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A framework for post-disaster communication using wireless ad hoc networks

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ABSTRACT

Disaster management system requires timely delivery of large volumes of accurate messages so that an appropriate decision can be made to minimize the severity. When a disaster strikes, most of the infrastructure for communication gets uprooted. As a result, communication gets hampered. A well designed Internet of things (IoT) can play a significant role in the post-disaster scenario to minimize the losses, and save the precious lives of animals and human beings. In this paper, we have proposed a framework for post-disaster communication using wireless ad hoc networks. The framework includes: (i) a multi-channel MAC protocol to improve the network throughput, (ii) an energy aware multi-path routing to overcome the higher energy depletion rate at nodes associated with single shortest path routing, and (iii) a distributed topology aware scheme to minimize the transmission power. Above proposals, taken together intend to increase the network throughput, reduce the end-to-end delay, and enhance the network lifetime of an ad hoc network deployed for disaster response. A multi-channel MAC protocol permits the transmission from hidden and exposed nodes without interfering with the on-going transmission. We have compared the proposed framework with an existing scheme called *Distressnet* [1]. Simulation results show that the proposed framework achieves higher throughput, lower end-to-end delay, and an increased network longevity.

1. Introduction

The hurricane Sandy in 2012, tsunami in 2011, terrorist attack on World Trade Center in 2001 have drawn lots of attention to improve the rescue operation following a disaster. In the last few years, there have been significant improvements in the disaster management front, yet there exists enough scope for further improvement. The challenges in disaster management are:

(i) Disaster cannot be predicted and its severity cannot be measured in advance.
(ii) It strikes suddenly, and uproots the entire communication system. Without a reliable communication system it is difficult to carry out the rescue operation.
(iii) Use of radio communication is severely affected due to increase in network traffic. Network deployed at the disaster site experience congestion due to massive exchange of voice and/or message. Entire region suffers from degraded communication which affects the rescue operation. Message delivery gets delayed due to congestion.

In many critical environments, wireless ad hoc networks represent key technologies providing several Internet of things (IoT) applications and services to users. As the infrastructure based network gets uprooted, wireless ad hoc networks can play a significant role in disaster mitigation [2–6]. It can be quickly deployed at the disaster affected site, and does not need any fixed networking infrastructure.

Wireless ad hoc networks designed for disaster mitigation must provide robust ubiquitous communication, sufficient enough to support the geographical coverage and mobility requirement of the people involved in rescue operation. However, the use of wireless ad hoc networks for disaster management faces the following challenges:

(i) *Energy constraint*: Nodes in wireless ad hoc networks have limited battery capacity, which must be judiciously used to increase the network lifetime. In a disaster scenario, networks should remain active as long as possible. To increase the network lifetime, attempt should be made to minimize the power consumption at nodes.
(ii) *Network congestion*: Traffic is likely to increase by many folds after the disaster. As a result, network gets congested, and

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collision takes place. Retransmission due to collision further aggravates the congestion. This decreases the network throughput and unnecessarily depletes energy at the node. For achieving higher throughput, congestion in the network has to be minimized.

(iii) *End-to-end delay*: Due to network congestion the end-to-end delay increases. For initiating prompt action, message should be timely delivered.

To address the above challenges, we propose a framework for disaster response using wireless ad hoc network. The main feature of the framework includes:

(i) a multi-channel MAC protocol to achieve higher throughput, and minimize the impact of hidden and exposed terminals,
(ii) an energy efficient node-disjoint multi-path routing to enhance network lifetime, and
(iii) distributed topology control mechanism to reduce the maximum transmission power at node level.

Rest of the paper is organized as follows: related work is discussed in Section 2. Proposed framework is presented in Section 3. Simulation results are discussed in Section 4 and few conclusions are drawn in Section 5.

2. Related work

Emergency response system uses various wireless technology such as cellular network, Wi-Fi, LR-WPANs (IEEE 802.15.4) [7,8], etc. Most of these technology operate in a client–server mode, and are fully dependent on the service provider such as base station and access points. Moreover, they are prone to congestion, and failure of base station or access point degrades the system performance. To overcome the above limitations, a peer-to-peer architecture using wireless ad hoc network is adopted by the researchers. Many frameworks and network models have been proposed and deeply studied in the literature to address the issues related to a disaster scenario [9–14]. A few of them are discussed here briefly.

In [15], authors propose an architecture for disaster recovery. The objective of the architecture (OEMAN) is to provide Internet connectivity in the disaster affected area. A network controller initiates the OEMAN configuration when disaster occurs. A command puts nodes into the emergency state. In emergency state node connected to an access point and download the disaster recovery configuration software. The disaster recovery configuration performs routing by creating a tree based topology. It also manages IP address allocation among nodes. OEMAN can detect unbalance traffic pattern and accordingly configure the network to balance the traffic among the nodes. An overloaded node can transfer the traffic to an alternate node using virtual access point. The model has provision to handle node mobility and node failure issues.

A tree based disaster recovery access network (TDRAN) to provide connectivity is presented in [16]. A node in TDRAN is configured as a software based access node and operated in two modes. In one mode, it manages its own network and in other mode acts as a relay and provide connectivity to other networks. The functionality of TDRAN mainly depends on wireless interface abstraction, virtual AP abstraction, reconfiguration support, and NAS auto downloading trigger. The model claims that it quickly establishes connectivity and can be extended further to support for large network. It does not rely on routing protocol but it builds a tree topology through which routing is done. However, detecting a link failure is a major challenge for TDRAN in a large network.

A communication for survivors (COMVIVOR) framework is presented for prompt response in emergency situations [17]. This framework considers smart positioning strategy for nodes to speed up the information propagation. It also considers virtual networking and epidemic networking. The epidemic spreading process is triggered by special purpose nodes. These nodes advertise evolution modules, and provide long range connectivity. The main focus on the framework is to provide a better positioning of the special purpose nodes. A node moves to different positions to improve the diffusion performances. The experimental results show that the dynamics of diffusion are enhanced by the smart positioning algorithm.

To maintain end-to-end routes, some systems adopted decentralized peer-to-peer architecture and employed delay tolerant network (DTN). Such an architecture is presented in [1]. It is based on DTN and IEEE 802.15.4 [8] to monitor messages of survivors in a disaster affected area. The network supports both on-demand and delay tolerant routing in connected as well as disconnected segments of the network.

A routing protocol for emergency communication is presented in [18]. Authors in this paper considered a hybrid network, consisting of both ad hoc and a cellular network to maintain connectivity between base station (BS) and nodes in a disaster affected area. In this hybrid network architecture, nodes communicate with base station; but switches to ad hoc mode when the link between the BS and a node fails. A route is discovered by monitoring neighbor's communication instead of broadcasting a route request packet. The network employs a dedicated medium access control protocol based on Time Division Multiplexing (TDM). It takes the advantage of TDM based MAC to reduce delay; but suffers from lower network throughput.

A network architecture for disaster recovery is presented in [19]. This architecture has the following: (i) ability to co-exists, both in ad hoc and other infrastructure based networks, (ii) easy to deploy and maintain, and (iii) automatic location determination. Authors modeled the survivors movement as a two-dimensional random walk, and they introduced a concept called *reward-based random walk*.

An energy efficient routing for disaster recovery is proposed in [20]. It is designed to achieve energy efficiency, and to improve the data transmission rate. An iterative algorithm is presented to maximize the network lifetime.

An emergency response framework to achieve reliable communication in dynamic wireless environment is discussed in [21]. The network is deployed with minimal infrastructure support and is operated in different phases. The framework elaborates the link characteristics and connectivity properties at different mobility scenarios.

A mobility model for emergency response is proposed in [22]. The model supports heterogeneous area-based movement on an optimal path with the provision for nodes to join or leave. The model allows a realistic traffic modeling, and was compared with random way-point (RWP) model. The authors claim that their proposed model has a significant impact on the performance analysis in emergency response.

In [23], authors evaluate different techniques for extending network coverage in disaster scenarios. Real world data are used to model the power outage probability of mobile stations. The technique compares the coverage of both static and mobile nodes. It also proposes an algorithm for static node. Simulation results show that static relays are much more efficient and reliable to extend network coverage.

3. Proposed work

When a disaster strikes, the number of persons seeking disaster information grows significantly. This may lead to congestion in the network, as a result end-to-end delay increases and degrades the network throughput drastically. Majority of the routing protocols selects the minimum-hop path between the source–destination pair in routing traffic. Reuse of the same path over and over again will lead to quicker depletion of battery power at the nodes on the path. Moreover, shortest path routing does not achieve load balancing in the network. A path break leads to loss of data and the reconfiguration of network takes longer time. A node transmitting with maximum