SURVEY ON RELIABILITY OF TRANSPORT PROTOCOLS FOR SENSOR NETWORKS

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ABSTRACT

This paper presents a survey on transport protocols for wireless sensor networks (WSN). In this paper we present current and future challenges in the design of transport layer protocols for sensor networks. Current transport layer protocols are compared based on how they implement reliable message delivery, congestion control, and energy efficiency.

INTRODUCTION

Wireless sensor networks (WSNs) provide a powerful means to collect information on a wide variety of natural phenomena. WSNs typically consist of a cluster of densely deployed nodes communicating with a sink node which, in turn, communicates with the outside world. WSNs are constrained by low power, dense deployment, and limited processing power and memory. WSNs are composed of small, cheap, self-contained, and disposable sensor nodes. The unique constraints imposed by WSNs present unique challenges in the design of suchnetworks.

The need for a transport layer to handle congestion and packet loss recovery in WSNs has been debated; the idea of a cheap, easily deployable network runs contrary to the costly, lengthy process of implementing a unique and specialized transport layer for a WSN. WSNs have advanced to the level of specialization where congestion control and reliability can be incorporated at each individual node.

Reliable data transmission in WNSs is difficult due to the following characteristics of WSNs:

- Limited processing capabilities and transmission range of sensornodes;
- Close proximity to ground causes signal attenuation or channel fading which leads to asymmetriclinks;
- Close proximity to ground and variable terrain also leads to shadowing which can effectively isolate nodes from thenetwork;
- Conservation of energy requires unused nodes and wake only whenneeded;
- Dense deployment of sensor nodes creates significant channel contention andcongestion.

The above characteristics can cause loss of data in WSNs. Fortunately, WSNs also provide unique features that can be leveraged to help mitigate losses and design energy efficient transport layer protocols by network designers. For example, When the nature of the data allows, it can be aggregated at intermediatenodes.

1. Network density, multiple paths to any given destination, and data aggregation in combination with a good choice of network layer can lessen some of the losses due to channel fading and shadowing.
2. Some amount of loss can be made acceptable by employing data aggregation at the sensor nodes.
3. Data aggregation may result in smaller packet size and consequently lower packetloss.
4. Granularity of sensing an event can becontrolled.
5. Some events may require a very roughgranularity.

RELIABILITY IN WIRELESS SENSOR NETWORKS

Traffic from many applications in WSNs is considered loss tolerant. Loss tolerance in WSNs is due to the dense deployment of sensor nodes and data aggregation properties, giving rise to directional reliability. The design of WSN transport layer protocols should exploit directional reliability to lower the number of transmissions, especially for sensors that are close together and are expected to generate highly correlated data [20], and decrease the computational overhead by lowering the amount of data to be aggregated.

Some transport layer protocols only offer unidirectional reliable message delivery, where the idea of directional reliability is especially important. In the rest of this section, we discuss the following three types of reliability in aWSN:

- **Point-to-point** – Communication between sink and a remotehost,
- **Point-to-multipoint** – Communication between sink and sensor nodes,
- **Multipoint-to-point** – Communication between sink and multiple wirelesssensors.

TRANSPORT PROTOCOLS FOR SENSOR NETWORKS

In addition to energy-efficient transport layer protocols in resource constrained WSNs, the protocol should also support

- Reliable messagedelivery,
- Congestion control,and
- Energyefficiency.

Congestion has a significant impact on the performance of reliability transport protocols. The only transport protocols that support both reliability and congestion control are STCP and, indirectly, DTC.

Although DTC was not developed as a solution to the congestion control problem, it relies on the TCP mechanisms. As to STCP, its end-to-end congestion control scheme mimics its limitation of end-to-end reliability. Both rely on end-to-end closed-loop rate adjustment, which is not good to deal with the frequent short term variations that frequently happen at intermediate points of routes in a multihop network. In order to constitute an effective answer to the congestion control problem, open-loop hop-by hop backpressure mechanisms (like in e.g. PCCP [17], ARC [18]) are necessary, besides the already mentioned end-to-end regulation. Traffic differentiation is another important functionality to assure appropriate QoS to different applications.

Different kinds of sensorial data require different reliability grades. Partial reliability grades are considered in ESRT, ART, STCP, DTSN, as well as the erasure code techniques proposed by Kim et al [9] (especially suited for audio and imaging). ART and STCP include mechanisms that can be used to deliver differentiated reliability based on the fraction of confirmed packets, while erasure codes with different code rates constitute an alternative means of offering different reliability grades. ESRT considers a single reliability grade for all traffic. DTSN supports different grades of reliability. Total reliability is based on end-to-end Selective Repeat ARQ, coupled with caching of data packets at intermediate nodes so that the number of end-to-end retransmissions is minimized. For scalable bulk data transfer such as still image transmission, partial reliability can be achieved by the Enhancement Flow and Forward Error Correction (FEC) options. The Enhancement Flow option consists of buffering only a fraction of a block of data packets at the source (designated the core), being transmitted with total reliability (e.g. this may correspond to a minimum image resolution). The remaining data packets that constitute the block (e.g. image resolution increments) are granted no guarantees, since they are considered enhancementdata.

When coupled with intermediate caching and/or FEC, the Enhancement Flow is able to achieve high reliability grades while significantly increasing the throughput in comparison with the total reliability service. DTSN only provides the basic mechanism, not addressing how the size of the core can be adapted to keep a uniform reliability level in the presence of a highly variable link quality. The dynamic management of stable and differentiated reliability grades is still a subject for research. While most of the WSN traffic is upstream by definition, some management and control tasks performed by the sink nodes involve downstream flows, possibly multicast/broadcast, with reliability requirements that vary with the specific application. Dynamic code update (DCU), re-configuration and querying are three important examples of such functions. PSFQ, GARUDA and ART (queries only) are designed to provide downstream multicast reliability. ART is the only one that explicitly considers both upstream and downstream reliablecommunication.

Almost all reliable transport protocols place the control of loss recovery at the receivers, ART and DTSN being an exception regarding the emission of ACK packets. Placing the control at the receiver enables continuous cleaning of the output queues at the sender, with a consequent increase in throughput.

However, this strategy also increases the ACK / NACK overhead, with consequences in terms of energy efficiency. It is thus worth evaluating whether sender-controlled or receiver-controlled loss recovery is more suitable to a given WSN application.

Reliable transport protocols usually try to fit only one or two from the following types of reliability: event-driven, packet-driven, block driven. Of these, only the first is specific of WSNs, being usually associated with a data-centric networking paradigm (i.e. if several sensors report the same event, the transport protocol should guaranteed that at least one of those reports reaches the sink node). With the exception of ESRT and RMST, no transport protocol explicitly addresses reliability in data-centric WSN applications. In fact, none of the transport protocols mentioned in this paper is able to provide full reliability in data-centric WSNapplications.

Table 1: Reliable transport protocols for WSNs.

Transport Protocol	**WSN Direction**	**Loss Detection and Notification**	**Loss Recovery Control**	**Loss Recovery**	**Type of Reliability**	**Reliability Level**	**XCast**
PSFQ [5] Pump Slow Fetch Quickly	Downstream	NACK	Receiver node	Hop-by-hop	Packet-driven	Total (unless complete packet block lost)	Multicast / Broadcast (a variant allows Unicast)
ESRT [6] Event to Sink Reliable Transport	Upstream	Implicit	Sink establishes update frequency	End-to-end Redundancy: frequency of update messages	Event-driven	Partial	Unicast
RMST [7] Reliable Multi-Segment Transport / Directed Diffusion [8]	Upstream	NACK	Receiver node	Hop-by-hop	Packet-driven	Total (unless complete packet block lost)	Unicast
Erasure Code ([9])	Upstream	N.A.	N.A.	N.A.	Block-driven	Partial	Unicast
RBC [10] Reliable Bursty Convergecast	Upstream	ACK / NACK (Implicit ACK at MAC layer only)	Receiver node	End-to-end (Hop-by-hop at MAC layer only)	Packet-driven	Total	Unicast
GARUDA [11]	Downstream	NACK	Receiver node	Two-tier two-stage	Packet-driven / Destination-driven	> PSFQ due to Wait-for-First-Packet	Multicast / Broadcast
DTC [12] Distributed TCP Caching	Upstream	ACK, SACK	Receiver node (sink)	Hop-by-hop	Packet-driven	Total	Unicast
ART [13] Asymmetric Reliable Transport	Upstream (events) / Downstream (queries)	NACK (queries) / ACK (events)	Sender (ACK) or Receiver node (NACK)	End-to-end	Packet-driven / Destination-driven (queries)	Partial / Total	Multicast (queries) / Unicast
ATP [14] Ad-hoc Transport Protocol	Upstream	SACK	Receiver node (sink)	End-to-end	Packet-driven	Total	Unicast
STCP [15] Sensor TCP	Upstream	ACK / NACK	Receiver node (sink)	End-to-end	Event-driven / Packet-driven	Customizable	Unicast
DTSN [16] Distributed Transport for Sensor Networks	Upstream	ACK, SACK	Receiver node (sink)	Hop-by-hop	Packet-driven / Block-driven	Partial / Total	Unicast

CONCLUSION

A transport layer is needed in wireless sensor networks to control congestion and ensure reliable delivery of messages from the sensor nodes to the sink. The limited energy, memory, and computational resources of sensor nodes require an energy-efficient transport layer. Traditional transport protocols, such as TCP/IP, do not provide an efficient enough alternative without serious modification; however, modifying TCP/IP may prove useful at sink nodes to optimize communication between regions in the sensor fields and hosts on foreign networks.

More research is needed on congestion control in sensor networks. A measure of data "goodness" to supplement a protocol, such as ESRT, may be beneficial in determining whether a data needs to be retransmitted. If the current aggregated data at a node does not measure up to the goodness level, the node could hold the data until more neighbors report information to be aggregated, thereby reducing the amount of data repeated on the network.

Sliding granularity protocol is another area of future research. A protocol similar to ESRT, that when notified of an event, dynamically shifts granularity so that messages can be watched more closely. This way protocols such as RMST or PSFQ that provide reliability based off a negative acknowledgement system would not have to account for the overhead of sending NACKs unless some event has been sensed.

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