Poster: Optimum Transmit Range and Capacity of Mobile Infostation Networks

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Abstract — **A mobile infostation network stipulates all transmissions to occur when nodes are in proximity. In this paper, the effect of transmit range on the capacity of four transmission strategies is studied. We show that a stipulated transmit range improves the capacity relative to the reference strategy with an unconstrained transmit range. This indicates an optimal trade-off exists between spatial transmission concurrency and spectral efficiency on individual links. The optimal number of neighbors is invariant to node density, and is between 0.6 to 1.2 for our transmission strategies. This result should be contrasted to a magic number of 6 to 8 neighbors for multihop networks, where the expected forward progress per hop is maximized. This reflects the different optimization criteria of mobile infostation and multihop ad hoc networks. In addition, the capacity per unit area increases linearly with node density. This is counter-intuitive but can be explained using a rescaling argument drawn from percolation theory.**

General Terms: Performance
Keywords: Capacity, Transmit Range, Mobile Infostation

I. INTRODUCTION

In a mobile infostation network, any two nodes communicate only when they have a very good channel. This occurs usually when nodes are in proximity. Under this transmission constraint, any pair of nodes is intermittently connected as mobility shuffles the node locations. The network capacity of mobile infostation networks compares favorably to multihop ad hoc networks [1], [2]. In [2] Gupta and Kumar showed that the per node throughput of a multihop network with n nodes drops to zero at a rate $O(\frac{1}{\sqrt{n \ln n}})$ in the limit of large n. Thus multihop networks do not scale with large network size. On the other hand, Grossglauser and Tse showed in [1] that the per node throughput of a mobile infostation networks is $O(1)$, independent of the number of nodes. This capacity is achieved through a two hop relay strategy. Suppose each node i has a packet to a destination node $d(i)$. When a node comes close to other nodes $k \neq d(i)$, it relays the packet to them, hoping that one of the relay nodes reaches the destination $d(i)$ and complete the second relay on its behalf. At the steady state, each node contains many packets addressed to various destinations. It is almost surely that each node has a packet addressed to its nearest neighbor at any network snapshot. Nevertheless, the order of magnitude improvement in network capacity comes at a cost. End to end transmissions incur a random delay that is at the same time scale of the mobility process.

Motivated by the dramatic capacity improvement of mobile infostation networks, there are a number of recent papers that explore the mobile infostation paradigm. Whereas [1] focused on unicast, [4], [6] addressed multicast in mobile infostation networks. [4] assumes nodes cooperate with each other in the network. In order to expedite data dissemination, a node also relays packets for other nodes if it has not done so for some time. The issue of noncooperation between nodes was explored in [6]. Transmissions between two proximate nodes are allowed only when both nodes benefit from a file exchange. Nevertheless, simple interference and mobility models are used in [6] to facilitate analysis.

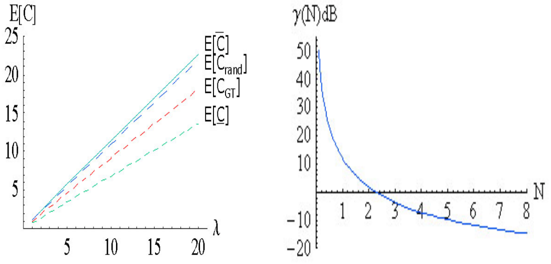
In the mobile infostation literature, the concept of physical proximity is not well characterized. In [6], it assumed that the planar network consists of discrete locations, in which any two collocated nodes can participate a file exchange. Physical proximity is defined in terms of a hypothetical grid of discrete points, leading to a overly simplified mobility and interference model. On the other hand, [1] assumed that a *candidate transmit node* always transmits to the closest receive node. Although the transmit and receive node pair has the shortest distance, this strategy may not perform well since this distance may be large in some pathological topology realizations. In these links, the benefit of spatial transmission concurrency may be more than offset by a simultaneous increase in total interference power in the network. It may be worthwhile to suppress the transmissions when the channel is less excellent, even though the receive node is the node closest in distance. The resultant decrease in total interference power due to the suppression of transmissions in the less excellent channels may be beneficial to the sum rate of the remaining connections. To ensure that only excellent channels are used, a natural strategy will be imposing an artificial *transmit range* for all nodes. A transmit node may well see many receive nodes beyond the transmit range due to the physical proximity of nodes. However, we impose this artificial transmit range and block all these potential transmissions. Here we explicitly trade spatial transmission concurrency for greater spectral efficiency of the remaining connections in the network. As far as the transmit node is concerned, all nodes within the transmit range are its *neighbors*. It is desirable to see if the stipulation of an artificial transmit range will further improve the network capacity.

II. CAPACITY MAXIMIZATION

We investigate four transmission strategies in this paper: a non-adaptive strategy, a random node in range strategy, a closest node in range strategy and the closest node strategy. In the non-adaptive strategy, the transmission rate is determined by the SIR at the transmit range boundary, $\gamma(r_0) = g(r_0)/Y$. Even if the SIR is higher when two nodes are closer than distance r_0, the additional link capacity warranted by the higher SIR is not exploited. We denote the capacity per unit area of the non-adaptive strategy as $E[\underline{C}]$ to allude that this strategy provides a lower performance bound to the four strategies.

Both the random node in range and the closest node in range strategies operate on the assumption of rate adaptive transmission. In the random node in range strategy, a candidate transmit node randomly selects a receive node when multiple receive nodes are within its range. In the closest node in range strategy, the closest node in range is selected to exploit the best channel. In the case there are no receive nodes in the range of a candidate transmit node, no transmission is scheduled. It is obvious the latter strategy has superior performance since the candidate transmit node always selects the receive node with the best SIR and link capacity. We denote the performance metric as $E[\overline{C}]$ to emphasize that this strategy provides an upper performance bound of all the four strategies. The corresponding metric for the random node in range strategy is denoted as $E[C_{rand}]$.

We also examine a reference strategy with an unconstrained transmit range, A candidate transmit node always transmits to



(a) (b)

Fig. 1. (a) The expected sum rate per unit area for the four strategies. (b) Illustration of SIR γ as a function of number of neighbors N.

the closest receive node even though it may be far away in some pathological topology realizations. This strategy is similar to the strategy in [1], though there is no consideration of rate adaptation in that paper. For the sake of fair comparison, however, we assume the reference strategy is rate adaptive in this paper. Hereafter, we refer to this strategy as the Grossglauser-Tse (GT) strategy. The corresponding capacity per unit area is denoted as $E[C_{GT}]$. Since there is no transmit range for this strategy, we optimize $E[C_{GT}]$ over θ.

In Figure 1(a), we compare the capacity of the four strategies. The non-adaptive strategy has the worst performance as expected. The closest node within range strategy outperforms the random node within range strategy by a small margin. At the optimal range, the average number of nodes within the transmit range is between 0.6 to 1.2 for the four strategies. Thus, most of the time a random node is exactly the same as the closest node. This explains the close performance of the two strategies. The GT strategy, however, has a capacity performance that is almost halfway between the optimal range strategies and the non-adaptive strategies, with $E[\overline{C}]/E[C_{GT}] = 1.25$. Although the GT strategy is rate adaptive, an unconstrained transmit range allows connection to a distant receive node in some pathological cases. By stipulating a transmit range that excludes transmissions to distant nodes, only good channels are exploited and network interference is reduced.

III. DISCUSSION

We have examined four transmission strategies in this paper, and showed that adaptive strategies with a stipulated transmit range perform substantially better than the GT strategy with an unconstrained transmit range. Our results imply there is a tradeoff between the spatial transmission concurrency and the spectral efficiency of each transmission. In order to maximize the capacity per unit area, it is necessary to limit the number of simultaneous transmissions to reduce the network interference power such that the SIR and the spectral efficiency of other connections are improved. Moreover, the random node within range strategy has a performance that is close to the closest node in range strategy. Thus a designer of multiple access protocols only needs to focus on contention of local channel when several receive nodes are in proximity. There is no need of a scheduling algorithm for prioritized transmissions.

Our results show that the optimum range of our strategies is between 0.6 to 1.2 neighbors independent of node density. These results can be contrasted to the results in [3], [5], which suggested that a magic number of 6 to 8 neighbors is optimum. A hypothetical line is drawn from a source to the destination node. The transmit range is chosen such that the the expected distance advance in one transmission projected to this line is maximized. This performance metric is called the *forward progress* in the literature. The concept of forward progress is predicated on the assumption that mobile nodes communicate using multihop routing. In this paper we show that capacity per unit area of a network snapshot can be fully utilized only if each transmit node sees one neighbor node on the average. This suggests that the mobile infostation network is a paradigm that fits into this optimization criterion.

To appreciate the potential improvement in *link capacity* over the multihop paradigm, we plot the expected SIR $\gamma(N)$ at the transmit range boundary as a function of number of neighbors of a node in Figure 1(b). As the number of neighbors N increase from 1 to 8, the SIR at the range boundary drops from 15dB to -15dB, a factor of 1000. The corresponding link capacity of a mobile infostation connection is 111.93 times over a multihop forwarding connection. The dramatic improvement in link capacity, together with [1] which explicitly show that the sum capacity in each network snapshot is sustainable in the long run, convince us that a much larger end-to-end throughput capacity is realizable for mobile infostation networks.

Recall that [1] showed the mobile infostation paradigm allows a network throughput that is scalable to the number of nodes. We have obtained exact capacity per unit area expressions as a function of transmit range, the fraction of candidate transmit nodes and node density. It turns out that the mobile infostation paradigm not only improves the spectral efficiency of a link over the multihop paradigm. It is somewhat surprising to find out that the spectral efficiency per unit area is linearly increasing with node density in mobile infostation networks. This is counter-intuitive since an increase in the node density is often accompanied by a corresponding increase of network interference. However, a mobile infostation also shrinks the transmit range such that the number of nodes within the transmit range remains constant. Thus, a mobile infostation also exploits the increase in physical proximity of the receive nodes as node density increases. The contrasting effects of increasing signal strength and increasing interference power at high node density work together that brings to the independence of link SIR's to node density. At high node density, the same sum capacity can be achieved at a smaller area, leading to an increase in capacity per unit area. This result has far reaching implications for the feasibility of future pervasive computing environments. The proliferation of mobile devices makes the deployment of dense node networks in the future almost a certainty. Unfortunately multihop networks suffers from the curse of node density. The excessive need of multihop forwarding in high node density environments drives the achievable per-node throughput to zero. In contrast, node density is a blessing in mobile infostation networks. The increase in interference power due to increased node density is counter-balanced by the improved channel due to the proximity of receive nodes at high node density. Since nodes are packed closer in high node density scenarios, better spatial concurrency is achieved, leading to an increase in capacity per unit area. Our results show that the capacity per unit area for mobile infostations actually goes to infinity as node density increases.

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