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Impact of network structure on the capacity of wireless multihop ad hoc communication

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Abstract

As a representative of a complex technological system, the so-called wireless multihop ad hoc communication networks are discussed. They represent an infrastructure-less generalization of todays wireless cellular phone networks. Lacking a central control authority, the ad hoc nodes have to coordinate themselves such that the overall network performs in an optimal way. A performance indicator is the end-to-end throughput capacity. Various models, generating differing ad hoc network structure via differing transmission power assignments, are constructed and characterized. They serve as input for a generic data traffic simulation as well as some semi-analytic estimations. The latter reveal that due to the most-critical-node effect the end-to-end throughput capacity sensitively depends on the underlying network structure, resulting in differing scaling laws with respect to network size.
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1. Introduction

Complex networked systems are widespread in nature, society and engineering. Some examples from biology are regulatory gene and metabolic networks, the neural network of the brain, the immune system, and, on larger scales, food webs and the ecosystem. Another example, now from the social sciences, is multiagent economics, where a multitude of large and small traders are interwoven together to curse the course of exchange rates and stock prices. Also engineering contributes with communication networks, such as the Internet, the world wide web and grid computing.

Recently, physics has started a new branch, the Statistical Physics of complex networks [1–3], which takes a generic and unifying perspective at all of those examples. So far, most of the focus has been on the structure of such networks. The analysis of a great deal of the above mentioned examples has led to the unifying scale-free discovery and its respective growth modeling with preferential attachment. Beyond structure, it is now also dynamics on and function of networks, which are about to move onto center stage. The new insight which along these lines has already been given to regulatory gene networks [4] constitutes for sure a remarkable highlight. The impact of structure on dynamics is also key to epidemic spreading and the proposal of efficient immunization strategies for populations and computer networks [5].

The structure and dynamical properties of engineered communication networks in general and computer as well as Internet traffic in particular were also discussed heavily within the physics community over the last years. Key issues have been besides network structure [6–8] also phase transition like behavior from a non-congested to a congested traffic regime [9–12] and self-similar data traffic [13]. So far, the analysis of network structure and dynamics has been mostly separated from each other. Only very recently a first coupling of these issues has been picked up, focusing on the impact of structure on synchronization dynamics [14]. In this paper, we introduce a new and intriguing complex technological system to the Physics community, the so-called wireless multihop ad hoc communication networks [15–18], and discuss the impact of network structure onto their performance to handle data traffic.

Wireless multihop ad hoc communication networks represent an infrastructureless generalization of todays wireless cellular phone networks [19–21]. Lacking a central control authority in the form of base stations, each end device acts as router and relays packets for other participants. End-to-end communications are possible via multihop connections. In order to ensure network connectivity, efficient discovery and execution of end-to-end routes and avoidance of data packet collisions on shared radio channels, the participating devices need coordination amongst themselves. Proposals [22,23] for such a coordination have already been put forward upon focusing on the connectivity issue. For the other two issues, routing and medium access control, the coordination is much more delicate. Routing efficiency would require rather short end-to-end routes, resulting in a small network diameter. Due to the overall presence of interference, medium access control takes care of collision avoidance for data packets traveling on different routes. It blocks all neighboring devices of an active one-hop transmission and thus would rather favor a small neighborhood, implying a small node degree. The opposite demands of these counteracting mechanisms leave the network in a state of

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