Caching Based Transport Optimization for Wireless Multimedia Sensor Networks

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ABSTRACT

Traditional transport layer protocols have been designed to perform end-to-end error control transparently to the intermediate nodes (e.g., TCP). To address the severe resource constraints featured by Wireless Sensor Networks (WSN), new paradigms have been developed such as intermediate caching where intermediate nodes are able to cache packets and if possible retransmit them on-demand to avoid incurring costly end-to-end retransmissions. Lately, Wireless Multimedia Sensor Network (WMSN) has been considered as a new research area whereby WSNs are targeted for the delivery of multimedia traffic. In this paper, we propose a NACK-based repair mechanism coupled with an adaptive MAC layer retransmission scheme in order to improve the performance of caching-based WMSN transport protocols. Specifically, our goal is to be able to reduce real-time end-to-end delay while maintaining reliability and energy efficiency in the presence of high channel error rates. Our simulation results show that the ensemble of both mechanisms provides better goodput performance while simultaneously improving energy efficiency. Furthermore, the improved protocol also achieves lower deadline miss ratios making it suitable for multimedia transport. While we demonstrate the effectiveness of the mechanisms by incorporating them into the basic Distributed Transport for Sensor Networks (DTSN) protocol, they are generic enough to be applicable to other WSN and WMSN transport protocols.

Keywords: Cross-Layer Optimization, Intermediate Caching, Multimedia, Transport, Wireless Multimedia Sensor Networks (WMSN)

INTRODUCTION

A Wireless Sensor Network (WSN) is typically composed of small autonomous resource-constrained devices that transmit data from sensor nodes to one or more sink nodes. Since WSN nodes operate autonomously, power-saving techniques are usually complemented with low power radio communications that lead to multi-hop data transmission from the sensor nodes to the sink nodes and vice versa. Besides leading to a lower throughput, multi-hop communications are also the cause of additional interference and hidden terminal problems due to spatial reuse, which, complemented with the fact that most WSN standards such as IEEE 802.15.4 specify...
operation in unlicensed ISM bands, means that radio links are usually more error-prone than in typical WLANs.

The traditional design of reliable transport protocols is end-to-end delivery of data segments from the source to the destination transparent to the intermediate nodes along the path (e.g., TCP). However, this semantic leads to poor performance (in terms of throughput and energy efficiency) when applied to WSNs. Thus, new semantics have been developed where part of the transport layer’s function is packet loss detection and recovery of lost segments, which can be performed either end-to-end or hop-by-hop. In the end-to-end semantic, the endpoints (sender or receiver) are responsible for loss detection and initiating loss recovery. On the other hand, in the hop-by-hop semantic, the intermediate nodes along the path from the sender to the receiver are responsible for these functions.

WSN protocols can be classified into two general classes based on how reliability is guaranteed or achieved, namely (1) packet-based and (2) event-based (Wang et al., 2006). With packet-based reliability, such as implemented in RMST (Stann & Heidemann, 2003), PSFQ (Wan, Campbell & Krishnamurthy, 2002), DTSN (Marchi, Grilo & Nunes, 2007), lost packets are detected at the sink and/or at intermediate nodes and a retransmission scheme is used. Loss signaling uses some kind of acknowledgment mechanism and loss recovery is performed either in a hop-by-hop or end-to-end manner. Furthermore, protocols that implement packet-based reliability can leverage on intermediate caching where cache points are able to help in retransmitting lost packets. On the other hand, event-based reliability such as addressed by ESRT (Akan & Akyildiz, 2005) and ERTP (Le, Hu, Corke & Jha, 2009) guarantees reliability through end-to-end source rate adjustment, where the perceived reliability at the sink is signaled back to the source. The source node increases the rate if the current reliability is not met (subject to congestion constraints) and reduces the rate if the required reliability is exceeded.

In addition to providing end-to-end reliability and congestion control, transport layer protocols designed to address the unique characteristics of the WSN paradigm as well as multimedia delivery need to be developed (Akyildiz, Melodia & Chowdhury, 2007). For example, high-data rate and real-time applications require new transport layer solutions that can meet strict delay deadline requirements as well as maintain energy efficiency. (Akan, 2007) has analyzed the performance of WSN transport protocols for multimedia communications and documented the poor performance of existing protocols. Furthermore, a more recent work by Misra, Reisslein, and Xue (2008) has reported based on their evaluation that the existing protocols are not well-suited for supporting multimedia traffic in WSNs. In Shaikh, Khelil, and Suri (2008), the authors concluded that existing protocols cannot be deployed in harsh environments where network connectivity is transient or volatile.

Paper contributions: We address the aforementioned problem by proposing transport layer mechanisms that can enhance the performance of caching-based WMSN transport protocols. Specifically, this paper makes the following contributions: (1) For the MAC Layer, we develop a tunable localized adaptive retransmission mechanism that provides probabilistic MAC layer reliability. In a cross-layer fashion, the MAC layer adapt the value of the retry limit based on the measured lower-layer physical error rate. (2) For the transport layer, we develop a NACK-based repair mechanism to proactively initiate intermediate retransmission once an out-of-sequence packet is detected, without waiting for the NACK to be sent from the receiver back to the sender. (3) We perform extensive simulations to analyze the performance improvement due to our proposed mechanisms. These transport layer mechanisms are completely decentralized and are simple enough to incorporate into other WSN transport protocols.

Related Work

In this section, we mainly focus on WSN transport protocols that support intermediate caching.