Mobile Ad Hoc Data Networks for Emergency Preparedness Telecommunications - Dynamic Power-Conscious Routing Concepts

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I. Introduction

In the next generation of wireless communication systems, there will be a need for the rapid deployment of independent mobile users. Significant examples include establishing survivable, efficient, dynamic communication for emergency/rescue operations and disaster relief efforts, e.g., the bombing of the Oklahoma City Federal Building, or the aftermath of a hurricane where cellular/PCS service may not be available. Typically, emergency/rescue communication is centralized, and the network is dependent on proper function of the central controllers. If the centralized infrastructure were to fail due to a disaster or any other reason, the network may collapse. Hence, advances in wireless communication should aid in making emergency preparedness systems and disaster relief networks robust and autonomous, and provide for reliable and secure inter-group communication.

Rescue operations and disaster relief scenarios cannot rely on centralized and organized connectivity, and can be termed as wireless mobile ad hoc networks (MANETs) for emergency telecommunication. A MANET is an autonomous collection of mobile nodes that communicate over relatively bandwidth-constrained wireless links. Each node is equipped with wireless receivers and transmitters using antennas that may be omni-directional, highly directional, or possibly steerable. Since nodes are mobile, the network topology may change rapidly and unpredictably over time. The network is *decentralized*, where all network activity including discovering the topology and delivering messages must be executed by the nodes themselves, i.e., routing functionality will be incorporated into mobile nodes. A MANET for emergency telecommunication may operate in a stand-alone manner or be connected to a larger network.

The set of applications for emergency MANETs is diverse, ranging from small, static networks that are constrained by power sources, to large-scale, mobile, highly dynamic networks. The design of network protocols for these networks is a complex issue. Regardless of the application, emergency telecommunication MANETs need efficient distributed algorithms to determine network organization (connectivity), link scheduling, and routing. However, determining viable routing paths and delivering messages in a decentralized environment where network topology fluctuates is not a well-defined problem. While the shortest path (based on a given cost function) from a source to a destination in a static network is usually the optimal route, this idea is not easily extended to MANETs. Factors such as variable wireless link quality, propagation path loss, fading, multiuser interference, power expended, and topological changes, become relevant issues. An emergency telecommunication network should be able to adaptively alter routing paths to alleviate any of these effects in order to maintain the performance and dependability of the network.

In this report, we focus on the Network Layer operation of *routing* and implications of power consumption for emergency MANETs. We discuss the benefits of power consciousness and conduct an initial investigation on the effects of energy-efficient wireless routing in MANETs. We develop an initial dynamic power-conscious routing scheme (minimum power routing - MPR) that incorporates physical layer and link layer statistics to conserve power, while compensating for the propagation path loss, shadowing and fading effects, and interference environment at the intended receiver. The main idea of MPR is to select the path between a given source and destination that will require the least amount of total power expended, while still maintaining an acceptable signal-to-noise ratio (SNR) at each receiver. A "cost" function is assigned to every link reflecting the transmitter power required to *reliably* communicate on that link. Routing decisions and cost updates are made based on feedback or information extracted from the received signal and special control packets. As an initial approach, we use the distributed Bellman-Ford algorithm to perform "shortest" path routing with the cost functions as the link distances. The resulting "shortest path" is the MPR path from a given source to a destination. We compare the performance of MPR to the common routing protocols of shortest distance routing with power control (SD-PC) and minimum hop routing with power control (MH-PC), and present our preliminary results.

II. Benefits of Power Consciousness

In an emergency telecommunication scenario, power may be supplied to static nodes through a generator, while mobile nodes operate off a battery supply. Clearly, a vital issue for emergency MANETs then is to conserve power while still delivering messages reliably, i.e., achieving a high packet success rate. This can be accomplished by altering the transmitter power of the emergency telecommunication nodes to use just that amount needed to maintain an acceptable SNR at the receiver. Reducing the transmitter power allows spatial reuse of the channel and thus, increases network throughput [1]. Using power control in an emergency situation mitigates the multiuser interference since a transmission will not interfere with as many nodes. This will increase the number of emergency or rescue mission nodes that may communicate simultaneously. Altering the transmission power also reduces the amount of interference caused to other emergency preparedness telecommunication networks or any other wireless network operating on adjacent radio frequency channels. In networks where nodes operate on battery power, e.g, hand-held radio being used by a rescue worker, conserving power is crucial since battery life determines whether a network is operational or not. For certain emergency telecommunication MANET applications - for example, hostage situation or terrorist attack - it is desirable to maintain a *low probability of intercept* and/or a *low probability of detection* [4]. Hence, rescue mission nodes would prefer to radiate as little power as necessary and transmit as infrequently as possible, thus decreasing the probability of detection (or interception).

The benefits of power conservation/control for emergency MANETs prompt the important question: What is the most power efficient way to route a packet from a source to a destination such that the packet is received with an acceptable packet success rate [5]? Since channel conditions and multiuser interference levels in an emergency situation are constantly changing with time, the transmitter power necessary on a particular link must be determined dynamically.

Previous research in the area of routing for MANETs has focused on establishing routes between different source and destination pairs (protocols proposed in the Internet Engineering Task Force - MANET Working Group). A connection between two nodes is considered either "present" or "absent" depending on if the distance between the nodes is less than or greater than a *threshold* distance. All links that are "present" are regarded as having the same link quality. This is a generalization (assumption) since the quality of any particular link depends on its location and surroundings. It is known that a node can exhaust its power supply trying to communicate reliably over a link that has a severe fade. Moreover, a centrally located node may experience excess traffic and multiuser interference. Communicating through this node may be inefficient and require many retransmissions, thereby expending more power. More recently, in [7], Wieselthier, Nguyen, and Ephremides addressed the problem of power conservation in the context of wireless multicasting, and in [3], Pursley, Russell, and Wysocarski considered this problem in a frequency-hopping ad-hoc network.

III. Power-Conscious Routing

There are clear benefits to conserving power in emergency telecommunication MANET applications, as discussed in Section II. In this Section, we develop a new power conscious routing concept for MANETs.

A. System Model

Consider a transmitter communicating with a receiver at a distance of r_0 in a MANET. As the transmitted signal propagates to the receiver, it is subject to the effects of shadowing and multipath fading, and its power decays with distance, i.e., $P_R \propto KFP_T r_0^{-\eta}$, where K is a constant, F is a non-negative random attenuation for the effects of shadowing and fading, P_T is the transmitter power, and η is the path loss exponent. At the receiver, the desired signal is corrupted by interference from other active nodes in the network. We assume that nodes know the identity of all other nodes in the network and the distances to their immediate neighbors, i.e., nodes that are within transmission range. Interfering nodes use the same modulation scheme as the transmitter and nodes can vary their transmit power up to a maximum power P_{max}. We assume that the multiuser interference is a Gaussian random process. At the receiver, the decoder maintains an estimate of the average SNR.

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