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Continuum percolation of wireless ad hoc communication networks

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Abstract

Wireless multi-hop ad hoc communication networks represent an infrastructure-less and self-organized generalization of todays wireless cellular networks. Connectivity within such a network is an important issue. Continuum percolation and technology-driven mutations thereof allow to address this issue in the static limit and to construct a simple distributed protocol, guaranteeing strong connectivity almost surely and independently of various typical uncorrelated and correlated random spatial patterns of participating ad hoc nodes.

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1. Introduction

Today's wireless communication mainly relies on cellular networks [1–3]. At first, the sending mobile device directly connects to its nearest base station. A backbone network then routes the communication packets to the cell, where the intended receiving

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mobile device is registered. Finally, the cell's base station transmits the passed-by message to the latter. As part of the centralized backbone infrastructure each base station acts as a router, possesses the network information, controls the single-hop communications within its cell and assigns different channels to its various mobile clients. The base stations need to be placed according to some optimized coverage layout. This requires an enormous planning effort ahead of operation and leads to a static infrastructure, hard to change and adapt to new, revised needs. This costly inflexibility motivates a flexible and infrastructure-less peer-to-peer concept: selforganizing wireless mobile ad hoc networks [4–7].

In a wireless ad hoc network, a sending mobile device uses inbetween mobile devices to communicate with the intended receiver. Such a multi-hop connection requires each mobile device to have additional router functionality. As a central control authority is missing, the participating devices need coordination amongst themselves to ensure network connectivity, efficient discovery and execution of end-to-end routes and avoidance of data packet collisions on shared radio channels; of course, mobility of the devices also has an impact on the network performance, which has to be coped with. Contrary to these global network features, the selforganizing coordination rules, called protocols in the jargon of electrical engineers, have to be local. Due to its limited transmission range, a mobile device is able to communicate only with its current spatial neighbors. Hence, it can only extract information on its local surrounding. Since this is the only input into the coordination rule, the latter is by definition local. Upon execution, it readjusts for example the device's transmission power to its new surrounding.

In this paper we focus on the important connectivity issue and ask: what is a good local coordination rule for transmission power management, which almost surely guarantees global connectivity for the whole network? We employ a simple static model for ad hoc communication networks. This allows a connection to continuum percolation theory [8,9] based on random geometric graphs [10,11]. The spatially distributed ad hoc devices correspond to nodes, which are more or less locally connected by communication links. Two nodes establish a mutual link, only if the first node lies within the transmission range of the second and vice versa. For the case of constant, isotropic transmission ranges, a further mapping onto the classical picture of continuum percolation [12,13], stemming from the transport physics in continuous random media, is straightforward: whenever discs with radius equaling half of the transmission range are placed around two nodes and overlap, the two nodes are linked.

Continuum percolation allows to study, for example, the dependence of the probability for strong connectivity on the transmission range and to find a critical range, above which the ad hoc network graph is almost surely connected. The critical transmission range can be translated into a critical node neighborhood degree ngb_{crit}. Hence, a simple local coordination rule would be for each node to adjust its transmission power to yield a little above ngb_{crit} neighbors. As we will demonstrate, such a rule is not flexible enough to perform equally well in various different environments, like homogeneous vs. heterogeneous random spatial arrangements of nodes or homogeneous vs. heterogeneous propagation media. Fortunately, such a rule is able to give some guidance to develop local coordination rules with improved adaptation properties. In some respect, these new rules represent technology-driven mutations of the