Spatial Throughput of Multi-hop Wireless Networks

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I. Introduction

In this work we focus on a microscopic analysis of decentralized ad hoc wireless networks ruling out the possibility of coordination between nodes. To this end, we jointly address the properties of the physical and the data link layer in the design of the media-access control (MAC) protocol and provide conclusions on routing strategies based on physical layer metrics. We thus provide a cross-layer setting in order to characterize the performance of wireless networks. We assume that nodes access the channel at random and employ simple protocols to retransmit the erroneously received packets, namely *Slotted Aloha*, and *Incremental Redundancy* using the wireless setting as described in [1]).

For this analysis, the nodes are taken to be spatially distributed on the plane according to a homogeneous spatial Poisson process which leads to a new representation of interference and collisions between concurrent transmissions. To derive the spatial throughput, we follow the analysis of Nelson and Kleinrock in [2] where they studied the spatial capacity of a slotted Aloha multi-hop network with capture. The spatial throughput is computed in terms of the product of the number of the simultaneously successful transmissions per unit area by the average jump (or expected forward progress) made by each transmission. We carry out its optimization with respect to the channel access probability p as defined in the case of the collision channel without feedback [3]. For the purpose of comparison of potential multi-hop routing protocols, we consider three strategies; one that maximizes the expected forward progress (**RS1**) based on long-term averages of signal-to-interference ratios, the second that relays packets to the closest node in range at each hop towards the final destination (**RS2**) and in the third where the next hop is selected to exploit the best channel and to be the most forward (**RS3**). This last strategy attempts to exploit *instantaneous* channel state information at transmission when choosing candidate routes, rather than relying on average signal-to-interference ratios.

II. Results

The closest node in range strategy (in a microscopic analysis) performs worse than the maximal forward progress strategy, this is in contrast to the results stemming from the Gupta Kumar model where communication is limited to nearest neighbors. The maximal expected forward strategy permits the computation of the optimal hop (or relay) distance.

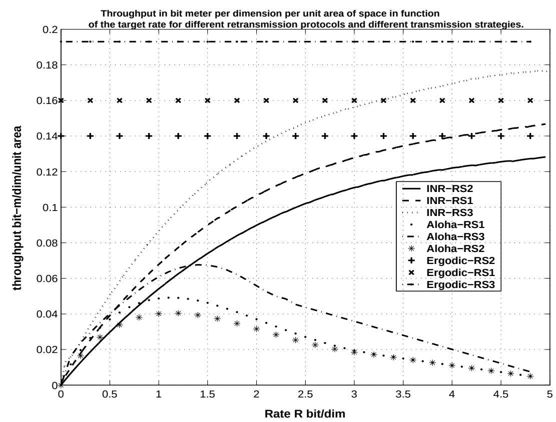

Fig. 1. The Spatial throughput (in bit-meter per dimension per unit area for different retransmission protocols and transmissions strategies. Transmit $SNR = 5dB$, node density $\sigma = 1$, power loss exponent $\alpha = 4$.

The channel driven strategy performs substantially better than the other strategies by exploiting transmissions only to nodes with instantaneously good channels. On each hop, the link capacity is then maximized. By this strategy, we are optimizing the spatial concurrency and the spectral efficiency of each link by exploiting multi-user diversity.

III. Conclusions and Future Work

We derived formulas for the spatial throughput for simple retransmission protocols and transmission strategies for random networks described by a spatial Poisson point process. A routing protocol aiming to maximize the expected forward progress and exploiting multi-user diversity is shown to significantly out-perform other schemes. Future work will focus on more advanced strategies for cooperation, the analysis of multi-user detection techniques, MIMO and directional antennas and practical coding strategies.

References

[1] Caire, G., Tuninetti, D., "The Throughput of Hybrid-ARQ Protocols for the Gaussian Collision Channel " *IEEE Transactions on Information Theory*, Volume: 47 Issue: 5, Pages: 1971 -1988, Jul. 2001.
[2] Nelson, R., Kleinrock, L., "The Spatial Capacity of a Slotted ALOHA Multihop Packet Radio Network with Capture" *IEEE Transactions on Communications*, Volume: COM-32, No. 6, June 1984.
[3] Massey, J., Mathys, P., "The collision channel without feedback", *IEEE Trans. Info. Theory*, vol. 31, pp. 192–204, March 1985.