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Stack Architectures and Protocols for Emerging Wireless Networks

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Recent devices developed for emerging wireless networks, such as 4G cellular networks, wireless mesh networks, and mobile ad hoc networks, support multiple communication substrates and require execution of multiple protocols within a layer, which cannot be supported efficiently by traditional, layered protocol stack approaches. While cross-layer approaches can be designed to support these new requirements, the lack of modularity makes cross-layer approaches inflexible and hence difficult to adapt for future devices and protocols. Thus, there is a need for a new protocol stack architecture to provide universal support for cross-layer interactions between layers in a modular stack framework, while also supporting multiple communication substrates and multiple protocols within a stack.

In this thesis, we first examine the X-Lisa protocol architecture, which achieves the goals of modularity and support for cross-layer interactions. However, recognizing the need for additional support for cross-layer interactions and for enabling multiple communication substrates and multiple protocols within a stack, we propose Universal Protocol Stack (UPS), which provides such support in a modular way through packet- switching, information-sharing, and memory management. To show that UPS is realizable with very low overhead and that it enables concurrent and independent execution of protocols of the same stack layer, we present a wireless sensor network test-bed evaluation, and we also simulate UPS using OPNET. Our implementation and simulations show that the overhead incurred to implement UPS is very low, and little or no modification is required to adapt existing protocols to the UPS framework. Both studies also show the advantage of enabling concurrent protocol execution within a stack layer, improving the successful packet delivery ratio or the total number of packets sent for the investigated scenarios.

A majority of existing communication protocols are developed with the assumption of a single radio. While there has been some initial work on protocols that use multiple radios, existing approaches are limited to specific application domains and specific radio interface implementations. In this thesis, we use UPS to support multiple radio interfaces by abstracting all the available interfaces using a single virtual interface. The selection of the specific physical interface to use per packet is done by the virtual inter- face, thus ensuring that no modifications of the upper layer protocols are required. This provides the opportunity for algorithms at the virtual interface to optimize the selection of the physical interface to improve the network performance. To test the virtual inter- face approach, we evaluate scenarios with multi-radio devices that support LTE, WiFi, and a CSMA network through simulations in ns-3. Results from these simulations show that the use of a virtual interface is feasible and can improve the network performance.

While new protocol stack architectures are important to enable protocol interactions and support for multiple protocols and substrates, efficient protocols are equally important to supporting emerging networks. In particular, emerging networks exhibit network dynamics, due to node mobility and limited energy supplies requiring node duty cycling, and time-varying channel conditions. In this thesis, we explore the use of receiver-based routing to support such network dynamics. Specifically, we look at receiver-based multicast and converge cast-routing. For multicast routing, we propose a stateless receiver-based multicast protocol that removes the need for costly state maintenance (e.g., tree/mesh/neighbor table maintenance). Our protocol, called RBMulticast (Receiver-Based Multicast), simply uses a list of the multicast members' (e.g., sinks') addresses, embedded in packet headers, to enable receivers to decide the best way to forward the multicast traffic. We simulated RBMulticast using OPNET and we implemented RBMulticast in a sensor network test-bed. Both simulation and experimental results confirm that RBMulticast provides high success rates and low delay without the burden of state maintenance.

Using the idea of receiver-based routing for converge cast transmissions, we derive a mathematical model to determine the energy dissipation of a node as a function of its duty cycle and its distance to the sink. We find the duty cycle as a function of node distance to the sink to minimize the expected energy dissipation. Additionally, in order to balance energy efficiency and latency, we develop a traffic-adaptive duty cycle approach that begins with the distance-based duty cycle assignment and adapts the duty cycle based on current local traffic patterns observed by the node.