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A Mobile Crisis Management System for Emergency Services: from Concept to Field Test

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ABSTRACT

During crisis situations, emergency services have to make a lot of crucial decisions, sometimes inevitably based on incomplete or outdated information caused by a lack of means of communication. Wireless ad hoc and mesh networks are a good solution for setting up emergency networks, as they do not rely on fixed infrastructure, can be set up quickly, and provide the necessary communication bandwidth. This paper introduces the GeoBIPS crisis management system architecture, which enables emergency services to collect and combine dynamic on-scene data with static information stored at local or distant servers, using a wireless mesh network. The usability of GeoBIPS has been proven by implementing the architecture on actual hardware which already has been evaluated positively by firemen during a real-life demonstration at a simulated house fire.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*Wireless Communication*; H.5.1 [**Information Interfaces and Presentation**]: Multimedia Information Systems

General Terms

Design, Experimentation

Keywords

Wireless Mesh, Emergency Services, 802.11, Channel Selection, Multiple Interfaces, Experimental Evaluation

1. INTRODUCTION

Acquiring the right information at the right time during a crisis situation is –even more so than during everyday life– of the utmost importance in order to make correct decisions. Unfortunately, it is precisely at this moment that one can not rely on normal communication infrastructure.

For some years, the disaster scenario has been the ultimate ad hoc networking paradigm, and not without a reason. However, even though countless publications are related to the potential applicability of ad hoc networks in emergency situations, few commercial deployments can be found.

The GeoBIPS crisis management system is developed in order to be able to access up to date information fast and easily during crisis situations. Using underlying wireless mesh networking technology [1], static and dynamic information from different sources can be combined and presented to the right persons. This way, life saving decisions can be made during critical moments of an intervention. As a use case for emergency situations, a fire scenario was selected.

The GeoBIPS system is not just a piece of paper; A large part of the research and development has been experimentally validated, and recently, GeoBIPS was evaluated by a fire brigade during an exercise at a fire school.

This paper presents the GeoBIPS architecture, and gives an overview of the different hardware and software components. Next, current observations and results are given. The paper concludes by looking at the future developments for the GeoBIPS project.

2. GEOBIPS ARCHITECTURE

2.1 Overview

Today, an intervention typically starts with a call received at an emergency center. The operator then decides which units and vehicles should be sent out in the field. Once arrived at the scene, the firemen prepare the equipment and the *reconnaissance team* (RT) enters the building. All actions are supervised by the *commanding officer* (CO), who does not enter the building himself. Using this traditional approach, communication between team members and CO is limited to voice. This voice communication can fail when entering buildings with lots of concrete, or steel constructions such as in modern buildings or ships. During some operations, the RT is followed by a cameraman, in order to make a live video stream of the intervention available outside the building. Nowadays such a live video stream is only

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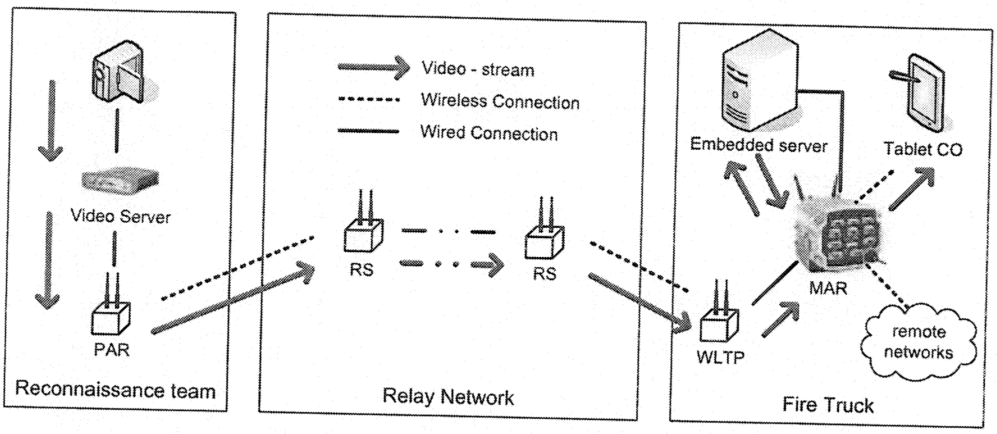

Figure 1: Equipment used at the emergency site

possible with the aid of at least 5 extra persons for guiding the cable of the wired camera through the building and therefore, it is only very rarely used during an intervention.

From the description above, it is clear that it is not easy for the CO or crisis center to make a correct judgment during the action. This problem originates from the fact that emergency services cannot rely on the communication infrastructure at the incident site.

The objective of GeoBIPS is to ameliorate this situation by deploying a self-forming broadband wireless mesh network at the fire scene as the team enters the building. Using this network and with the help of equipment installed in a fire truck, the CO and crisis center are permanently connected to the RT over a wireless multi-hop broadband connection. This enables the CO to acquire up to date information, both from the RT (e.g. video feed) and from a crisis center (e.g. intervention plans). At the same time, the CO can send useful data (e.g. a fact sheet on hazardous materials that will be found at the scene) to his team.

Figure 1 gives an overview of the emergency site equipment used by GeoBIPS. Three main parts can be distinguished. The devices on the left side of the figure are carried by the cameraman in the RT. The dual-mode camera is sensitive to the visual and infra red spectrum, making it possible to shoot pictures in the dark or to find victims behind clouds of smoke. The analog video output of the camera is then fed to a video server, which encodes and packetizes the video in real time into an MPEG4 RTP packet stream. These packets are sent to the *Portable Access Router* (PAR) over ethernet. The PAR has two functions: it sends the video packets out over a wireless ad hoc interface, and it serves as an access point for the RT. Firemen can connect to this access point with a ruggedized PDA and send or receive data, and voice over IP.

The equipment on the right side of Figure 1 is installed on or near the firetruck. As the RT exits the firetruck, the cameraman's PAR automatically connects wirelessly to the truck-mounted *Wireless Link Termination Point* (WLTP) and an ad hoc network is formed. The video and audio stream arriving from the RT is sent to the embedded server, where they are both stored. After the mission is over, the stored video and audio data can be replayed in order to evaluate the operation, so emergency services can learn from previous experiences.

The embedded server is connected to the central router, a Cisco 3200 series *Mobile Access Router* (MAR), which is mounted on the firetruck. As the MAR is powered by the fire truck alternator, it is not limited in power. The MAR can connect to a distant network (e.g. crisis center) either by using a local hotspot, a GPRS, or UMTS connection, thus forming a gateway node. In addition, the MAR sets up a local hotspot around the firetruck. The commanding officer connects to this hotspot with a tablet computer, and immediately sees the video shot by the reconnaissance team. In order not to overload the network between WLTP and PAR, this video is streamed in real-time from the embedded server. Adding a second tablet to the scene thus only increases the load on the MAR hotspot, and not on the wireless network started at the WLTP. The MAR gateway node connects the local mesh/relay network with the distant network of the crisis center, and so an interworking between fixed and wireless networks is achieved. The crisis center can follow the ongoing action and assist the CO.

The last and most important part of Figure 1 is the mesh network in the middle. As the reconnaissance team moves further into the burning building, the distance between WLTP and PAR grows and obstacles get in the way. This results in a degraded connection quality and if no actions would be taken, throughput would drop fast. The degrading signal quality is indicated to the firemen by the On The Go Coverage Indicator (OTG-CI, see Section 2.4 below). To solve the signal quality problem, the firemen place a new node between WLTP and PAR. The node is automatically added to the existing ad hoc network, creating a wireless mesh. A dynamic channel selection algorithm (explained in Section 2.3) then automatically selects a subset of this mesh as a relaying path and reconfigures the wireless network interfaces of the nodes, so that orthogonal paths are used on neighboring links. The single hop wireless connection is now replaced by a multi-channel multi-hop network and end-to-end throughput remains satisfactory. Every time the OTG-CI indicates a signal problem, an extra node is deployed, and the wireless mesh network grows larger.

2.2 Wireless Mesh Network

The previous section showed how network connectivity between the PAR, carried by the reconnaissance team, and the WLTP, mounted on the firetruck, is maintained by adding

Mesh Routers (MR) as the firemen move away from the truck. These three types of nodes are all supported by the same type of hardware: the mesh network is built using modified versions of the Access Cubes (formerly know as Meshcubes) by 4G Systems. An Access Cube is an integrated system that consists of a basic I/O and CPU PCB, with multiple wireless 802.11 a/b/g interfaces stacked on top. It is small in size (default 7x5x7cm when used with two wireless interfaces and without antennas), has low power consumption and runs a modifiable Linux distribution.

For use in the GeoBIPS project, we needed to make some modifications to this design. Firstly, the standard version of these cubes is fed with a power adapter; Obviously, firemen can not rely on power outlets in a burning building, so three light-weight batteries (Li-ion, 3.7V, 2200mAh) were added to every MR and to the PAR. This off course can not be done using the standard casing, so the cube hardware was put in a new one sized 15x7.5x6cm. Secondly, we replaced the standard antennas with embedded omni-directional antennas, resulting in an overall smaller and more robust portable mesh device which can easily run on batteries for three to four hours. Our measurements have shown that this new design results in higher signal strength. This signal strength amelioration is attributed to the new antennas, which use considerably shorter cabling between wireless interface and antenna, resulting in reduced cable losses. Additionally, the shorter antenna cable fits more relaxed into the casing, and a straight cable means less loss.

Traditional ad hoc networks with a single interface do not scale very well [6]. Because the wireless nodes have to contend for access to the shared wireless medium, throughput in multi-hop networks drops fast when the number of nodes increases. The availability of multiple wireless interfaces at the MR, allows this problem to be avoided by using an intelligent channel selection algorithm. More details are provided in Section 2.3 below.

Optimized Link State Routing (OLSR, [4]) was selected as a routing protocol. OLSR is a proactive link state routing protocol developed for ad hoc networks, that builds up a routing table based on information gathered by the periodic exchange of control packets. We chose a proactive routing protocol because bandwidth information must be disseminated through the network in a proactive way (as described in Section 2.4). After a cube has booted, which takes about 30 seconds, it immediately and automatically sends out OLSR control packets containing information on neighboring links. The existing nodes in the network quickly become aware of the existence of a new node, and routes are recalculated. When a new node is being added to the mesh network and a new relay route is chosen, the RT video stream continues to run uninterrupted towards the fire truck, although a few packets are lost, leading to some minor artifacts. Thus, new nodes can be added seamlessly into the network.

If a node dies, for example, it gets buried when a part of a building collapses, the neighboring nodes will no longer receive OLSR control messages. This problem will be detected by the network, and, if available, a new route will be chosen. This reconfiguration takes place automatically. However, contrary to adding a node, this does not happen completely seamlessly, and video is lost for about a second.

The security in the mesh network can be guaranteed by using an IPsec tunnel between MAR and PAR for voice and video. This is necessary, as otherwise the information streams could be tapped by bystanders, who could potentially misuse the acquired data. Additionally, the MRs could be loaded with a pre-shared authentication key, as a fire squad knows in advance which equipment will be used. This key could then be used to sign all OLSR routing messages, in order to prevent rogue nodes from entering the network.

One might wonder why forwarding is done at L3 instead of using a L2 bridging technique, as is done by several commercial vendors of network equipment? By developing a solution at the routing layer, in the future, the GeoBIPS system can be extended to support multiple emergency squads which can reuse MRs placed by other teams. It would then also be possible to, for example, provide different shielded ad hoc network overlays (one network overlay for each logical team) using common mesh router infrastructure. However, the current implementation does not support multiple teams yet.

2.3 Dynamic Channel Selection

When deploying infrastructured wireless networks, it is important to choose which frequencies to use. If multiple access points use the same or interfering frequencies and are in each others reach, the overall throughput of the network drops due to interference.

When deploying an ad-hoc network, such as the mesh network in the GeoBIPS system, things become more complicated. The location of each node in the wireless mesh is not known in advance. This makes planning of frequency usage impossible to do, since one doesn't know which nodes may interfere. The only viable option is to use *Dynamic Channel Selection.* Using Dynamic Channel Selection, it is the network that organizes the use of frequencies in such a way that the best throughput can be achieved.

The GeoBIPS system uses the following algorithm to achieve dynamic channel selection: All MRs have notion of a *default channel.* This is the channel that is always used by the last hop (the hop from the last mesh node to the PAR). If a new node is powered on, it joins the network using this default channel by putting one of its wireless interfaces in that channel. To minimize interference, the previous last hop and the new node, that will be the new last hop, should communicate on a different channel than the default channel, since that will be used on the link between the new node and the PAR. To accomplish this, the newly inserted node uses its second wireless interface to do a scan. During that scan, it detects any wireless network in range, and records the strength of each received signal. This way, the new node knows which channels are in use and how strong the signal on these channels is.

The next step is to decide which channel to switch to on the link from the new node to the previous last node. If the mesh network operates on the 802.11a standard, this is relatively easy to decide. Using 802.11a, none of the available channels interfere. The new link should thus switch to any unused channel.

If the mesh network operates on the 802.11g standard, the choice of channels is severely limited due to the fact that only three of the available channels are non-interfering. The new link should then operate on a channel that is least interfering with the active channels at that location. The node takes into account that weak signals generate less interference than strong signals and selects the new frequency in a heuristic way to try and minimize the interference on the new channel.

Once a new channel is selected, the link between the previous last hop node and the new node is switched to the new channel.

In the current implementation, we chose to only switch channels in the event of adding a new node to the network or when a node dies. If the channel conditions change (e.g. a third-party access point suddenly becomes active and interferes with the mesh network), no channel switching is performed; This could possibly interrupt video and voice communication in an unacceptable way, since changing the channel somewhere in the middle of the mesh network has an impact on neighboring links, which would possibly lead to switching channels on most links in the network.

2.4 On The Go Coverage Indicator

During deployment of the dynamic mesh network, it is indispensable for the fire fighters to know where to place the nodes, in order to ensure an optimal connection between them and the fire truck. The placement of the nodes will largely determine the end-to-end throughput in the mesh. On the other hand, the reconnaissance team likes to be informed about the state of the network. For example, if there is a node failure, they can take proper action. To satisfy those needs, we developed and implemented a monitoring tool, called the On The Go Coverage Indicator, which visualizes this in a clear and simple manner.

The OTG-CI is installed at the PAR, and continuously monitors the signal strength to the nearest node in the mesh network. As the RT moves further inside the building, the signal strength will drop and as soon as it drops under a certain threshold, the fire fighter will be notified to deploy a new node. In order to provide redundancy, this threshold is deliberately chosen by experiments in such way that the penultimate node that was placed can be reached with good signal strength. The lack of absolute values for signal strength or noise floor in 802.11 [2], forces us to measure RSSI (Received Signal Strength Indicator) values, which can be retrieved from the driver.

To measure the state of the mesh network, we extended the OLSR routing protocol. Each node will estimate link capacity to each of his neighbors by sending packet pair probes. Two back-to-back packets (first a small one which acts as a trigger, then a larger one) are sent to a neighbor. The time difference on arrival will be measured and communicated back to the sender. The minimum of a certain amount of samples will be considered to estimate the link capacity. This technique is used because of its responsiveness and minimum load impact on the network. It should be noted that packet pair probing is not always very accurate, since it ignores certain factors that affect packet delivery time. However, it will give a good indication of the current state of the network [3, 5].

The link capacity to each of a node's neighbors that is measured by packet pair probing, together with link channel information will now be disseminated through the network, by means of the existing OLSR messages. As OLSR is proactive, each node has knowledge of the whole topology of the mesh network. The link capacity and channel information can be used to make an end-to-end bandwidth estimation of a route, by identifying the bottleneck-link, taking into account the channels that are used in the path. The OTG-CI now has an overview of the current state of the wireless mesh network. In case of a node failure or throughput degradation, the fire fighter will be alerted and provided with information about the problem.

3. CURRENT RESULTS

3.1 Measurements

We performed several tests of the modified OLSR protocol and the dynamic channel switching techniques described earlier. Because it is important that link breaks are detected rapidly, we used the modified OLSR protocol with the following parameters:

- HELLO interval: 250 ms
- TC interval: 250 ms
- MID interval: 250 ms

A link is considered to have failed if three successive HELLO packets are missed.

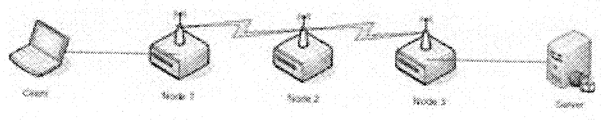

Figure 2: Test Setup

The measurements shown below are from the setup shown in Figure 2. When the test starts, the middle MN is not participating in the OLSR protocol, and is not used to relay information. 15 seconds after the start of the test, the middle MN is activated, and integrates in the network. It subsequently switches the channel on its link with Node 1, creating a topology in which the information is relayed over two wireless links. During the test, a video with an average bitrate of 2 Mbps using MPEG4 encoding was transmitted from the video server to the client using the RTP protocol.

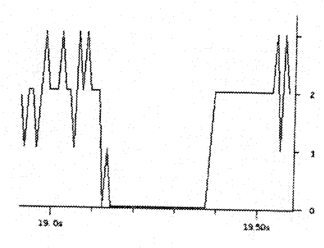

Figure 3: Switching channels

Figure 3 shows what happens on the client when the middle cube switches channel. The x axis shows the number of seconds the video is running, while the y axis denotes the number of RTP packets received by the client during a 10 ms interval. During 254.46 ms, no signal is being received due to the channel switching. This corresponds to 47 missed RTP packets, and is noticeable in the form of artifacts when watching the video.

When the middle node is suddenly removed from the network (e.g. by pulling the power cable), connection is lost during 1032.45 ms. This is 4 times longer than the gap that occurs when introducing a node into the network, because the other two nodes cannot anticipate a link failure, while anticipating a channel switch is possible.

During that 1 s period, the detection of a link failure and a proper reaction, namely another channel switch to restore the end-to-end connection has taken place. So, if any one node in the GeoBIPS mesh network fails, we can restore the end-to-end connection within one second, provided that the two neighbors of the failing node are within each others range. If they are not, end-to-end connectivity is completely lost.

While performing throughput measurements, we noticed a performance drop that we believe is caused by interference between different interfaces of a single MR. This phenomenon was also reported by other researchers [8]. However, multi-hop throughput remains satisfactory for transmitting both video and audio of good quality.

3.2 Field Test

On March 29, 2006, the GeoBIPS crisis management system was tested by firemen at the provincial training facility for firemen and ambulancemen from the city of Antwerp. Tests were performed under the eye of national press, which showed a lot of interest in the project. A selection of press coverage can be found at the project's website [7]. During these tests, voice communication and the connection towards the crisis center were not demonstrated yet, as implementation is still ongoing.

The test location was a large hangar that used to be part of a military base. Inside the hangar there are several training buildings, which can be filled with smoke, allowing firemen to train their skills. A fire was simulated in one of these buildings, and then a fire squad came to action. A fire truck arrived at the scene, and all men disembarked. Outside the building, we set up a large screen which showed an exact copy of the tablet carried by the CO. While the cameraman switched on his camera and started following the reconnaissance team, the CO started his GeoBIPS application on the tablet computer. Immediately, the video showed up on screen, and a GUI allowed the CO to download and manipulate an intervention plan from the embedded server.

It was then shown to the public how the RT entered the building, and how they placed a MR in the first room. As the RT continued its reconnaissance procedure through a cloud of smoke, video images gave a clear view of ongoing action, enabling the CO to make a correct judgment on this crisis situation. Shortly after placing a second MR, a victim was found and brought outside. During the intervention, the video was automatically rerouted from a single hop wireless path to a three hop wireless path, without any interruption of the video stream.

This simulated intervention was exceptionally interesting for us, as it proved the usability of the developed GeoBIPS system in a real crisis environment. Thanks to the automatic integration of new MR, this system can easily be used without the need of any knowledge about networks. The positive feedback that was given by the firemen that used the system, convinces us that the use of wireless mesh technology surely has its value outside a research lab.

4. CONCLUSION AND FUTURE WORK

We have introduced an architecture for a mobile crisis management system and have proven its feasibility and usability by implementation and evaluation in a real-life emergency environment. It was shown how an emergency network can be set up fast and easily using mesh technology, without the need for technical knowledge, and, how dynamic and static information can be combined during an intervention, in order to achieve a clear overview of ongoing events. We are currently optimizing the channel selection algorithm and the On The Go Coverage Indicator, as this will lead to an even more robust system design. Additionally, extensive measurements will be performed in order to further characterize the system's dynamics in various environments.

5. ACKNOWLEDGMENT

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The Third International Conference on Quality of Se Heterogeneous Wired/Wireless Networks

(QShine 2006)

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August 7 — 9, 2006

Message from the General Chairs

QShine 2006 is the third annual conference on Quality of Service (QoS) in Wireless/Wireline Networks. The conference addresses interdisciplin wireless/wireline networks, with quality of service as the main theme. [synergy of all members of the organizing committees, QShine 2006 is | together innovative researchers, developers and practitioners from acac and government laboratories to disseminate their significant findings and t ideas and visions toward pushing the frontier of the research area fertilization. We are fortunate to have two eminent research leaders, I Maxemchuk and Dr. Mischa Schwwartz, to deliver keynote speeches to set conference.

The success of a conference can, to a large extent, be measured by the en participants and the backing of sponsors through financial and other tangil behalf of the organizing committees of QShine 2006 we would like ext welcome to all participants to Waterloo. We would also like to take this express our sincere appreciation to our sponsors, including Create-N Sigmobile, University of Waterloo, Research in Motion (RIM), and Bell C generous sponsorship that will undoubtedly contribute to the success of QS

The soul of any conference is the technical program. Continuing the tradi two QShine conferences, our Technical Program Chairs, Dr. Baochun Li a Mohapatra, have assembled a significant technical program. We would es thank Dr. Baochun Li for superbly doubling as the webmaster for QShine 2(

Different from QShine 2004 and 2005, QShine 2006 also hosts a worksl Workshop Chair, Dr. Alexander Sprintson, has formatted a set of very challenging topics for the workshops.

The backbone of the QShine conference series is the Steering Committee, Co-Chairs, Dr. Imrich Chlamtac and Dr. Michael Fang. As with QShine 2 credit for the success of QShine 2006 belongs to the members of the Steeri

Jon Mark, General Chair

Sherman Shen, Vice General Chair

Message from the Program Chairs

Since 2004, QShine has been a very successful series of conferences provic International forum for the presentation and discussion of new research an Quality of Service (QoS) in heterogeneous wireless and wireline networks. (Service research has expanded its scope, and continues to be an active res the networking community. It has been the tradition of past QShine confere represent inter-disciplinary and focused research, with an emphasis on innc Building on the successes of previous conferences in 2004 and 2005, QShin continues to bring together researchers, developers, and practitioners work to discuss recent and innovative results, and to identify future directions an developing practical systems where predictable and controlled performance requirement in heterogeneous and hybrid wireless networks.

The Technical Program of QShine 2006 is, arguably, stronger than ever in t QShine. In addition to traditional QoS topics such as fairness, scheduling ar control, the scope of this year's QShine has successfully included high-quali some new and emerging research directions, including wireless and sensor overlay and peer-to-peer networks, and ultra-wideband wireless networks. new sessions have been included, such as "Algorithms in Sensor Networks,' Incentives and Overlays," as well as "Multimedia." The other sessions have complete spectrum of Quality of Service research in wireless and wireline n are also fortunate to have our keynote speakers, Professor Nicholas F. Max Professor Mischa Schwartz, to enlighten us on their own perspectives on th Quality of Service and networking research.

Much effort by the Technical Program Committee has gone into putting tog quality technical program. The quality and quantity of submissions were bo program committee has had a difficult task to select 49 papers among man deserving paper submissions. Similar to QShine of the previous years, the r process has been completed within a very short period of time, in order to i latest results in the area of Quality of Service in wireless networks. Our spe the members of the Technical Program Committee and many external revie which the success of the conference would not be possible. We also thank a submitted papers to QShine, revised their papers for camera-ready submis ultimately made a strong technical program possible.

Last but not the least, we would like to thank ICST for organizing the subm cameraready papers, putting together this Proceedings in a very short peric publishing all the papers electronically in the ACM digital library.

Enjoy the conference!

Baochun Li and Prasant Mohapatra, QShine 2006 Program Chairs
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First International Workshop on "Wireless mesh: mov applications" (WiMeshNets 2006)

Keynote Speech

Victor Bahl

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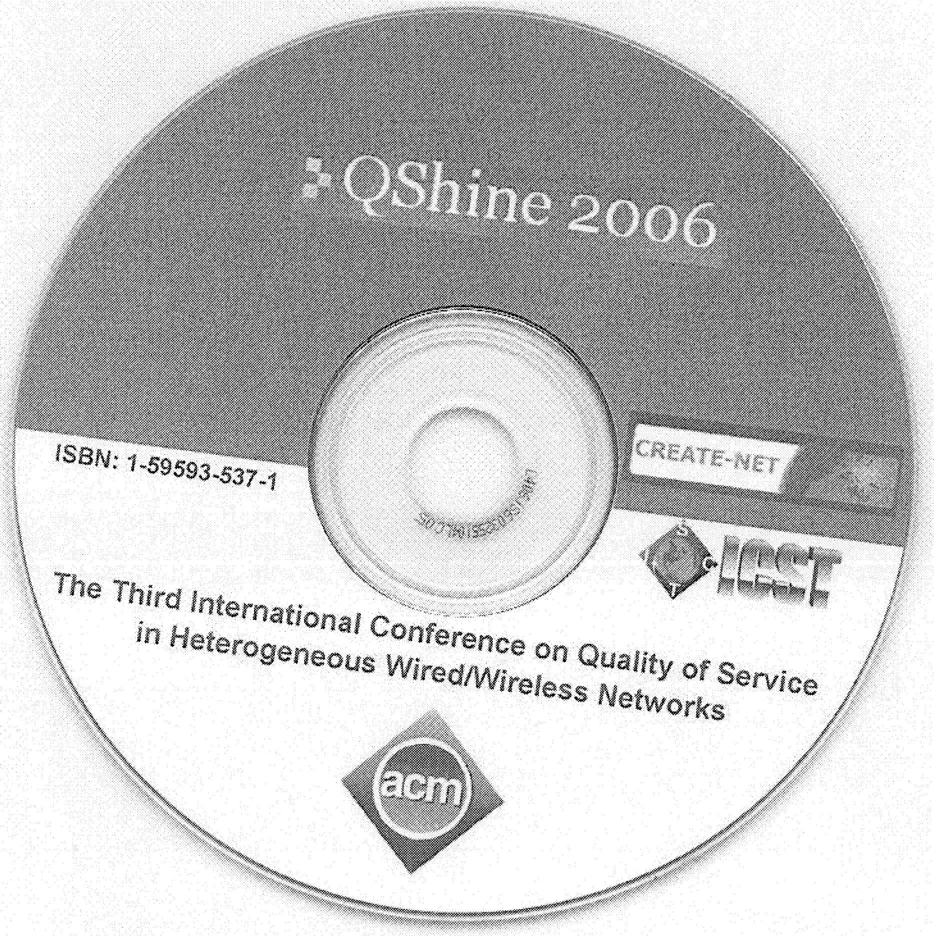
Routing challenges - Peer to Peer Applications on a Community Mesh Ne

Johnathan Ishmael, Nicholas Race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