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SUPPORTING MOUNTAIN RESCUE OPERATIONS WITH IPV6, MOBILE ROUTING AND MIDDLEWARE

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Abstract

The domain of Mountain Rescue poses many challenges for providing on-location communications for multiple roaming rescuers in areas that have little or no fixed network coverage. Furthermore, controllers at HQ are often unable to efficiently manage and monitor search operations. In this paper we describe how these challenges can be solved using a combination of new IPv6 networking protocols, mobile routers and appropriate middleware. We use the operations of the Cockermouth Mountain Rescue Team (CMRT) in Cumbria, UK as the basis for our testbed. However, the solutions we provide are also applicable to many mobile search and rescue scenarios in harsh communication environments (e.g. earthquakes, floods, tsunamis and major terrorist events).

In rural locations, available network infrastructure is limited if not entirely absent. Deploying mobile routers in rescue vehicles and in rescuer's backpacks allows us to bring the networks to the location. Furthermore, mobile routers can utilise any existing networking infrastructure available on location. Using IPv6-based protocols, the mobile routers automatically detect available networks and configure themselves appropriately. This includes networks projected by rescue vehicles, other mobile routers and any available fixed networks (e.g. GSM, GPRS, UMTS and TETRA). Rescuer's mobile devices configure themselves in a similar manner and rescuers can talk hands-free, in full-duplex mode with one-to-one, one-to-many, or open broadcasts. Middleware deployed throughout the system provides constant real-time monitoring of search operations. All operations can be monitored and managed via 2D and 3D visual displays at the HQ. Rescue vehicles, search groups and rescuers can be tracked, monitored and ordered to move to different locations. Controllers are able to consult knowledge databases concerned with rescue personnel, geographical information, previous incidents and radio coverage. In addition, intelligent search algorithms in the middleware can be cross-referenced with the knowledge databases to help controllers manage and monitor search operations more efficiently.

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Introduction

It is our central research hypothesis that innovation in mobile networking and middleware can greatly benefit search and rescue operations in emergency and crisis situations. Being able to move entire networks (as well as single user devices) in a seamless manner in response to specific areas of need is of critical importance. The new Internet Protocol, IPv6, plus related network mobility protocols can help us achieve this. In addition, the ability for a command and control centre to monitor and manage rescue personnel and other resources in real-time can significantly increase operational efficiency. The ability to support mobile search and rescue teams in such fashion is the focus of Lancaster University's involvement in the u-2010 project (http://www.u-2010.eu). Our testbed concentrates on Mountain Rescue in the English Lake District, Cumbria, UK. The domain of Mountain Rescue services is an ideal candidate with which to test out the u-2010 paradigm. Typical Mountain Rescue missions consist of one or more mobile teams that need to communicate in areas where there is little or no communications infrastructure. However, the underlying principles of our research will apply to any mobile search and rescue operations such as in the aftermath of tsunamis, hurricanes, floods, earthquakes and major terrorist events. Initially, the users of the system we are deploying are the Cockermouth Mountain Rescue Team (CMRT). The user base will most likely be expanded to include other mountain rescue teams within the Cumbria region. In addition, a secondary deployment in Slovenia will see the Slovenian Mountain Rescue Association (SMRA) as the main users.

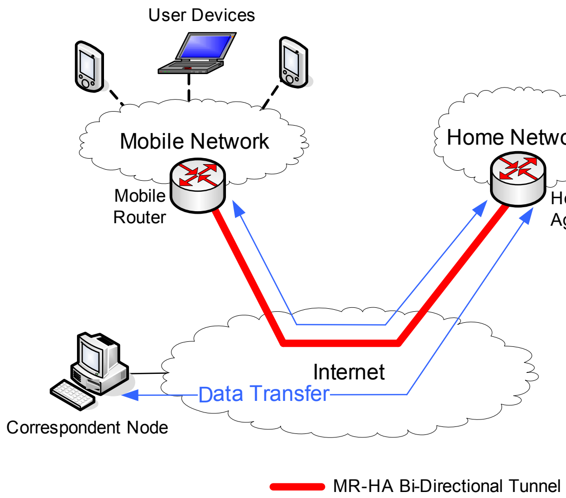
IP version 6

The Internet Protocol version 6 (IPv6) (Deering, 98) is the new generation of the basic protocol of the Internet. IP is the common language of the Internet, every device connected to the Internet must support it. The legacy version of IP (IPv4) has several shortcomings which complicate, and in some cases present a barrier to, the further development of the Internet. The coming IPv6 revolution will remove these barriers and provide a feature-rich environment for the future of global networking. The new addressing format in IPv6 is large enough to allow even the most seemingly insignificant electronic devices to have a globally reachable presence on the Internet. This will spearhead the new drive towards ubiquitous computing and leverages new networking models such as Personal Area Networks (PANs) and sensor networks. The hierarchical addressing format in IPv6 also eliminates inefficient routing tables inside core Internet routers. IPv6 also includes a feature called 'Neighbour Discovery' which means that hosts can automatically detect an IPv6 network and configure their host addresses accordingly (Narten, 98). Not only does this remove a large burden for network administrators, it is extremely beneficial for mobile hosts that can move from network to network. This is exploited by the mobile flavour of IPv6, Mobile IPv6 (Johnson, 98), which allows any host to roam and attach to different networks whilst hiding mobility from users and applications thus providing seamless user experience. A more in-depth description of IPv6 is out of scope for this paper. However, the reader is referred to (Johnson, 98) and (Dunmore, 05b), the latter containing a thorough deployment guide in addition to describing the main features of the protocol.

Network Mobility

While the idea of network mobility may seem a novel idea or even an extravagance to some, for first responders in crisis situations and especially mobile search and rescue teams, it makes perfect sense. Network mobility provides the capability for distinct local networks to move and attach to different points of other networks while still retaining mobile transparency to the users and applications inside the local network. Thus, teams of rescuers and emergency responders will be able to keep their usual network identities and configurations while they are moving around and attaching to different provider networks as they become available. This allows the rescue and emergency workers to concentrate on their tasks in hand rather than have to re-configure user devices to use whichever provider network is available at that precise time and location. The Internet Engineering Task Force (IETF) has long concentrated on individual host mobility in IPv6 via the Mobile IPv6 standard. In 2001 a new IETF working group known as Network Mobility (NEMO) was started with the aim of facilitating the mobility of entire networks. The work was motivated by the intent to support network mobility models such as Personal Area Networks (PANs), networks of in-vehicle devices and access networks in public transportation (e.g. buses, airplanes and trains). To fulfil these requirements, the NEMO Working Group developed the NEMO Basic Support Protocol (Devarapalli, 05). Every mobile network contains a Mobile Router (MR) which is responsible for connecting to new networks but also hiding the mobility from nodes inside its own network. Every mobile network also has a Home Agent (HA) located on its home network which is used as a relay whenever the mobile network is away from home.

Figure 1 NEMO Basic Support



The design of the NEMO Basic Support Protocol is heavily based on the Mobile IPv6 standard. The protocol relies specifically on a bi-directional tunnel that is instantiated between a mobile network's MR and its HA located in its home network. It is via this so-called MR-HA bi-directional tunnel that all traffic destined for the mobile network must travel whenever the mobile network is away from its home network. Referring to Figure 1, the Mobile Network is away from home and a bi-directional tunnel is been established between its MR and its HA. Any packets being exchanged between the user devices on the mobile network and nodes elsewhere on the Internet, will be relayed (or 'tunnelled') via the HA. An example path taken by packets to/from a correspondent node is shown.

Middleware

At present, the control room at CMRT headquarters (HQ) hosts a database that logs calls and basic details of search and rescue operations. However, the limited communications infrastructure prevents any real-time (or even quasi real-time) monitoring and management of search operations in progress. This often results in resources (rescue workers, vehicles, dogs etc.) being deployed in a sub optimal manner. In general, the rescuer workers rely on their knowledge of the terrain and experience of past operations to conduct their searches. For simple search operations, this usually suffices. However, for complex multi-team searches, the limitations of the communications infrastructure coupled with the lack of real-time monitoring and management tools, means that teams operate in an inefficient manner. This potentially increases the time taken to locate and rescue casualties. Middleware deployed throughout our new system will provide constant real-time monitoring of search operations. All operations can be monitored and managed via 2D and 3D visual displays at the HQ. Rescue vehicles, search groups and rescuers can be tracked, monitored and ordered to move to different locations. Controllers are able to consult knowledge databases concerned with rescue personnel, geographical information, previous incidents and radio coverage. In addition, intelligent search algorithms in the middleware can be cross-referenced with the knowledge databases to help controllers manage and monitor search operations more efficiently.

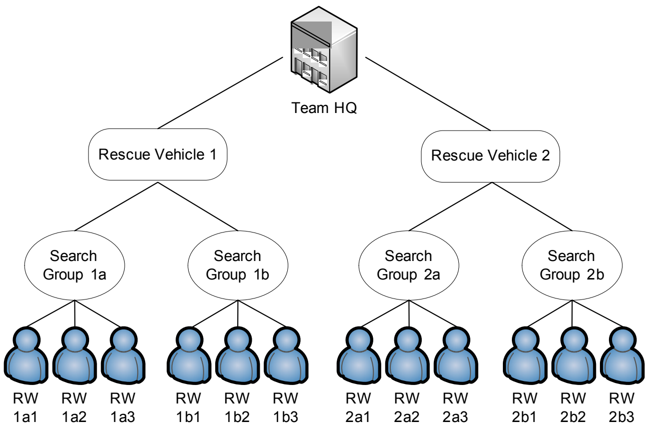
The rest of this paper is structured as follows. The following section looks at the general envisaged networking model for Mountain Rescue services, how the mobile routers are deployed and how the IPv6 network mobility protocols are used. It also describes how the monitoring and management middleware functions. After this we briefly list our sources of information. Finally, we present and discuss our findings from running the system on our mobile testbed at Lancaster University.

Thesis

The General Network Model

Lancaster University is on the border of the English Lake District, which is extremely popular with hikers, fell runners and mountain climbers. In cooperation with the CMRT, Lancaster University is deploying IPv6 mobile routers to provide them with an on-mountain data networking solution. Lancaster University is also responsible for network connectivity of all the schools and colleges in the Lancaster and Cumbria counties via the CLEO (Cumbria and Lancashire Education Online - http://www.cleo.net.uk) initiative, which uses CANLMAN (Cumbria And North Lancashire Metropolitan Area Network – http://www.canlman.net.uk). The importance of this is that we can provide the backhaul network access that the Mountain Rescue service's mobile networks can rely on.

Figure 2 Mountain Rescue Hierarchy



In a typical Mountain Rescue operation, each Mountain Rescue Team (e.g. CMRT) will have several search groups which will be assigned to a base vehicle and, in turn each individual rescue worker will be assigned to a search group. This leads to an obvious hierarchical relationship as depicted in Figure 2. However, these relationships are loose in that rescue vehicles, search groups, and individual rescue workers may sometimes change their 'points of attachment' as a search operation evolves. Referring to Figure 2, we determine that each search group represents one distinct local network, with its rescue workers being nodes on that network. Since each search group can change location, the search group network becomes mobile. In a similar fashion, the rescue vehicles are their own distinct mobile networks, only the Team HQ remains static. To further complicate things, any rescue worker can move in such a fashion that they can attach to a network of a different search group or even a different rescue vehicle. How all this confusion can be organised using IPv6 and network mobility is discussed in the next section.

Providing sufficient network connectivity in such remote rural locations is very challenging. The choice of network infrastructure is limited as wired connectivity is restricted to major towns. In addition, fixed public networks such as GSM, GPRS and UMTS have patchy or non-existent coverage in some areas. However, any connectivity we can provide on

CANLMAN plus any public wireless networks, plus possible satellite connectivity (provided by u-2010) can all be exploited by IPv6 mobile routers. Furthermore, we can build coverage 'on-demand' by locating portable 802.11, 802.16 or GSM/GPRS base stations with the mobile routers.

Figure 3 General Network Model

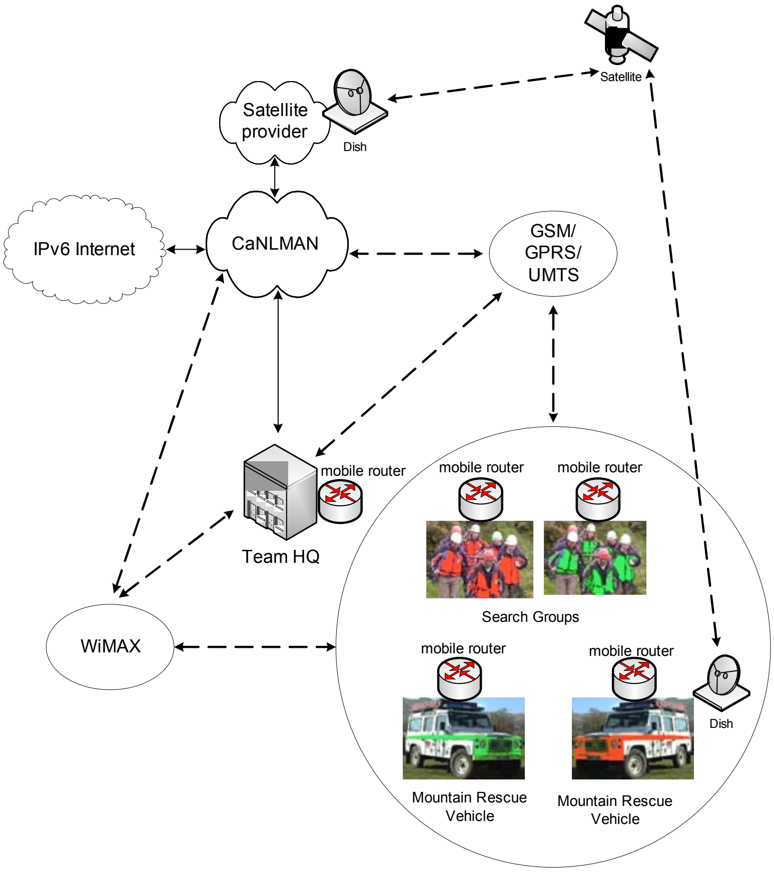


Figure 3 illustrates an example network infrastructure for the Mountain Rescue deployment. Mobile routers are located with the rescue vehicles. Using high gain directional antennae, we can project a hotspot of connectivity across an area being covered by the search groups assigned to that vehicle. Network technologies such as 802.11 and/or 802.16/WiMAX can be used to achieve this connectivity. The vehicle mobile routers can use GSM/GPRS/UMTS connectivity as the uplink to the Team HQ. Other options are to support point-to-point or point-to-multipoint WiMAX links or bi-directional satellite links via appropriate antenna and transceiver assemblies on the rescue vehicles connected to the mobile routers. Small form factor mobile routers are integrated into backpacks of designated rescue workers thus providing connectivity for each search group. In general, each search group will have its own 802.11 hotspot that rescue workers can connect to. Thus, rescue workers are not only connected to others in the same search group, but also with Team HQ via their rescue vehicle and also with rescue workers from other search groups via the wireless networks of different search groups and the search vehicles. If a rescue worker has connectivity to any of search group's wireless network then they have connectivity to the overall network. Since the mobile routers can also bridge different wireless networks, the effective coverage area can be expanded.

Yet it is IPv6 and network mobility that truly facilitates this capability. Using IPv6 neighbour discovery a rescue worker's device will automatically detect the network of a different search group and attach to it without any user involvement (assuming the usual network has been lost). Any existing applications would normally be broken at this point. However, using

NEMO, the applications can go on using the old IPv6 addresses and do not even realise the device has moved.

IPv6 Network Mobility and Mobile Routers

At first glance the Mountain Rescue network model appears to be a swarm of mobile nodes that move randomly and therefore the best networking model to apply might seem to be a Mobile Ad-Hoc Network (MANET) model. However, as previously mentioned our Mountain Rescue Team has a distinct command and control hierarchy that needs to be reflected in the network model. While not as strict a hierarchy as a military organisation, nevertheless consultation with members of the actual team revealed that the hierarchy is important. Therefore, mobility patterns tend to verge towards distinct clusters of individuals that move randomly in relation to other clusters but in relatively similar directions in relation to individuals in the same cluster. Thus a network mobility model is more appropriate as the routing model reflects the natural hierarchy as opposed to the flat routing architecture in MANET protocols.

Referring back to Figures 2 and 3, our network mobility solution defines each search group as a mobile network. In addition, each rescue vehicle is also a distinct mobile network. The home network of both rescue vehicles is the Team HQ, where a Home Agent is located. Similarly the home network of a search group is the rescue vehicle to which it belongs. The mobile routers located at the rescue vehicles also act as a HA for the search groups that belong to it. Each search group has a mobile router (in the backpack of a designated rescue workers) which connects to other networks as the search groups move. In their usual 'home' topology all traffic proceeds as with normal routing. However, if search group 1b (Figure 2) moves away from rescue vehicle 1 and automatically picks up (using IPv6 neighbour discovery) rescue vehicle 2, the NEMO Basic Support Protocol is activated. A bi-directional tunnel is established between the MR of search group 1b and the HA located at rescue vehicle 1. Traffic is now tunnelled to/from search group 1b via the HA at rescue vehicle 1. In this way, all the user devices attached to search group 1b do not have to change their IPv6 addresses and existing application sessions are not broken due to the movement.

NEMO also supports nested network mobility. After search group 1b has moved, search group 2b could move out of range of all other networks except that of search group 1 and attach at that point. Thus, search group 2b is now connected to the overall network via search group 1b. We now have nested mobile networks as search group 2b is away from home, connected to search group 1b, which is also away from home. This introduces 2 levels of tunnelling. In general *n* levels of mobility introduces *n* tunnels and associated tunnel overhead and latency. Further details of applying NEMO to Mountain Rescue services can be found in our previous papers (McCarthy, 05), (McCarthy, 06a). Thus, whilst the bi-directional tunnel approach in NEMO BS provides a good short term solution for supporting mobile networks, it does impose a sub-optimal routing model (known as triangular, pinball or dog-leg routing). In order to overcome the problems generated by triangular routing, a technique termed Route Optimisation (RO) was developed in Mobile IPv6 which allowed the mobile node to update the correspondent node with its new address after moving. However, in the case of NEMO, there are more complex issues to consider. To mirror the Mobile IPv6 RO would mean updating *all* correspondent nodes for *every* local host attached to the mobile network; an unacceptable level of overhead. Route Optimisation in NEMO is an on-going topic which has not been definitively solved as of yet. One RO technique for NEMO is to use a 'Reverse Routing Header' (RRH) which is an IPv6 routing header extension for NEMO BS that tries to 'record' the optimum path across mobile networks (Thubert, 07). In tests across our testbed, we found this to be a slight improvement over NEMO BS (McCarthy, 06a).

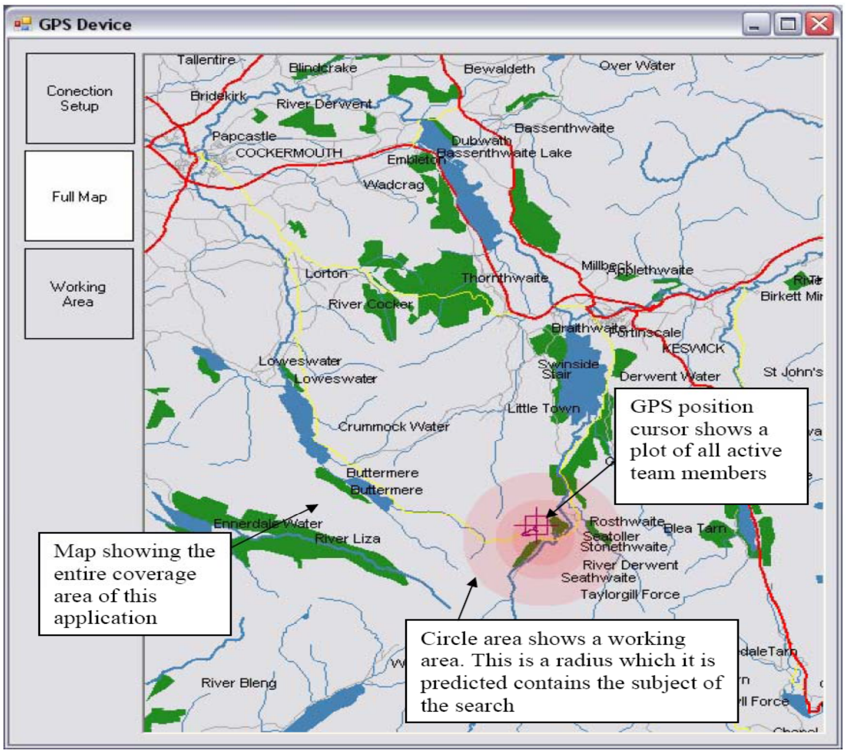
Monitoring and Management Middleware

To complement our network mobility solution for Mountain Rescue, we are developing middleware that allows the Mountain Rescue Team to monitor and manage search operations in real-time. The middleware is present at the Team HQ, and at the rescue vehicles, and utilises several knowledge databases in addition to providing real-time location updates of rescue personnel and vehicles. The knowledge databases consist of: Rescue Personnel, Geographical Information System, Previous Incidents, Communications and Search Theory.

The rescue personnel database contains detailed information on the Mountain Rescue personnel. This information includes any specialist skills (e.g. medical, dog handling, climbing), their contact details and work patterns (rescue workers are volunteers), current location and availability. When an emergency call is received at the Team HQ, the middleware automatically searches the database and displays which Team members are available and the set of skills that are covered.

The Geographical Information System (GIS) contains all the geographical data relevant to the Mountain Rescue Team's jurisdiction. This includes detailed terrain maps, roads, land features, car parks, hotels, campsites etc. It also has a dynamic element so that events such as rockfalls, landslides, severe weather, livestock movements, road blockages and traffic conditions can be overlayed onto the static geographical information. The middleware can query this database to gain geographical information for any area with the region. It is used primarily for displaying locations of personnel and vehicles during a search operation.

Figure 4 Predicting Locations



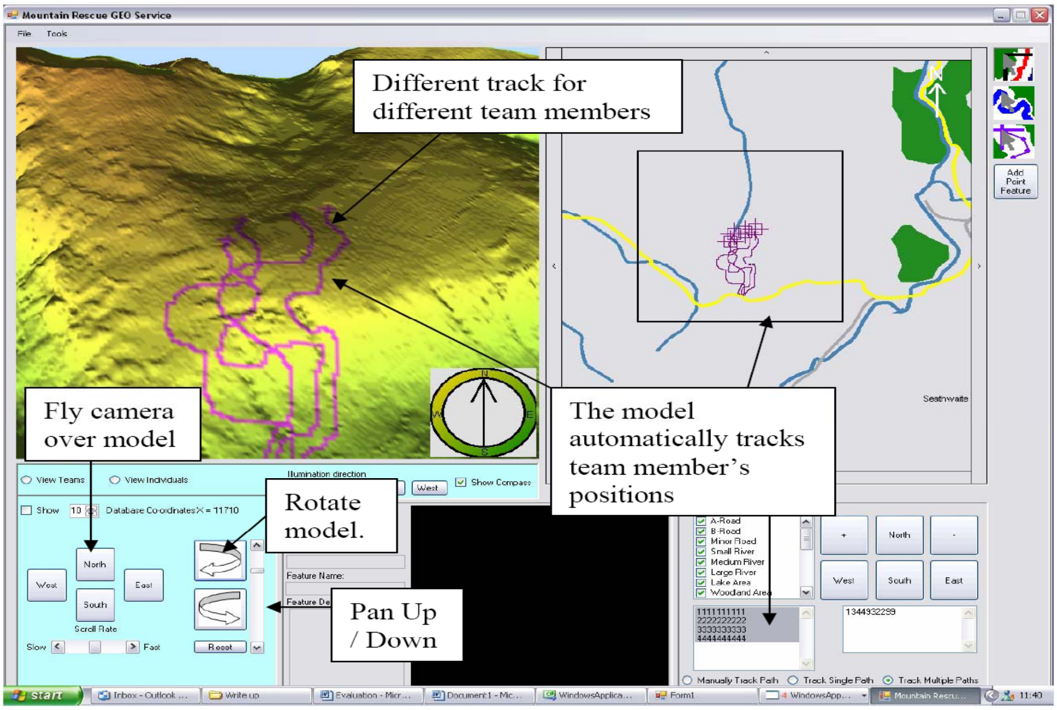
Details of all previous call-out incidents are stored on the Previous Incidents database. This includes the locations of the casualties, their injuries, the nature of the accident, the weather conditions, time of year etc. All this helps the middleware use statistical techniques to extrapolate likely locations for missing casualties when their locations cannot be ascertained from the emergency call. The most likely problem areas where the casualty might be located can be displayed in the control room (Figure 4) and relayed to the devices of the rescue workers.

The Communications database holds 'maps' of coverage areas for several wireless networking technologies such as GSM/GPRS, Tetra and 802.11 as projected from vehicles in certain locations. The purpose of this is so that the Mountain Rescue Team know in advance where there are black holes in connectivity so they can adapt accordingly. For example, cross-referencing with the GIS also allows controllers at HQ to analyse terrain and reception data and then inform rescue vehicles of the optimum locations to park in order to provide temporary connectivity to the search groups on the mountainside.

We also have a Search Theory database embedded in the middleware. This can suggest search patterns for the search groups to take based on the information obtained from the emergency call and the cross-referencing of the other databases.

The main feature of the middleware is the real-time tracking and monitoring of rescue personnel, search dogs and vehicles. Using the mobile networks and wireless infrastructure provided, GPS devices in the vehicles or worn by rescue workers/search dogs continuously update the server part of the middleware with their locations. The locations of Team members and vehicles are displayed in the Team HQ and at terminals in the rescue vehicles overlayed onto 2D or 3D maps of the search area (see Figure 5).

Figure 5 Screenshot of the middleware



Users of the middleware can add/remove details from the display such as contours, roads, land features, rescue workers, search groups etc. The routes taken by rescue workers can be displayed as 'snail trails'. All movements are logged so that missions can be played back later to evaluate efficiency.

Sources of Information

Our main sources of information for this paper are the Cockermouth Mountain Rescue Team, the Slovenia Mountain Rescue Association and various RFCs, Internet Drafts from the Internet Engineering Task Force as well as mailing list discussions. In liaison with the aforementioned Mountain Rescue personnel we identified a set of requirements, both user-orientated and technical, which acted as the criteria by which our system was designed. Space constraints prevent us from discussing these requirements in detail here. The interested reader is referred to (U-2010, 07).

Findings and Discussion

In this section we discuss some of the findings we lessons we have learnt from running the system on our mobile testbed at Lancaster University. For the mobile routers we are using 5 Cisco 3200 Mobile Access Routers (MARs). We also use standard PCs and laptops running

Linux and NEPL (NEMO Platform for Linux) to act as mobile routers. The current mobile router devices that we use are fine for deploying in the rescue vehicles. However, we have found them too bulky and heavy to be easily carried by individual rescue workers in their backpacks. Additionally, since the 3200 is intended to be powered via the vehicle's battery, we found it extremely difficult to replicate this using a battery light and small enough to be carried. We are thus developing prototype devices running embedded Linux that will serve as personal mobile routers.

The NEMO BS Protocol can be used to produce a working solution to our Mountain Rescue scenario. However, NEMO BS capability is not efficient enough to support real-time or time-sensitive applications such as VoIP or video streaming. However, for 'elastic' applications such as the location updates for our monitoring middleware, it is sufficient. We also considered the NEMO Route Optimisation technique RRH's ability to improve the overall performance. We found that the RRH technique could provide some performance improvements yet it is still inadequate to support the real-time applications that we want. We have mentioned how Mobile IPv6 RO is not suitable for NEMO. However, even if we could have a NEMO RO technique similar to that of Mobile IPv6, it would still be someway short of supporting real-time applications such as VoIP due to handover latencies in the order of seconds, as demonstrated in the 6NET project (Dunmore, 05a). Thus, we need better RO techniques to be able to support VoIP and real-time streaming. This is why we are investigating the idea of using MANET protocols together with NEMO to provide route optimisation for mobile networks that are close together physically although not topologically. For more details on this, please see (McCarthy, 06b).

In our middleware tests we have found that to avoid location update storms to the server (when rescue workers turn on devices at roughly the same time), we configure location updates to be slightly randomised within a given time period +/- 20%. Thus, if we configure a location update period of 30 seconds, the actual period will be pseudo-random between 27 and 36 seconds. In addition, location updates are set according to the entity being located. A rescue worker will move more slowly than a vehicle or a search dog. In general the faster the movement, the more frequent the location updates need to be. Many simulated operations (from GPS logs of actual missions) have revealed where resources could have been deployed more efficiently and search time reduced. We are still improving the system and aim to be using it on real missions in late 2007 or early 2008.

In summary, the system to date is very promising despite a number of challenges that need to be overcome. While the system can clearly provide mountain rescue teams with automatic, mobile ad-hoc communication, it does not yet have the ability to support real-time applications. Similarly, while mobile router devices can be carried in backpacks, they are not yet small, light and durable enough for live deployment. To conclude the answer to our central research hypothesis, our experience with the system indicates that this will be a very promising tool for Mountain Rescue services. However, because we have yet to deploy the system in the field, we cannot at this time make any concrete conclusions as to the effectiveness of the tool in real missions. This will, of course, be for future study.

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Author Biography

Martin Dunmore is a Research Associate in the Computing Department at Lancaster University. He received a BSc (Hons) in Computer Science in 1997 and a Ph.D. in Distributed Computing in 2001, both from Lancaster University. His research interests include IPv6, wireless and mobile computing, ad hoc networking, QoS, traffic engineering, and intelligent network systems. Some of the previous European projects he has worked on include Eurescom P702, PETERPAN and 6NET. In P702, he developed an IPv6 MPEG video service that utilised the IPv6 flow label field for marking its relevant traffic streams in a coordinated fashion with RSVP. In PETERPAN he designed a "Hybrid Edge Device" that interfaced between the IP access and ATM core network boundary, which integrated the QoS paradigms of IETF Integrated Services and the ATM ITU-T/ATM-F QoS classes. In 6NET he was leader of the workpackage that investigated and deployed IPv6 solutions for Mobility, WLANs, VPNs, QoS and Site Multihoming. Martin has also been involved in numerous other research efforts such as the LANDMARC project, BERMUDA (which enabled IPv6 service between the Universities of Lancaster, Southampton and UCL) and collaboration with DERA (now Qinetiq) on the use of QoS, mobility and IPv6 in military contexts. During his time in 6NET he helped to launch the UKERNA Wireless Advisory Group which aims to provide advice to all UK Universities and Colleges on matters concerning wireless and mobile networking.