Ad Hoc Wireless Networks: a Communication-Theoretic Approach

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Ad hoc wireless networking is currently a hot research area, especially because there is an increasing need for connectivity "anywhere" and, in particular, "anyhow." While traditional networks have fixed nodes with wired connections (either optical fibers or copper lines), ad hoc wireless networks can be described as *multi-hop wireless networks* with *mobile* nodes. However, the mobility condition can be relaxed, and we can consider an ad hoc wireless network as a network where all the nodes are connected to the local environment through wireless links, and where there is not a central or dominant node--as opposed to, for example, the case of cellular wireless networks where a base station is located in each cell. All the nodes in an ad hoc wireless network are at the same hierarchical level. In this sense, sensor networks can be regarded as a special case of ad hoc wireless networks.

Our project has focused on developing a communication theory-oriented framework for ad hoc wireless networks. In fact, most of the existing literature focuses on higher layers (as the network and medium access control (MAC) layers), "taking for granted" that the lower layers, and in particular the physical layer, can successfully cope with the channel impairments. This assumption is reasonable in networks with very reliable communication links (e.g., fixed optical networks). However, this assumption could be problematic in the case of wireless networks, where the radio communication links are very unreliable and subject to weather and environmental impairments. This leads to a more severe channel distortion (e.g., channels with fading, either non-selective or selective). Hence, it is necessary to take into account the channel characteristics in designing an ad hoc wireless network. In particular, it is desirable to come up with an integrated design
comprising both the physical and network/MAC layers.

The main research directions considered in this work include (but are not limited to) the following.

- We have first considered the case of reservation-based multi-hop communications among fixed nodes with regular topology: a pictorial scheme is shown in Figure 1. This simple scenario has allowed to derive many insights about the behaviour of ad hoc wireless networks. For example, the concept of *minimum spatial energy density*, quantifying the minimum energy floating the network and necessary to guarantee communications, has been formalized, and closed-form expressions have been derived in various cases. A novel symbol-level approach to the evaluation of the inter-node interference affecting the communications has been derived [1].
- We have introduced and the concept of *effective transport capacity*, which links the transport capacity, the information-theoretic quantity quantifying the rate-distance product carried by the network, with the physical characteristics of the network. In particular, we have shown the existence of a drastic threshold between a sub-critical region (where connectivity rapidly drops to zero) and a

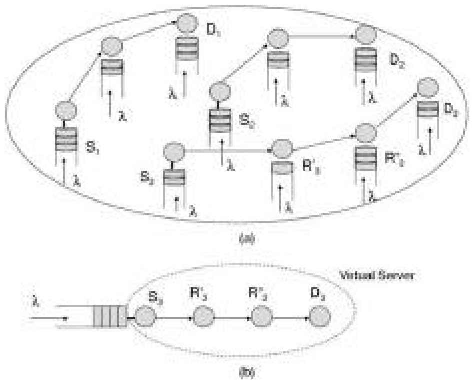

Figure 1: Ad hoc wirless network with reservation-based multi-hop communications.

supercritical region (where complete connectivity exists). Our results match with existing results based on the theory of continuum percolation[2]

- Our approach has allowed to evaluate the impact of mobility through closed-form expressions, rather than through lengthy simulations [3].
- Non-reservation-based ad hoc wireless networks have been considered, where a source-destination pair of nodes communicate through more than a single route [4].
- Unlike the conventional wisdom, we have shown that the concept of neighbors of a node is a good indicator of connectivity only if the topology is regular [5,6].
- Topology of the nodes plays a major role in determining the network performance. We have evaluated the impact of node *clusters* [7], and we have clarified the relationship, in terms of obtainable performance, between the cases of uniform and non-uniform topologies [8].
- We have clarified the trade-off between transmitted power and connectivity: our results show that, for a given traffic load offered to the network, there exists an "optimal" value of the transmission power which a node should use [9].
- Through a simple discrete-time communication model, the existence of an "optimal" channel utilization ratio, in order for the effective transport capacity of the network to be maximized, has been shown.

We believe that the framework generated through this project will be very useful and will allow to understand better, from a physical viewpoint, the characteristics of ad hoc wireless networks. Many extensions are currently under investigation, and it is worth remarking that they can all be interpreted as various aspects of a global and novel vision for ad hoc wireless networks [12].

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