfully delivered frames are very high, e.g., more than 1 second. Note also that the delay of the first frame delivered by RMST is unacceptably high, (i.e., 170 seconds), because of the extra time spent while retransmitting the lost packets.

Cumulative frame jitter is defined as the variance of the



(a) (b)

Fig. 4. (a) Frame end-to-end delay and (b) cumulative jitter performance.



(a)

(b)

Fig. 5. (a) Frame PSNR; (b)delay-bounded frame PSNR, i.e., each point represents a received frame.

inter-frame time. In Fig. 4(b), it is shown that only the initial frames have an acceptable jitter while the jitter increases linearly along other frames. The frame loss gets bursty with time since the congestion in the network increases as more frames are injected, which amplifies the time difference between successfully delivered frames.

4) PSNR and Delay-bounded PSNR: Typical PSNR of a frame should be more than 30 dB to provide a reasonable quality to the end-user. In Fig. 5(a) the resulting PSNR of the received frames are shown. The PSNR levels change between 5 and 20 dB and tend to decrease as the network gets more congested, which implies poor received video quality.

We also measure the *delay-bounded PSNR* to observe the effect of real-time delay bounds on the reliable communication objective for applications such as real-time video target tracking. Here, PSNR of the received frame should be at a certain level within a certain delay bound. In Fig. 5(b), delay-bounded PSNR is shown for various delay bounds for a duration of 60 frame transmission. When delay bound is 2 seconds, most of the received frames satisfy the delay bound, thus, a certain level of PSNR (10 dB) is achieved. Number of received frames with required reliability level decreases with the application-specific delay bound. For a delay bound of 0.5 seconds, none of the protocols achieves delay-bounded PSNR objective.

IV. Conclusion

In this letter, through simulation experimental results, it is shown that the existing transport protocols provide very poor performance for real-time multimedia delivery in WSN. Although ESRT provides application level reliability, it does not provide multimedia specific source rate regulation. CODA and SenTCP use feedback packets from intermediate nodes towards source to control congestion, however, when there is excessive traffic on the forward path, the reverse path is not available at all, leading high packet loss rate, waste of energy and poor received video quality. The protocols under observation do not consider delay, thus, frame delays are high and delay-bounded PSNR is very low. High bandwidth demand, energy-efficient reliable multimedia delivery, and real-time delay requirements are the most important challenges that need to be addressed by the new multimedia communication protocols for WSN. Due to strict coupling of different communication layers, cross-layer paradigm seems promising in order to address multimedia challenges, and new technologies such as ultra wide band (UWB) transmission should be considered to solve high bandwidth demand with low power consumption.

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] E. Gurses and O. B. Akan, “Multimedia communication in wireless sensor networks,” *Annals of Telecommun.*, vol. 60, no. 7-8, pp. 799-827, July-Aug. 2005.

[3] O. B. Akan and I. F. Akyildiz, “Event-to-sink reliable transport in wireless sensor networks,” *IEEE/ACM Trans. Networking*, vol. 13, pp. 1003-1016, Oct. 2005.

[4] C. Wan, S. B. Eisenman, and A. T. Campbell, “CODA: congestion detection and avoidance in sensor networks,” in *Proc. ACM Sensys 2003*, Nov. 2003.

[5] C. Wang, K. Sohraby, and B. Li, “SenTCP: a hop-by-hop congestion control protocol for wireless sensor networks,” in *Proc. IEEE INFOCOM 2005*, March 2005.

[6] F. Stan and J. Heidemann, “RMST: reliable data transport in sensor networks,” in *Proc. IEEE SNPA 2003*, pp. 102-112, May 2003.

[7] C. Y. Wan, A. T. Campbell, and L. Krishnamurthy, “PSFQ: a reliable transport protocol for wireless sensor networks,” in *Proc. ACM WSNA 2002*, pp. 1-11, Sept. 2002.

[8] 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.

[9] EvalVid - a video quality evaluation tool-set, http://www.tkn.tu-berlin.de/research/evalvid.

[10] C. Intanagonwiwat, R. Govindan, D. Estrin, J. Heidemann, and F. Silva, “Directed diffusion for wireless sensor networking,” *IEEE/ACM Trans. Networking,* vol. 11, no. 1, Feb. 2003.

[11] Y. Sankarasubramaniam, I. F. Akyildiz, and S. W. McLaughlin, “Energy efficiency based packet size optimization in wireless sensor networks,” in *Proc. IEEE SNPA 2003,* pp. 1-8, 2003.

[12] Network Simulator - (ns-2), http://www.isi.edu/nsnam/ns/.