A Multimedia Communication System for Collaborative Emergency Response Operation in Disaster-affected Areas

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ABSTRACT

This paper describes an emergency network platform based on a hybrid combination of mobile ad hoc networks (MANET), a satellite IP network operating with conventional terrestrial Internet. It is designed for collaborative simultaneous emergency response operations deployed in a number of disaster-affected areas. The architecture of the network called DUMBONET together with our emergency response applications are described. Experience from a real-life experimental testbed is discussed. Our implementation involves multidisciplinary research areas as MANET routing, peer-to-peer computing, sensor network and face recognition. The paper also identifies potential research challenges that we intend to investigate to further enhance the capabilities of our system.

Keywords: *disaster emergency response communication, mobile ad hoc network (MANET), optimized link state routing (OLSR), peer-to-peer ubiquitous computing, face recognition, sensor network, multimedia communication.*

1. Introduction

In disaster-struck fields where traditional communication services such as fixed or mobile telephone and local internet access are completely inoperable, a fast-deploying multimedia communication system that a number of emergency rescue teams can rely on and collaborate with a distant command headquarter will prove very useful in saving the lives of victims. Our main contribution is an actual proof-of-concept system, under a project called ‘Digital Ubiquitous Mobile Broadband OLSR’ or DUMBO, developed by intERLab and its partners for search and rescue operations in disaster-struck situations. This paper explains the design of our emergency network called DUMBONET and our emergency response application system. The paper also describes our field experience and identifies several challenges to overcome to improve our system.

2. The Design of DUMBONET

DUMBONET was designed to operate in real physical disaster-affected fields. The goal is to provide rescue teams who may simultaneously explore physically isolated disaster fields with mobile ad-hoc multimedia internet communication among field team members and with a distant command headquarter. Having multimedia internet capabilities allows rescuers to collaborate more effectively by sending and receiving rich and crucial multimedia information. Rescuers may also consult with case experts through the Internet to gain knowledge necessary for the operation.

2.1. The Architecture of DUMBONET

DUMBONET is a single mobile ad hoc network comprising a number of connected sites each with a variety of mobile nodes, end systems and link capacities. A node on the net can communicate with any other node belonging to the same site, or with a node at any another site which is of a distance away as well as communicating with a remote headquarter situated on the normal Internet. Within each site, nodes share a relatively similar network conditions while between sites a long delay satellite link is used to allow long distance. The headquarter is considered a special site having the privilege of talking to every sites on the net and sometimes broadcast messages to all sites. A normal site of DUMBONET can maintain a communication channel with the headquarter while possibly opening up communication channels with other selected peering sites on the net based on demand.

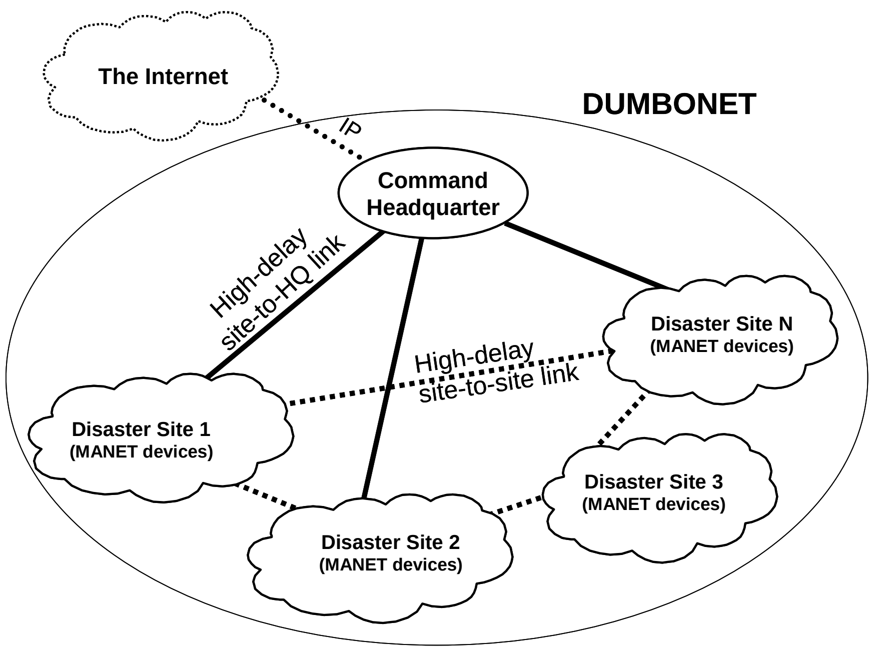

Figure 1: DUMBONET Architecture

Figure 1 shows an abstract model of DUMBONET. We assume a number of isolated disaster-affected sites and a distant command headquarter. At each disaster site, as traditional communication infrastructure is no longer available, we shall bring in mobile devices capable of creating a self-organizing, self-resilient mobile ad-hoc network (MANET) that permits multimedia communication among the devices. We also need to provide multimedia communication among different sites and with the command headquarter. A highly practical choice is to deploy satellite access which can restore connectivity in a relatively short amount of time but it has a high propagation delay. Our main challenge is to create a single networking domain called 'DUMBONET' that enables effective multimedia communication among the disaster-affected sites and with the command headquarter. DUMBONET consists of heterogeneous networks having different MANET devices, various link types (i.e. WiFi, satellite, and terrestrial) with very different link characteristics (i.e. bandwidth, packet loss pattern, and delay.)

In Figure 2, each rescuer carries a WiFi capable mobile device, which is either a lightweight laptop computer or a personal digital assistant (PDA). The use of mobile devices are of our interest in search and rescue operations because rescuers can conveniently carry mobile devices to almost everywhere. For the laptop computers, we chose a relatively inexpensive model that has built-in multimedia capabilities (webcam, microphone, and speaker.) For the PDAs, we had the Nokia 770 "Internet tablet" [1]. To form a MANET, every mobile device is set to use the ad-hoc (peer-to-peer) WiFi mode and to run the Optimized Link State Routing (OLSR) protocol [2]. The OLSR protocol uses a special mechanism called Multi-Point Relay (MPR) to reduce the number of flooded messages by collaboratively selecting few nodes who would be in better spatial positions to forward messages on behalf of some other nodes. In DUMBONET, each PDA acts as an OLSR router. Each laptop computer functions both as an OLSR router and as a rescuer's multimedia application terminal.

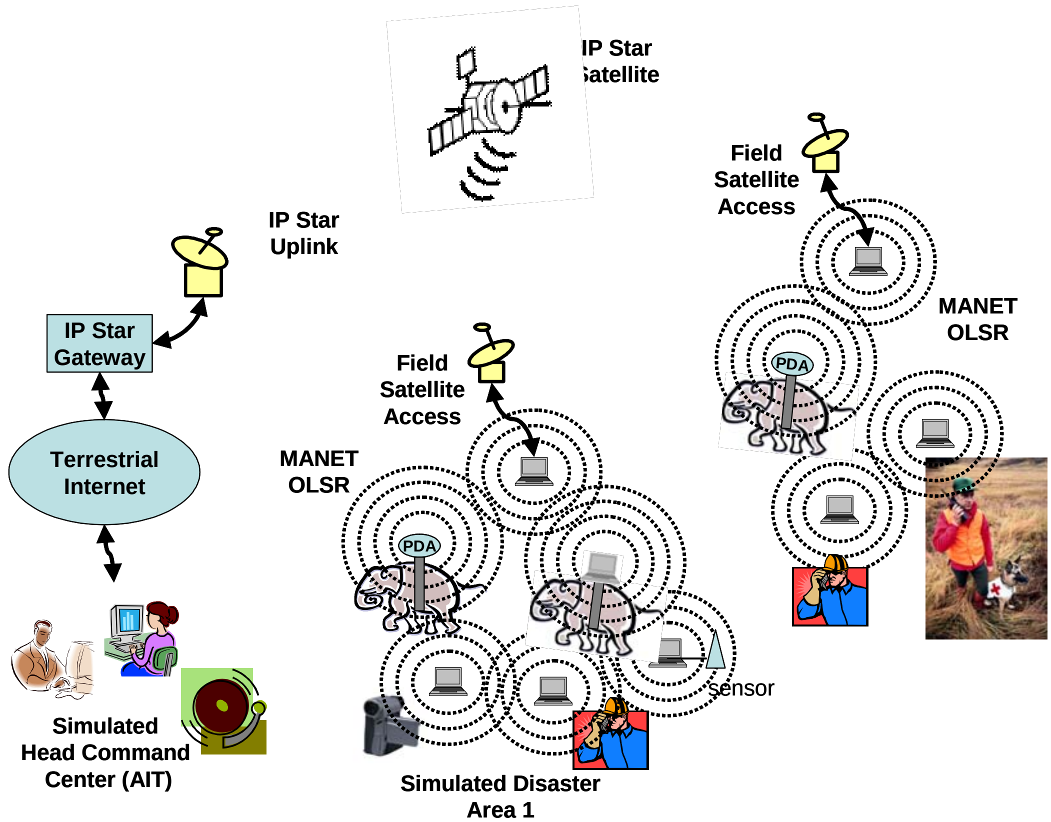

Figure 2 : DUMBONET Testbed

We use a geostationary satellite, known as IPStar [4] which provides a broadband internet service, to establish connectivity among a number of disaster sites and to a single command headquarter. The satellite allows us to quickly restore internet connectivity in the disaster-affected areas where traditional terrestrial communication infrastructure is severely disabled. A short internet restoration time, within a few hours, should prove extremely beneficial to the search and rescue operation.

In DUMBONET, we use virtual private network (VPN) to hide network heterogeneity that arises from the use of different networking technologies consisting of satellite, MANET, and terrestrial internet. From the perspective of mobile devices, they belong to the same private IPv4 subnet (e.g. 192.168.1.0) that spans across all different geographical locations (i.e. the headquarter and disaster-affected sites). At the present, we only use the OLSR protocol to route traffic among the devices that may not have direct wireless contact but are located within the same foresaid private IP subnet. The OLSR protocol also has additional routing capabilities, such as HNA, that we have not used. The entire DUMBONET is a single OLSR-driven network that includes local MANETs, and inter-site links through VPN and satellite.

2.2 Applications on DUMBONET

2.2.1 Multimedia Communication System

We deploy a specially customized multimedia application that allows every rescuer and a command headquarter to communicate using video, voice and short messages. The rescuer application operates relatively in peer-to-peer (P2P) mode that does not need a centralized server. The command headquarter application, if running, is a special version of the peer-to-peer multimedia application which has a more complete view of the search and rescue operation. The command center application additionally runs a face image similarity search application which is based on the well-known Eigenface algorithm. It incorporates a mathematical dimensionality reduction technique that helps identify victims by comparing the features of the query face image to the face image features of the known missing persons.

2.2.2 Sensors on DUMBONET

Placing sensors on DUMBONET provides useful information for rescue operation as well as for emergency warning or preparedness operation. Sensor equipments from the Live E! project [3] have been enhanced with OLSR routing capability and integrated into DUMBONET to provide rescuers with the readings of temperature, humidity, pressure, wind speed, wind direction, rainfall and CO_2. Sensor applications are useful in terms of measuring and identifying environmental and potentially harmful factors that may affect the rescue operation.

Figure 3 below shows one of the sensor equipments deployed in our system and its connectivity configurations.

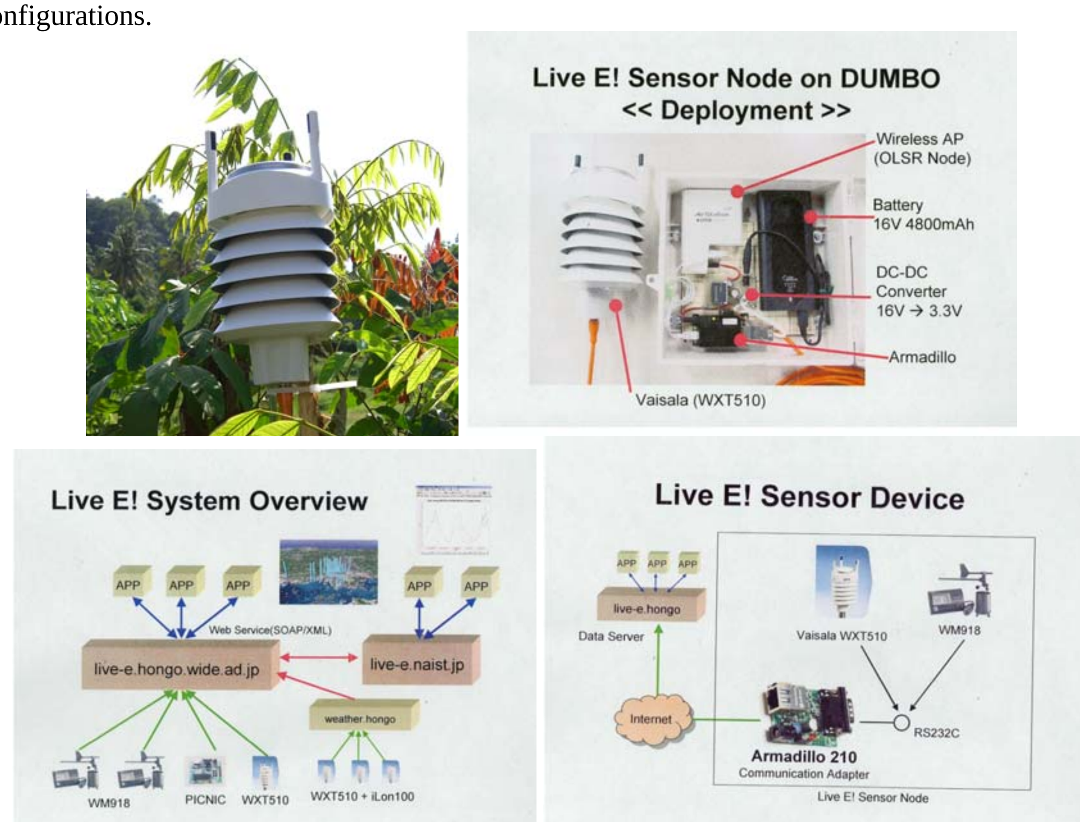

Figure 3: Sensor equipment deployed in DUMBONET and its connectivity configurations

3. Our Experiment and Demonstration

We had done quite a number of tests on campus before the debut of DUMBONET and our emergency response applications on December 1, 2006 in Phuket. Phuket was one of the 2004 tsunami-struck provinces in Thailand. There were two simulated isolated disaster sites in Phuket; each was an elephant camp. In AIT, slightly north of Bangkok, we hosted a simulated command headquarter which is connected to the Internet through terrestrial mean. Few days prior to our demonstration, we had a temporary IPStar [4] broadband internet satellite dish deployed at each elephant camp. The satellite access installation took approximately less than three hours. The two sites in Phuket and the one command headquarter in Bangkok were bridged together using a VPN software called OpenVPN [5]. PDAs and laptop computers located in all the three sites ran OLSR software [6], [7] creating one single OLSR MANET routing domain. Each device could send/receive IP traffic to/from all other devices that were in the OLSR routing domain spanned across the three sites over a hybrid WiFi – Satellite – Internet network.

During the demonstration in Phuket, rescuers rode elephants, carried a mobile device and entered into some geographically challenged areas, like a dense jungle trail and a hilly terrain, while communicating and collaborating with the command headquarter who orchestrated and oversaw a simulated rescue operation.

Figure 4 shows some screenshots of the applications obtained during test runs. On the left is the screenshot of the command headquarter application where many multimedia streams from Phuket were simultaneously visible. On the right, the status of the OLSR routing table is shown along with the rescuer application.

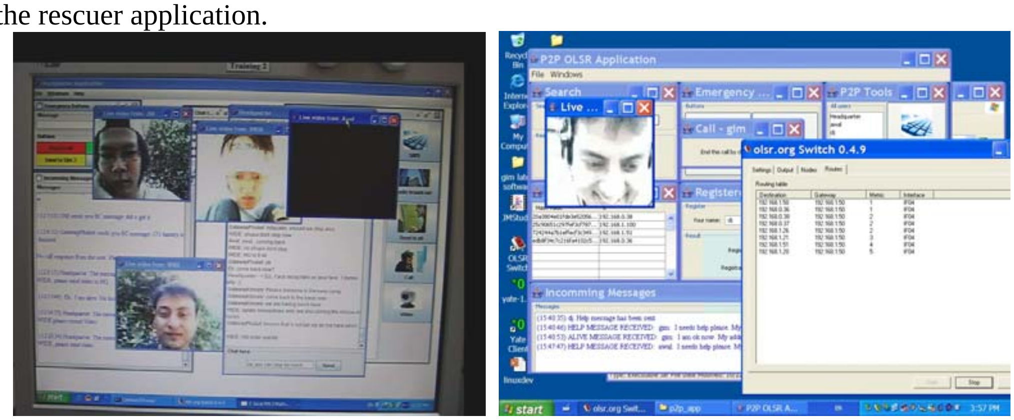

Figure 4: Screenshots of the emergency response applications during some test runs

Identification of victims is another essential task. With multimedia information streaming, it is easier to identify victims based on their appearances. Face recognition [8] or face similarity search is used to identify victims. Figure 5 shows some example results from the face image similarity search application during our test runs. A still face image in the upper left corner was captured from the field's video transmission and used as a query image. Images on the right were the closely matched results taken from our database of known faces (the top-12 similarity matches were shown).

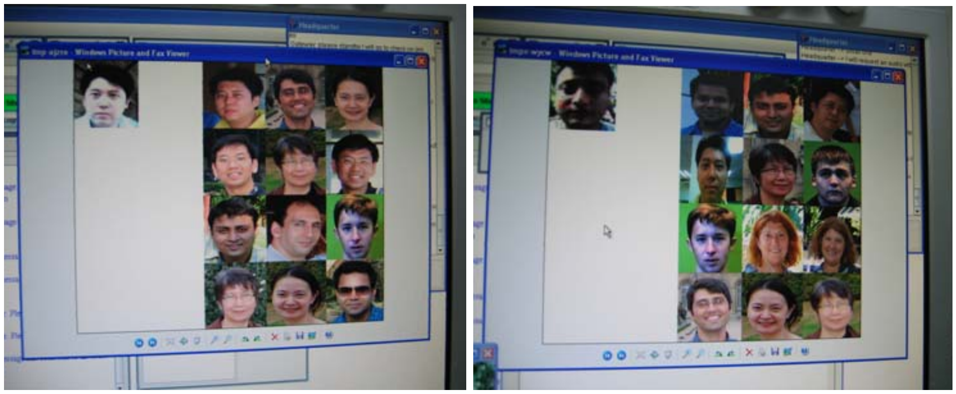

Figure 5: Example outcomes from the face image similarity search

4. Challenges in DUMBONET and Emergency Response Applications

Maintaining MANET connectivity and quality of service (QoS) in disaster-affected areas is one of our primary research areas. The operational range of the IEEE 802.11b WiFi is typically between 30 - 100 meters. There is a tradeoff between the WiFi power setting and the operational distance as a device transmitting at a higher power level covers a wider operational area but results in a shorter battery life. Each device's actual operational range is further limited due to other environmental factors like obstacles, debris, difficult terrains, antenna angle/orientation, and more. In certain test cases, we found the actual OLSR routing path not to be what we had anticipated. Variants in device power settings and WiFi chipsets could result in one mobile device choosing a physically farther device as its preferable MPR instead of choosing a physically nearer one.

The default OLSR implementation assumes homogenous network and does not take into account the different characteristics of the links when computing MANET routes. For example, the OLSR's neighbor discovery mechanism (i.e. HELLO) does not distinguish a next hop WiFi neighbor that transmits at 10mW from a next hop WiFi neighbor that transmits at 100mW. Likewise, it does not distinguish a regular WiFi link from a link that incidentally passes through a satellite tunnel (i.e. through the VPN bridge.) One of our research aims is to introduce link-characteristic awareness into OLSR.

The use of small low-cost WiFi access points which have been flashed with OLSR firmware [9] is one of our research interests because these access point devices have been equipped with better antennas and may supplement purely as OLSR routers. We are also interested in MANET topology formation along with GPS-capable devices coupled with OLSR extension, as rescuers still have certain control over the MANET topology should they experience bad signal reception.

A MANET environment has variable bandwidths, topology changes and oftentimes severe packet losses. The long propagation delay of the satellite channel also deteriorates the quality of interactive streaming audio. The common E-model [9] would predict bad-quality voice over IP (VoIP) experiences in most of our test scenarios. The need to improve the quality of video and audio streaming, especially through the uses of powerful codec and error correction methods, is highly apparent. In addition, emergency response applications must be resilient in the MANET environment

We understand the importance of automated identification of victims and objects. Automated online identification and classification enhances rescuers' capabilities to recognize victims and objects beyond initial trainings. There have been significant research progresses in the field of human face recognition [8]. Digital images obtained from the field may appear occluded, obscured, disoriented, or distorted, making identification task difficult. Our present implementation of face image identification works on still images. We look forward to incorporating effective and efficient image/video content identification techniques as a part of our emergency response applications.

Scaling the emergency response platform to work with several disaster sites simultaneously is an important investigation. The 2004 tsunami disaster actually damaged several shores across Andaman sea and Indian ocean. MANET typically works well in small to medium sized homogenous wireless networks. We need to devise a practical way to effectively communicate among many disaster-affected sites, potentially located in different geographical regions. Additionally, equipment durability could be another concern, as rescuers may have to enter tough areas such as ones at high-altitude, having rough terrains, being underwater, or having extreme temperature/humidity.

Deploying OLSR-capable sensor equipments in DUMBONET is one of our research investigations. Sensor information allows rescuers to better judge situations when responding to specific threats. Sensor information can also be used in simulation or computational models to predict or evaluate potential outcomes or to warn rescuers of dangers.

Providing security capabilities for DUMBONET and emergency response applications is also necessary as medical and personal information will have to pass through this system. There are needs to integrate encryption, authentication, verification and access control methods into DUMBONET along with the emergency response applications.

5. Conclusion

We have presented an emergency network platform based on OLSR, called DUMBONET along with its P2P multimedia communication system for collaborative emergency response operations in disaster-affected areas. Our work is a multidisciplinary effort that aims to create a real, viable system that can be used during disaster-related emergency situations that traditional communication infrastructure is not operational. We have tested our system in the field to gain better understanding and insights. Our field experience along with potential research issues and enhancements have been described. We will continue to improve many aspects of DUMBONET and our emergency response applications in the time to come.

Acknowledgements:

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The initial idea of experimenting with MANET in emergency situation came from discussions of the responsible researchers of the three teams: Philippe Jacquet (INRIA), Kanchana Kancanasut (AIT) and Ryuji Wakikawa (WIDE).

Our special thanks go to our friends and colleagues who volunteered to join the DUMBONET experiments in December, 2006. For details please refer to http://www.interlab.ait.ac.th/DUMBO

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