Building A Long-distance Multimedia Wireless Mesh Network for Collaborative Disaster Emergency Responses

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Abstract

We designed and built a fully functional prototype of the long-distance multimedia wireless mesh network (WMN) that can aid disaster emergency response crews during the time of large-scale disaster. We assume that the wired networking infrastructure has been completely wiped out by the disaster and that emergency response crews need to bring in WMN multimedia communication technology to collaborate their work. Our WMN prototype utilizes a hybrid satellite - WiFi connectivity to connect among several isolated disaster-affected sites and a command headquarter. We describe the multimedia and sensor application framework deployed in our WMN. We describe our field tests and a successful live demonstration. Our system allows us a unique opportunity to explore the real-world behaviors of the routing protocol and the application in a very high delay WMN environment. We also describe challenges to overcome in our future work to improve our system.

Keywords: *Disaster Emergency Response Wireless Mesh Network; Optimized Link State Routing (OLSR), Hybrid Satellite WiFi Mesh Network; Peer-to-Peer (P2P) Applications; Sensor Networks, Face Recognition*

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1 Introduction

The Tsunami event in December 2004 devastated several areas in countries along the shores of Indian ocean [1]. One of the worst aftermaths was the breakdown of telecommunications infrastructure -- no telephone and internet. It took days to regain communications with some of the distant isolated islands. Emergency search and rescue operations were hampered. Our researchers took the Tsunami event as a serious cause to explore an alternative communication and application methodology that can be established in the affected fields after the occurrence of such a large scale disaster.

The ability to turn ordinary portable equipments, like laptop computers and personal digital assistants (PDAs), into a powerful self-organizing system of wireless networking equipments will prove very valuable during the time of large-scale disasters. Having multimedia communications capabilities will also make the tasks of emergency rescuers much more effective and safer. Queries such as “We encounter an unknown object in this area, would it be dangerous?” or “Did you find someone who looks like this photo?” cannot be easily handled by depending on voice communications alone. With today’s combination of (1) relatively inexpensive hardware; (2) mostly free or open source software in multimedia and wireless networking; and (3) our own programming and customization efforts, we have shown that a self-organizing, multimedia communication system to aid the rescuers is realizable and sufficiently practical for real emergency response operations.

In this article we describe our experience in creating a fully functional prototype of the long-distance multimedia wireless mesh network that can aid the collaboration of disaster emergency response operations. We first investigate the operational requirements. Next, we describe our choice of the routing protocol. Then we describe the application framework for multimedia disaster emergency response operations and our field test experience. We then describe further challenges to overcome and summarize our work.

2 A Wireless Mesh Network for Multimedia Disaster Emergency Response Communications : Requirements and Design

A wireless mesh network (WMN) [2] is a self-configured, self-resilient network that may consist of infrastructure-based wireless mesh routers and non-infrastructure wireless mesh clients. A wireless mesh router (WMR) is typically a non-moving node that has one or more wireless radio interfaces. Each WMR is capable of multi-hop routing and may have multiple wireless radio technologies (e.g. WiFi and Microwave) to expand the network coverage. A wireless mesh client (WMC), usually having one wireless interface, can also perform multi-hop routing. A special class of WMNs having only moving wireless nodes, without wireless mesh routers, is typically referred to as a Mobile Ad-Hoc Network (MANET).

After a large-scale disaster strike, one of the top priorities is to restore communications as quickly as possible to aid emergency response crews. A reasonable choice is to create a MANET for a team of emergency workers working at a particular disaster-affected site.

Typical MANETs are based on IEEE 802.11b/g WiFi and may span up to few kilometers with multi-hop routing. Nevertheless, history shows that many emergency response teams have to work simultaneously at several disaster-affected sites located in different geographical regions (e.g. on the islands and shores that a Tsunami swept through). Likewise, the emergency response operations usually require a central command headquarter to coordinate rescue efforts being carried out by different teams at different sites.

To span the coverage of communications, we need to build a WMN that utilizes different wireless radio communication technologies: short-range vs. long-range to be precise. With a contribution from a satellite internet service provider, we were able to create a long-distance high-speed WMN that merges several site WiFi MANET networks together through the use of a geostationary satellite internet service. Using the satellite has certain advantages. First, the wide footprint of the satellite enables us to cover extensive regions. Second, the satellite is a very reliable communication backbone. Third, our own experience shows that setting up a satellite internet access can be accomplished in less than three (3) hours, which is relatively quick when compared to the restoration of wired network infrastructure. However, communications passing through the satellite will be subject to high propagation delay: the typical unidirectional geostationary satellite propagation delay is approximately 240 milliseconds.

Figure 1 illustrates the main components of our WMN for multimedia disaster emergency response communications. At each disaster site, we use laptops and PDAs to form a local MANET that runs on WiFi. One special node at each site is a WMR that has both WiFi and satellite interfaces. The WMRs allow traffic to pass among disaster-affected sites and a remote command headquarter. We deploy a virtual private network (VPN) among the site WMRs and the mesh router at the command headquarter to hide network heterogeneity. By doing so, all the wireless mesh clients at the disaster sites and the fixed nodes at the command headquarter belong to one single routing domain.

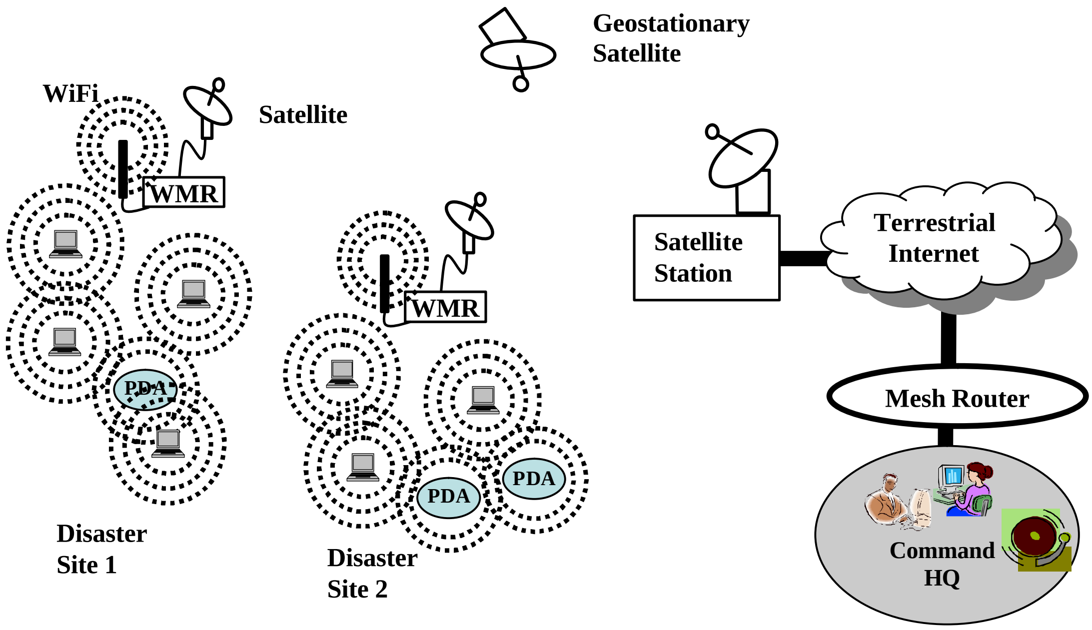

Figure 1) Wireless Mesh Network for Multimedia Disaster Emergency Response Communications. Our wireless mesh routers (WMR) have both WiFi and satellite interfaces. We can interconnect two or more isolated disaster sites (e.g. isolated islands) in similar configurations.

Figure 2 illustrates three (3) categories of bidirectional communications commonly required by most emergency response operations: (A) intra-site; (B) site-to-HQ; and (C) site-to-site communications. In the site-to-site scenario, our satellite internet service provider does not allow direct site-to-site traffic among the field satellite access equipments because of control and security reasons. The site-to-site traffic from the source must be sent through the satellite to a terrestrial satellite gateway. The terrestrial satellite gateway then re-sends such traffic through the satellite to the destination site. Hence, the site-to-site communications are subject to the highest propagation delay among all the three.

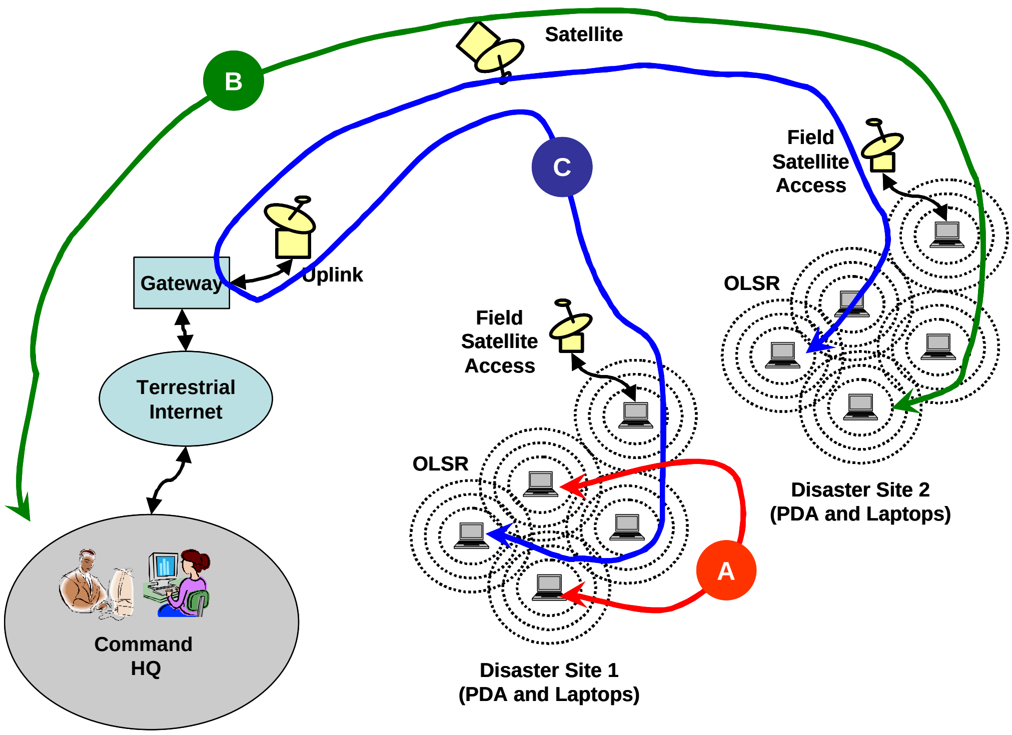

Figure 2) Three types of multimedia communications commonly required during disaster emergency response operations : (A) intra-site; (B) site-to-HQ; (C) site-to-site.

3 The Optimized Link State Routing (OLSR) Protocol: An Overview

We need a WMN routing protocol to allow internet-like, IP-based multimedia communications among the command headquarter and the mobile nodes at the disaster sites. Based on the focus and expertise of our research team, we have selected the Optimized Link State Routing protocol (OLSR) [3] as the main routing protocol in constructing our WMN for emergency responses.

There is a number of publicly available OLSR implementations (e.g. in [4] through [6]). Each node (a laptop or a PDA) running the OLSR periodically sends out a 'HELLO' message to discover its neighbor nodes. Figure 3 below illustrates some OLSR node relationships from the perspective of node A. A directed arrow from one node to the other node (e.g. from A to C) means that the latter node (e.g. C) can hear from the first node (e.g. A) but the opposite may not be true. In this case, node A is a one-hop neighbor of node C because node C can receive transmission from node A. A double-headed arrow denotes a situation where both nodes properly hear each other and hence form a one-hop symmetric, bi-directional link. All the neighbors having at least one symmetric link with a specific node are called the symmetric one-hop neighbors of such a node.

The OLSR has a notion of symmetric two-hop neighbors. A symmetric two-hop neighbor of node A is a node having at least one symmetric link to a symmetric one-hop neighbor of A. On a further restriction, a symmetric *strict* two-hop neighbor of node A must not be a one-hop neighbor of node A. In Figure 3 below, nodes D and E are symmetric two-hop neighbors of node A. However, only node E is a symmetric strict two-hop neighbor of node A.

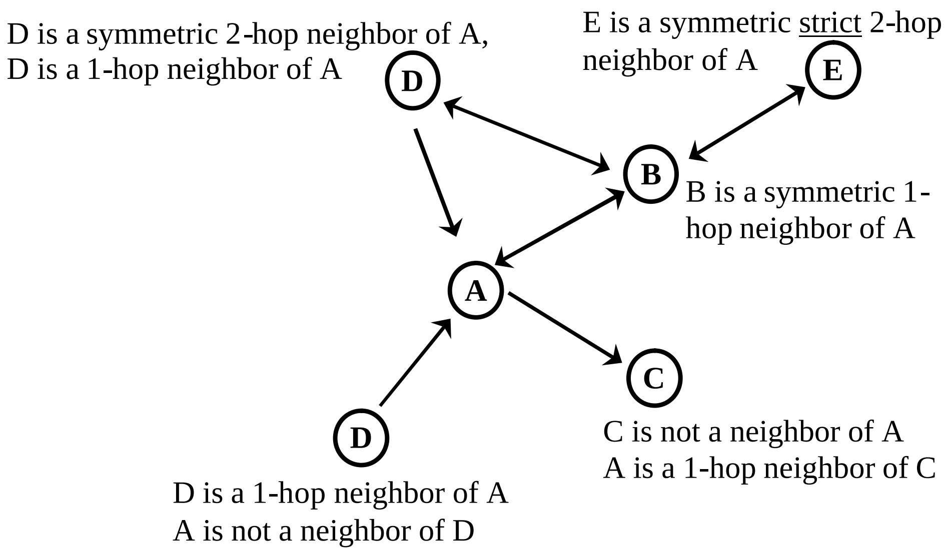

Figure 3) Some of the OLSR node relationships, based on the perspective of node A.

The OLSR attempts to reduce the number of broadcast or flooded messages by using the concept of multipoint relay (MPR). To relay messages to all of the strict two-hop neighbors of a particular node, the node may need only a few symmetric one-hop neighbors to relay the messages. In Figure 4 below, nodes in the set { L, M, N, O, P, Q, R, S, T, U } are the symmetric strict two-hop neighbors of node A. By using only nodes H and K as the MPR nodes, it allows node A to send messages and reach all of its symmetric strict two-hop neighbors. There is no need for nodes I and J to relay messages from node A.

By carefully selecting a sequence of MPRs, a piece of information can either be relayed to a specific destination or be made known to the whole network much more efficiently than every node doing naïve flooding. Using the MPR technique reduces overall energy consumption and network access contentions. There are many different ways to choose MPRs (e.g. see [3], [4]) and it is an optimization problem beyond the scope of this article.

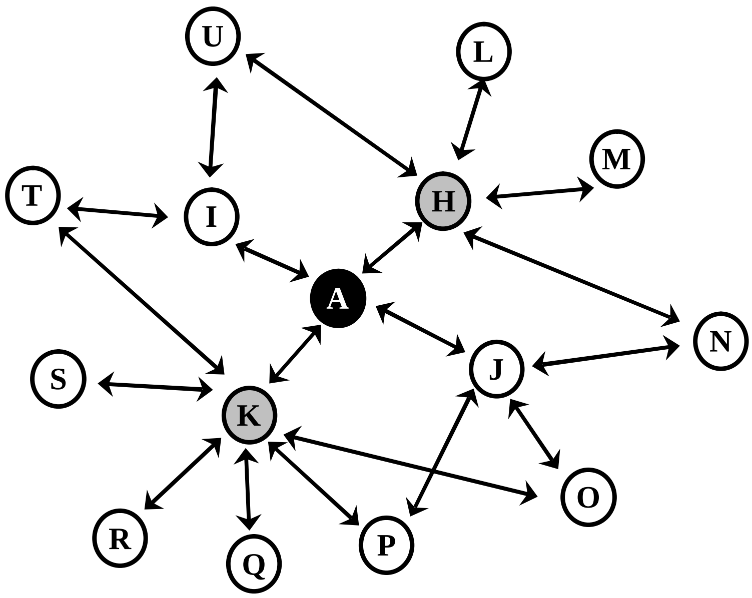

Figure 4) Multipoint Relay (MPR). If node A selects nodes H and K as MPR nodes, it suffices to reach all the symmetric strict two-hop neighbors of node A.

The OLSR can also work when a node has two or more network interfaces (regardless of being wired or wireless). This allows the OLSR to function on a WMR as well as on a WMC. OLSR nodes also periodically exchange their topology information through topology control (TC) messages. Hence every reachable OLSR node knows the global picture of the nodes in the same network.

The OLSR allows customizable protocol extensions. One may define new message types to be included in OLSR protocol messages that are exchanged among OLSR nodes. The ability to extend the protocol is useful when we may wish to create an application that may have cross-layered capabilities when running on top of the OLSR. One example is to implement a peer-to-peer (P2P) application that may use the OLSR routing layer to diffuse specific information (e.g. node and service capabilities) into the whole OLSR network.

There are proposals to enhance the capability of the OLSR. The first example is to monitor link quality (see [4]) to determine which links should be used when forwarding the packets – i.e. to become a good candidate link, the link should not lose too many packets. The second example is to make the OLSR routing layer aware of the physical locations and movements of the nodes. This may be done by adding the geographical coordinates and known heading derived from the Global Positioning System (GPS) and using such information to aid the computation of routes

As a link state protocol, the OLSR still has a limit in terms of scalability. Default OLSR implementations do not consider link heterogeneity, either in terms of available bandwidth or delay. A hierarchical version of the OLSR, dubbed 'HOLSR', has been proposed to deal with heterogeneity and scalability [7]. At the time of our experiment, we chose one implementation of regular OLSR available from URL: http://www.olsr.org and the other available from URL: http://menetou.inria.fr/oolsr/.

4 P2P WMN Multimedia Emergency Response Applications and Our Field Test Experience

In disaster emergency response operations, the need for self-configuring and self-healing applications is also highly apparent. Disaster emergency crews must focus on saving lives and should spend the least time on application setup and troubleshooting.

Our researchers customized three application software components intended for disaster emergency response operations. The first application component is a multimedia communication software that allows rescuers to communicate and collaborate. The software operates in a peer-to-peer (P2P) manner that does not need a centralized server. Within the coverage of the WMN, every rescuer can make voice or video calls, and participate in instant messaging dialogs with any other rescuer and with the command headquarter. Although we have a notion of the command headquarter (HQ) application, the HQ application is just a peer instance that has additional capabilities. The multimedia communication software runs on relatively inexpensive laptops that have built-in camera, microphone, speaker, and WiFi. The rescuers may easily carry such laptops into the disaster-affected fields.

Each application instance connected to the WMN should be able to register its presence and discover the capabilities of other peer application instances in the same WMN. To do so, we use a technique known as distributed hashing table (DHT). Each node participating in the DHT is responsible for storing information items associated with a subspace of keys derived from a common hashing function. The hashing function usually has a very large key space (e.g. 160-bit keys) . When a node is queried about data value associated with a specific key *k*, either the queried node is the one who has the information item associated with the key *k* itself, or the node should be able to refer to another different node that is ‘closer’ to the node that actually stores the information item associated with the key *k*. The DHT relies on the underlying overlay network (e.g. the routing layer) to refer from one node to the other node. Some may have seen this overlay approach not being as efficient as possible. Hence, there have been cross-layered research interests to incorporate DHT operations into the OLSR (e.g. the OLSR may collaborate with DHT by directly manipulating DHT’s store/lookup requests and by being able to refer a query to a ‘closer’ node).

Figure 5 shows some of our equipments and the field tests of our P2P WMN multimedia emergency response applications. In the figure, we used the laptops to function as WMN relay nodes that also run the P2P WMN multimedia emergency response applications. Small PDAs were used only as WMN relay nodes -- they did not run user applications. At each simulated disaster site, one laptop had both a WiFi interface and an interface to the satellite internet uplink, hence acting as a WMR to allow communications with the other disaster site and with the command headquarter. Some other laptops were carried on elephants to extend the WMN coverage. The elephants also have a natural advantage to easily enter jungles, debris fields and other areas that are hard to access by humans.

Figure 5) Equipments and field experiments of our multimedia emergency response WMN

(Photos are courtesy of invited researchers and guests who participated in the field experiments)

The second application component is the sensor application which allows reading of such environmental data as temperature, humidity, pressure, wind speed, wind direction, rainfall and CO2. Sensor applications are important in emergency disaster response operations. Sensors can help reduce risks and warn of imminent dangers that rescuer teams may face. With a research collaboration with the Live E! working group, the WIDE project [8], the Live E! sensor equipments have been enhanced with OLSR interface and integrated into our WMN, making them a crucial part of our WMN experiments. We expect to work with more types of intelligent sensors in a near future.

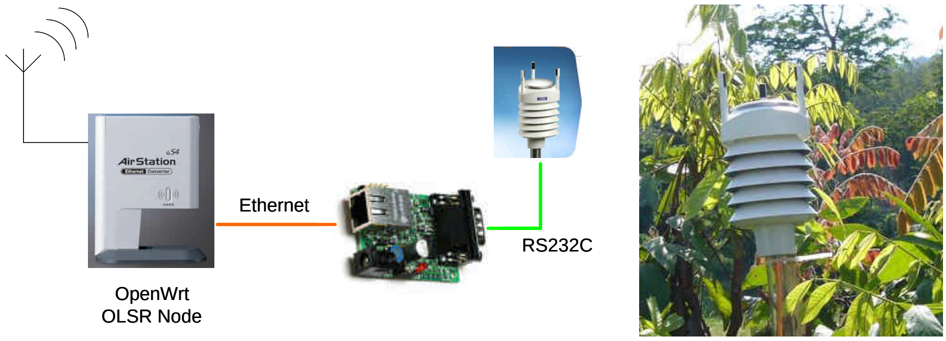

Figure 6) One of the Live E! sensor nodes connected to the WMN in our field experiments

(Photos are courtesy of H.Ochiai, H.Esaki, S.Matsuura, M.Yamanouchi, and Y.Tsuchimoto)

The third application component is a face recognition software that allows rescuers to compare face images captured from the site to the collection of known faces. We implemented a face recognition software based on the well-known Eigenface approach [9]. Rescuers can send live video feeds via the WMN to the command headquarter where still face images can be extracted and the face matching takes place. Other intelligent video processing and machine vision techniques are also being planned for a future release. This shall answer the need to search and identify survivors and victims from large-scale disasters.

We successfully organized a live demonstration of our system on December 1, 2006 between two simulated disaster-affected sites in Phuket and a simulated remote command headquarter in upper Bangkok. For further details, please visit our project website: http://www.interlab.ait.ac.th/dumbo/index.php

5 Challenges in WMN for Disaster Emergency Responses

The WMN environment can have highly variable packet loss rates and delay characteristics. We observed from our real field tests that the packet loss rate could occasionally exceeds 20%. Packet losses in the WMN can result from various reasons. Example causes include the limited processing power of the mobile nodes (e.g. running multimedia applications while also performing the routing function); node mobility; antenna orientation; transmission power; radio channel access contentions. Packet losses virtually complicate the operations of all software components. WMN nodes may have trouble with DHT registration and query with the others. The quality of voice and video conversations are significantly affected. The sensor data can be lost. As video quality degrade, the face recognition software may have trouble identifying blurry face images. It also consumes more power when the network is very lossy as the applications and users have to re-transmit the lost information. Under normal operation, all applications work just fine. However, under occasional severe packet loss moments, we find that the communications through text messaging is the most reliable.

Running the OLSR and the P2P multimedia emergency response applications in a high-delay hybrid satellite-WiFi environment poses several challenges. Example issues include : how do one achieves almost fully automatic self-configurable property at all the disaster sites which are potentially isolated and distant but interconnected through the satellite? How quickly would the routing tables at all the nodes get converged? If there is significant mobility or changes in a certain part of the WMN, how should the routing layer react? How would applications maintain session continuity? These are the issues that our researchers will continue to investigate.

Generally, a WMN for disaster emergency responses could use a lot of security enhancements. In most disaster response operations, the focus would be on bringing in the helps as soon as possible. Medical information may have to be transmitted through insecure network, making privacy a disputable issue. Authenticating emergency crews and classifying their privileges in WMN resource usage and control are also important. Physical signal interference or jamming may occur, either intentionally or unintentionally, while the rescue operations are being carried on.

The issue of WMN resource usage fairness is pretty much undefined in most emergency situations. How much bandwidth should be reserved for critical medical communications, for general commands an queries, for situation reports and for some other activities? and by what means?

A measurement tool is being independently developed in our laboratory to measure the quality of the OLSR-based WMN. Having such a tool will significantly make us understand what is really going on and it could serve as an alert tool when the WMN suddenly appears bad or when the rescuers are losing WMN connectivity.

Lastly, software interaction/conflict and interoperability issues should not be overlook. We found from our field experiments that many real-world software items do interact.

That is, when we run each of those software independently, it works just fine. But when we run two or more of them, they simply do not work together or give strange behaviors.

6 Summary

We have presented our experience in developing and deploying a long-distance multimedia wireless mesh network (WMN) aimed for disaster emergency response operations after a large scale disaster strike. On the networking side, our solution utilizes a hybrid WiFi and satellite connectivity thus making it a unique opportunity to observe the real-world behaviors of the routing protocol (and our applications) in a very high delay setting. On the application side, we customized a number of WMN-capable application software items: multimedia communication, sensor equipment, face recognition that are useful to handle disaster emergency scenarios. We did several tests during November 2006 and successfully demonstrated our system on December 1, 2006. We are still challenged by many field and research issues for our future research work to come.

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