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A centrality-based topology control protocol for wireless mesh networks

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ABSTRACT

Nodes in wireless multi-hop networks establish links with their neighbors, which are used for data transmission. In general, in this kind of networks every node has the possibility of acting as a router, forwarding the received packets when they are not the final destination of the carried data. Due to the routing protocol procedures, when the network is quite dense the overload added by the routing management messages can be very high. To reduce the effects of this overload a topology control mechanism can be used, which can be implemented using different techniques. One of these techniques consists of enabling or disabling the routing functionality in every node. Many advantages result from selecting just a subset of nodes for routing tasks: reduction of collisions, protocol overhead, interference and energy consumption, better network organization and scalability. In this paper, a new protocol for topology control in wireless mesh networks is proposed. The protocol is based on the centrality metrics developed by social network analysts. Our target network is a wireless mesh network created by user hand-held devices. For this kind of networks, we aim to construct a connected dominating set that includes the most central nodes. The resulting performance using the three most common centrality measures (degree, closeness and betweenness) is evaluated. As we are working with dynamic and decentralized networks, a distributed implementation is also proposed and evaluated. Some simulations have been carried out to analyze the benefits of the proposed mechanism when reactive or proactive routing protocols are used. The results confirm that the use of the topology control contributes to a better network performance.

1. Introduction

Smart environments, smart devices, smart interaction, computing anytime and anywhere, …, the accelerated development of information technologies and mobile devices results in people and/or “things” increasingly dependent on the online services offered through the Internet. In such scenario, Wireless Mesh Networks (WMNs) have evolved as a cost effective possible solution for user uninterrupted access to networking facilities. Valued features like robustness, reliability, easy deployment and maintenance, self-forming and self-configuration, make WMNs an important alternative to achieve an always-on connectivity. Among the three typical architectures of WMNs [1], which are infrastructure, client and hybrid meshing, the present work focus on the client meshing one. In this case, the end-user devices are able to simultaneously provide application interface, routing and network configuration capabilities. Nowadays, the most common hand-held device used by an increasing number of people is the smart phone. The evolution of such mobile devices with their variety of embedded sensors results now in a

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not only communication equipment, but a complete sensing system [2]. Numerous applications are emerging in many fields like health, traffic, human behavior, environment monitoring, social networking and commerce [2]. With this perspective it is entirely feasible to consider a WMN composed by mobile phone users moving around a city as a cost-effective complement to commercial cellular networks. One of the major concerns in this kind of devices is related to their energy consumption. Therefore, optimization techniques that aim to reduce it are always required [3].

Topology control techniques have been developed to improve the energy efficiency and the battery lifetime of a variety of networks. It also aims to reduce collisions, protocol overhead, and interference by means of a better control over the network connections and redundancy [4]. In general, there are three main types of topology control approaches [4]. First, power control techniques [5,6], adjust the communication range of the wireless nodes by means of the transmission power of their transceivers. This way, nodes are able to better manage their neighborhood size, interference level, power consumption and connectivity. Secondly, power mode mechanisms [7,8] control the active or sleep operation modes of the nodes to dispense with redundant stations and still achieve the desired connectivity. Finally, hierarchical clustering approaches [9–11] aim to construct an efficient virtual backbone for data forwarding by the selection of a connected dominating set (CDS). From graph theory, a CDS of a graph is a connected subset in which all the nodes that does not pertain at that subset have at least one adjacent neighbor inside the subset. Due to the reduced number of nodes developing routing task, the main advantages of this CDS-based topology control are: collisions, protocol overhead and energy consumption reduction, efficient network organization and scalability improvement. In this work we evaluate an alternative method for this last category of topology control based on social network analysis metrics.

In this context, thanks to the increasing availability of network maps which depicts the behavior of complex systems and the universality of their characteristics [12], network science appears as the renewed study of the structure and the dynamic behavior of a variety of networked systems [13]. Accordingly, social network analysts have developed an important set of measures and metrics which allow understanding the behavior and quantify the topology features of a diversity of networks [14]. Specifically, in this work we focus on centrality metrics developed to identify the most important actors (nodes) in a network by means of graph theory definitions and concepts.

In summary, the purpose of this work is to present and evaluate an alternative topology control mechanism based on centrality measures borrowed from social network analysis. This topology optimization has been applied to a client wireless mesh network formed with user handheld devices.

The rest of the paper is organized as follows. In Section 2 we report and analyze the related work. Section 3 provides a background on centrality metrics. Section 4 presents and evaluates the proposed topology control mechanism. A performance evaluation has been carried out by means of simulations, taking into account both reactive and proactive routing protocols. The results are presented in Section 5. Finally, the conclusions and future works are summarized in Section 6.

2. Related work

Nowadays, the application of complex networks techniques and social network analysis concepts to improve the performance of wireless ad hoc networks is growing as a fertile research area [15]. Some recent works are summarized in the following. [16–18] apply the small world phenomena, re-popularized by [19], to reduce the average path length of the network. The basic idea of these proposals is to modify the physical topology of the network based on the social features of the underlying graph. The small world property (or low average path length) could be achieved either by the aggregation of long-ranged links [17] or by a combination of rewiring, deletion and/or addition of links/nodes [16]. Authors in [18] combine centrality measures with directional beamforming to create long-range links between more central nodes. The same authors extend their study to sparse highly partitioned networks in [20].

SimBet [21] is a routing protocol designed for delay-tolerant MANETs. It uses two social network analysis metrics (centrality and similarity) for message forwarding decisions. Betweenness centrality is selected to identify more suitable bridge nodes, and the similarity measure is used to find nodes that are closer to the destination neighborhood. A utility function combines the similarity and the betweenness utilities and allows adjusting the relative importance of them. For performance evaluation both utilities has been assigned the same importance. For their part, authors in [22] apply social network analysis metrics to detect critical nodes in a WMN. They show how network reliability substantially degrades when coordinated attacks are directed to highest centrality nodes. Simulations evince that nodes with high betweenness centrality exhibit a greater impact than nodes with high degree or closeness centrality. Authors also propose a socially-aware TDMA channel access scheduling algorithm. The main idea is to give higher priority (assigning more time slots) to nodes with high closeness centrality values. Simulations show important throughput improvements at the expense of increased delay.

The time-evolution of the topological characteristics of vehicular networks from the perspective of graph theory and social network analysis is the subject addressed in [23]. It is confirmed that relevant and useful information about the behavior of the VANETs could be inferred from the centrality metrics. The importance of nodes with high centrality values on the design of more efficient VANET protocols is also discussed.

A topology control algorithm for WSN based in edge betweenness centrality [24] is proposed in [25]. This metric is used to identify most relevant edges or links between nodes, regarding energy consumption. For each node, the aim of the proposal is to select a set of logical neighbors that minimize energy consumption and fulfill QoS requirements. Simulation results show better performance