The Effect of Introducing Redundancy in a Probabilistic Forwarding Protocol

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I. Motivation and Problem Description

An ad-hoc network is a network of nodes which communicate with each other without relying on any centralized infrastructure. Certain applications involving ad-hoc networks require information to be broadcast from a source node to all the other nodes in the network. Flooding is a common strategy for broadcasting content to all nodes. In this strategy, each node, upon receiving a new message packet, forwards it to all its one-hop neighbours. While this strategy is simple and easy to implement, it is wasteful in terms of overall power consumption as the total number of transmissions across all nodes in the network can be quite high.

An attractive alternative that has been considered in the literature is probabilistic retransmission or probabilistic forwarding, in which each node in the network, upon receiving a new packet, decides to broadcast it to its one-hop neighbours with probability p, and takes no action with probability $1-p$. Probabilistic forwarding has been known to save considerable message overhead when compared to flooding while at the same time improving the end-to-end latency and throughput.

In our work [1], we study the effect of introducing redundancy, in the form of coded packets, into this probabilistic forwarding protocol. For this, consider a graph $G = (V, E)$ where V is the vertex set with N vertices (nodes) and E is the set of edges (communication links). We assume that the source node has k data packets to broadcast, which are encoded into $n \geq k$ coded packets using a Maximum Distance Separable (MDS) code. Thus, reception of any k of these n coded packets are sufficient to recover the original k data packets. The source node then broadcasts all n coded packets to its one-hop neighbours, from whence the probabilistic forwarding protocol takes over. Each packet which is received for the first time at a node, is transmitted with probability p independently of other packets and other nodes. Subsequent receptions of the same packet are ignored. This probabilistic retransmission continues until the time there are no further transmissions in the system. Our interest is in determining the minimum forwarding probability p for a "successful broadcast", which we take to be the event that the expected fraction of network nodes that receive at least k of the n coded packets is close to 1. The performance measure of interest is the expected total number of transmissions across all nodes when the nodes forward a packet with this minimum probability.

II. Some Results and Future Work

Simulations of the probabilistic forwarding protocol as described above, with additional redundancy due to coding, were performed on different types of graphs. Our simulation results show that, over a variety of network topologies that are highly connected — for example, grids, and random geometric graphs (RGG) above the connectivity threshold — the expected total number of transmissions by all the nodes of the network decreases initially to a minimum and then increases as the redundancy $\rho = \frac{n-k}{k}$ is increased. This means that there is some value of redundancy which is optimal, in the sense that it minimizes the number of transmissions. Consequently, a network in the grid or the random geometric topology performs best when operated at this value of redundancy and the corresponding minimum forwarding probability. On the other hand, over trees, our simulations indicate that there is no benefit to introducing redundancy in the probabilistic forwarding protocol. In fact, we have been able to analyze and show that, on d-ary trees, the expected total number of transmissions increases with redundancy.

Heuristically, the behaviour on grids and RGGs, can be attributed to the existence of multiple paths between the source node and any other node in these graphs. On trees, the presence of a unique path from the root to any node on the tree is vital in showing that the expected total number of transmissions increases with redundancy. In order to test our hypothesis more systematically, further simulations of the probabilistic forwarding protocol was performed on graphs with different number of paths from the source to any node on the graph. The simulation results support our hypothesis that number of paths from the source to any node in a network is an important factor in determining whether or not the probabilistic forwarding protocol over the network would benefit from coding-based redundancy. In future work, we hope to be able to precisely characterize how multiple paths lead to a reduction in the overall number of transmissions needed for a successful broadcast.

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[1] V. Kumar B. R., R. Antony, and N. Kashyap, "The effect of introducing redundancy in a probabilistic forwarding protocol," submitted to the *Twenty-fourth National Conference on Communications (NCC) 2018*, Hyderabad, India, Feb 2018.