TRANSPORT AND LINK-LEVEL PROTOCOLS FOR WIRELESS NETWORKS AND EXTREME ENVIRONMENTS

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ABSTRACT

The widespread deployment of wireless links and the expected explosion in the use of wireless broadband systems makes it important for link and transport layer protocols to perform well in these environments. Wireless paths, especially multi-hop paths present challenges in terms of bounded end-to-end delay, end-to-end packet error rate (PER) experienced by the transport layer and achievable goodput. Current transport protocols such as TCP-SACK are known to fail as the PER goes above 5 % PER.

In this thesis, we develop transport and link-level protocols that use the principles of fragmentation, loss estimation and Forward Error Correction (FEC). Our design structures these building blocks to perform well even under high loss rates (up to 50 % PER). Analysis of the scheme enables us to tune the protocols based on their different needs while providing insight into the most favorable configuration. We also illuminate the issue of balance of functionality and interactions between the link and transport layers. At the link layer, these mechanisms are designed to meet the objectives of having bounded delay while exporting a negligible residual error rate. Link-layer mechanisms are designed to be robust under conditions of disruptions when no communication is possible. This is accomplished by using mode-switching and outage detection techniques designed to combat disruptions. However, over multi-hop paths, per-hop residual loss rates may aggregate and result in significant end-to-end loss rates (¿ 5%). Link-level mechanisms by themselves are insufficient and support at the transport layer is needed under high end-to-end loss rate scenarios. At the transport layer, we concentrate on tackling the residual error rate while operating on a longer time-scale. Our contributions include: (a) A highly loss-tolerant TCP protocol (LT-TCP) using an adaptive, end-to-end hybrid ARQ/FEC reliability strategy exploiting ECN for congestion detection. (b) A link-layer hybrid ARQ/FEC protocol (LL-HARQ) resulting in small residual PER, bounded link latency and high goodput even under bursty/high loss and outage conditions. (c) Demonstration that the combination achieves improved end-to-end performance (delay, loss and goodput) over traditional approaches. We present performance results for a comprehensive set of scenarios including different loss/error models as well as under different (1-hop and multi-hop) topologies.

We then tested the LT-TCP protocol in an 802.11b setting where we consider errors introduced by cross-system interference (by modeling Bluetooth traffic) as well as co-channel interference (by modeling two interfering 802.11 cells). We find that such setups are susceptible to "capture" or channel outages and that LT-TCP can provide benefits under such capture scenarios, particularly as the RTT increases. Measurements on the Open-Access Research Testbed for Next-Generation Wireless Networks (ORBIT) were used to study the impact of noise-induced errors on the performance of currently deployed protocols in real systems. We show how the performance of current protocols degrades as the error rate go up and how retransmissions at the link layer can lead to unwanted interactions between link and transport layers. These measurements give insights into the impact of wireless packet losses and bolster the case for developing protocols that are robust to high loss rates. Finally, we used real-world traces gathered from airplane flights to study the nature of outage and disruption events and to model packet losses on airborne wireless links. These link characteristics and models of packet losses were used to test and refine our link and transport protocols and to validate the efficacy of our proposed solutions under realistic conditions.