INFORMATION TRANSPORT IN WIRELESS AD HOC NETWORKS: CAPACITY, CONTROL AND OPTIMIZATION

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ABSTRACT

A wireless ad hoc network (WANET) is an autonomous collection of nodes that communicate over relatively bandwidth constrained wireless links. The network is infrastructureless and dynamic, where nodes communicate primarily with nearby nodes, and exchange neighbor information to enable routing throughout the network. Mobile ad hoc networks (MANETs) and wireless sensor networks (WSNs) are two typical examples of WANETs. In these network scenarios, efficient information transport is the primary objective as well as the biggest challenge of the network design. In this thesis, we develop methodologies and techniques to characterize, control and optimize information transport in WANETs.

On one hand, as routing has been recognized as a basic operation for information transport in such infrastructureless networks, we develop an analytical framework to study the capacity of information transport in WANETs with practical routing strategies. Different from existing analytical works where routing/relaying schemes are idealized and the impact of routing control traffic is not considered, we explicitly characterize the coexistence of the routing control traffic and data traffic with a multi-class queue model at each node. We investigate the scaling property of the throughput, maximum mobility degree supported by the network and mobility-induced throughput deficiencies, under prevalent proactive and reactive routing strategies. We then show that the proposed analytical model can be extended to evaluate various routing optimization techniques as well as to study routing/relaying strategies other than proactive or reactive routing. The connection between the derived throughput result and some well-known network throughput capacity results in the literature is also established.

On the other hand, from a design perspective, we investigate optimal control strategies for information transport in WANETs. We first focus on the cross-layer control of operations in the lowest three layers (i.e., physical, link and network layers) of the protocol stack in WANETs. A layered *sequential* decision framework is developed to optimize the routing/forwarding operation in the network layer, the

link scheduling operation in the link layer and the transmission control operation (i.e., transmission power/rate control) in the physical layer. Although scheduling and transmission control should be jointly optimized in general, under a constant nodal transmission power setting, a *separation* principle is further identified, which shows that scheduling and transmission control can be separately designed without loss of optimality, given appropriate information conveyed between the layers. In the network layer, the benefit of cross-layer information for routing performance is quantified and the optimal routing/forwarding strategy is characterized.

We further consider the control and optimization of information transport in two specific application scenarios in WANETs. One is the control of the data aggregation operation in WSNs, where data aggregation is a data processing procedure to reduce redundant information transport in the network. An intrinsic trade-off between the energy gain and the extra delay induced by data aggregation is identified and the control targets to determine the optimal instant to terminate a data aggregation operation and forward the aggregated samples, where the optimality is in the sense that the desired energy-delay trade-off is achieved. By considering the randomness of the sample arrival instants and the uncertainty of the availability of the multi-access communication channel, a sequential decision process model is developed to analyze this problem and determine optimal control strategies. Another application scenario is the location information management in MANETs. We consider the control of location information updates in the location service where nodes are mobile and need to maintain their up-to-date location information in the network. A trade-off exists between the costs in location information update operations, on one hand, and the additional incurred costs in the application (e.g., position-based routing) due to location errors, on the other hand. Again, a sequential decision process model is proposed to analyze this trade-off and provide design guidelines on selecting good location information update strategies in practice.

In all design cases, efficient algorithms based on the corresponding proposed decision models are also developed to achieve optimal/near-optimal control performance in practice.