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**Abstract:**

This document provides a description of the IPv6 network mobility demonstrators produced by Lancaster University within the extension period of 6NET.

**Keywords:**

network mobility, mobile IPv6, MIPv6, demonstrators, remote network support, mobile library, mountain rescue, cisco 3200.

**Executive Summary**

This document provides a description of the IPv6 network mobility demonstrators produced by Lancaster University within the extension period of 6NET. During the 6NET project, WP4 has been heavily involved in host mobility in IPv6 with respect to deploying the Mobile IPv6 protocol. During the extension period of the project, it was a natural progression to investigate network mobility in IPv6 and how this very new area could be applied to real user scenarios.

In collaboration with Cisco, Lancaster University began a long term research programme concerning the application of network mobility to several identified user scenarios. Within the timeframe of the 6NET extension, we produced several demonstrators applicable to the user scenarios identified; namely Remote Network Support, Mobile Library services and Mountain Rescue services.

All the demonstrators were shown at the GARR IPv6 event in Pisa, May 2005 and the Mountain Rescue services demonstrator was also shown at the Terena Networking Conference in Poznan, June 2005.

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# 1 Introduction

Within the 6NET project, Lancaster University and Cisco have instigated a long term research programme that aims to exploit the concept of IPv6 network mobility using Cisco 3200 series mobile routers. We are implementing IPv6 network mobility in three distinct user scenarios (described in the following pages) each providing different challenges from the mobile network infrastructure. These three scenarios are Remote Network Support, a Mobile Library and Mountain Rescue.

Within the timeframe of the 6NET extension, we produced several demonstrators applicable to the user scenarios identified. All the demonstrators were shown at the GARR IPv6 event in Pisa, May 2005 and the Mountain Rescue services demonstrator was also shown at the Terena Networking Conference in Poznan, June 2005.

The following pages describe the IPv6 network mobility paradigm and the user scenario demonstrators that were developed. The next section provides a brief introduction to IPv6 network mobility, section three describes the Remote Network Support scenario and demonstrator, section four describes the Mobile Library scenario and demonstrator and section five describes the Mountain Rescue scenario and demonstrator.

# 2 IPv6 Network Mobility

Through its Mobile IPv4 and Mobile IPv6 standards [3], [1] the Internet Engineering Task Force (IETF) has long concentrated on individual host mobility, attempting to solve the problem of maintaining a host's IP address whilst it is mobile in the Internet. In 2001 a new IETF working group called Network Mobility (NEMO) was started with the aim of facilitating the physical mobility of entire networks within the Internet. The work was motivated by the intent to support network mobility models for Personal Area Networks (PANs), networks of in-vehicle devices and access networks in public transportation vehicles (buses, airplanes, trains, etc). Furthermore, the hosts inside these mobile networks would remain unaware of their mobility.

## 2.1 NEMO Basic Support Protocol

To fulfil these requirements the NEMO Working Group developed the NEMO Basic Support Protocol [7]. The NEMO Basic Support Protocol relies specifically on a bi-directional tunnel that is instantiated between a mobile network's Mobile Router (MR) and the Home-Agent (HA) of the mobile router. It is via this so-called MR-HA bi-directional tunnel that all traffic destined for the networks served by the mobile router must travel (whilst the mobile router is away from its home network).

When a MR roams away from its home network and joins a foreign network, it will configure itself with an IPv6 Care-of Address (CoA) from the foreign network. The MR then registers that address with its Home-Agent (HA). Packets destined for the that MR's network (or any of its subnets) are intercepted by the HA and then encapsulated and transmitted via a bi-directional tunnel to the MR (known as the MR-HA bi-directional tunnel).

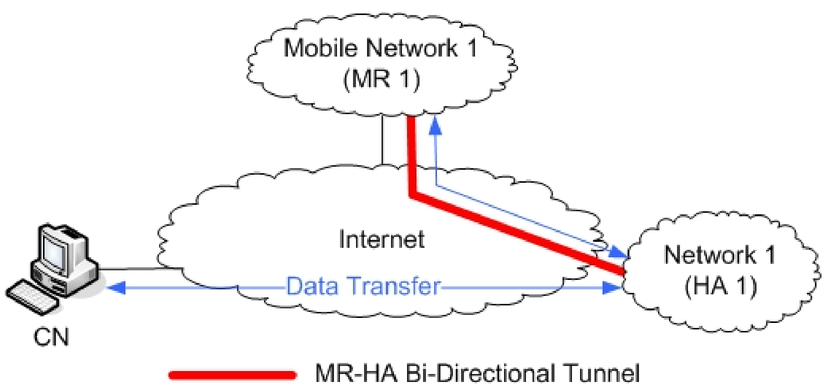


**Figure 1 Nemo Basic Operation**

When a mobile network attaches to another (roaming) mobile network, this creates a topology of nested mobile networks. This nested topology introduces multiple MR-HA tunnels, multiplying the inefficiency problems created by sub-optimal routing and tunnelling mentioned earlier.

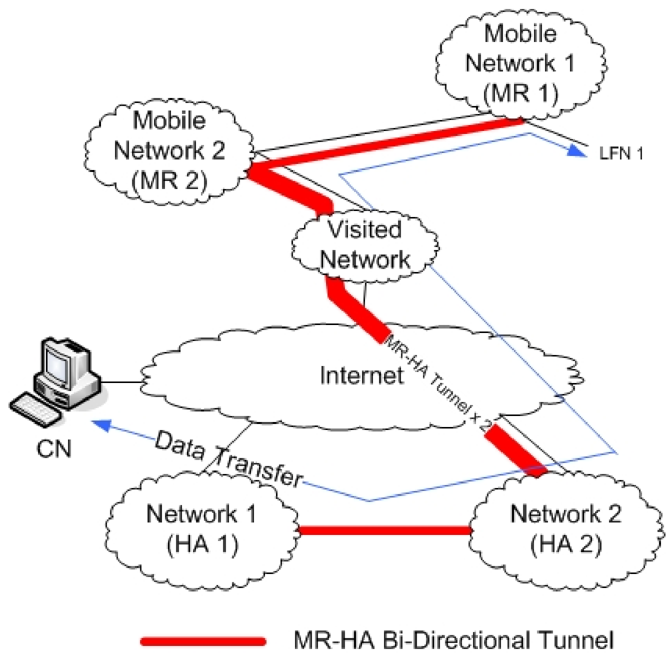


**Figure 2 An Example of Nested Mobile Networks**

Figure 2 illustrates how this nested topology introduces multiple MR-HA tunnels. Consider the flow of packets travelling from the CN toward LFN1 located on Mobile Network 1, packets will first be sent to the home network of Mobile Network 1 at which point they will be intercepted by HA 1 and forwarded on to the home network of Mobile Network 2 (because this is where Mobile Network 1’s CoA identifies it as being located). At this point the already encapsulated packets will be intercepted, further encapsulated and then forwarded to Mobile Network 2’s MR. This means that between the endpoints of HA 2 and Mobile Network 2’s MR the packets are encapsulated twice (once by Mobile Network 1’s MR-HA Tunnel and once by Mobile Network 2’s MR-HA Tunnel).

## 2.2 NEMO Route Optimisation

Whilst the bi-directional tunnel approach of the NEMO Basic Support Protocol provides a good short term solution to the problem of supporting mobile networks, it does impose a sub-optimal routing model (known as triangular, pinball or dog-leg routing). This carries with it many inherent issues that were first experienced in the early days of Mobile IP:

- Using a sub-optimal route obviously increases packet latency between communicating hosts.
- The tunnel overhead (40-bytes for an IPv6-in-IPv6 tunnel) reduces the effective path MTU, which in turn reduces potential throughput.
- Extra processing overhead for encapsulating and decapsulating packets at tunnel endpoints can be an issue for low power devices and further increases packet latency.

In order to overcome these problems, a technique known as Route Optimisation (RO) was developed in Mobile IPv6 which allows the Mobile Node (MN) to directly inform the CN of its current location thus eliminating the need for tunnelling via the MN's HA..

Unfortunately, the particular technique used for route optimisation in MIPv6 cannot be directly applied to the case of mobile networks for two reasons:

1. *Incorrect context*. A MR is not the same as a MN in MIPv6. The MR would have to perform RO with all the CNs that are communicating with the MNNs inside its network. Not only does this break the end-to-end philosophy of the Internet, it also leads to more problems. For example, state proportional to the number of MNNs and all their CNs would need to be held on the MR and a complicated trust model would need to be engineered.
2. *Multiple levels of mobility*. MIPv6 only deals with a single layer of mobility. Since mobile networks can be nested there can be multiple layers of mobility occurring simultaneously. Thus, a given MR's current CoA is not sufficient evidence to be able to determine the optimal route between that MR and an arbitrary CN.

In light of this, route optimisation for mobile networks is an on-going research topic and has not been definitively solved yet.

# 3 Remote Network Support

Lancaster University is responsible for network connectivity of all the schools and colleges in the Lancaster and Cumbria counties via the CLEO (Cumbria and Lancashire Education Online) initiative [11] which uses CANLMAN (Cumbria And North Lancashire Metropolitan Area Network) [12]. The purpose of this demonstrator is to add mobile router technology to Lancaster University's network support team that must visit remote (often rural) locations to attend to network service disruptions and to perform general network maintenance.

Enabling the network response team with mobile router technology will provide extra functionality in two ways:

1. Provide the remote network support team with flexible connectivity back to the campus network and also the wider Internet. This will provide the team members with access to on-line resources while repairing the network fault, allowing the team to fix problems more efficiently.
2. Provide temporary Internet connectivity to the remote site while the primary network is down. Not only will this reduce the effective downtime of the network as seen by the end users, but it will give the support team valuable breathing space whilst they carry out the repairs.

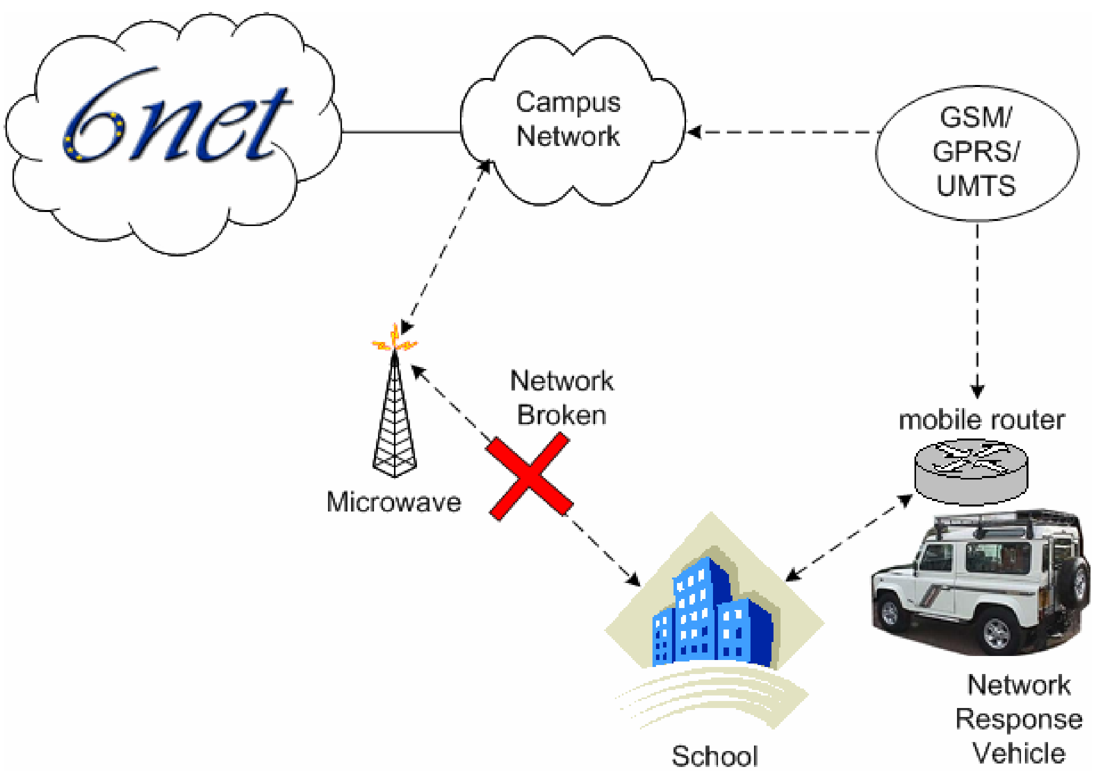


**Figure 3 Remote Network Support Scenario**

## 3.1 Technical Approach

Providing 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. Many schools are connected to the MAN backbone using a variety of wireless/microwave links both proprietary and standards based. Satellite links are an option but are generally too expensive. The mobile router located in the response vehicle supports 802.11 and provides GSM/GPRS connectivity as a fallback mechanism. Another option would have been to support point-to-point microwave links (a proprietary forerunner of WiMAX) via an antenna and transceiver assembly on the response vehicle connected to the mobile router (the transceiver will look like 10BaseT to the mobile router). However, with the anticipated emergence of WiMAX compliant products in late 2005 / 2006 we decided to forego the expense of current non-compliant hardware.

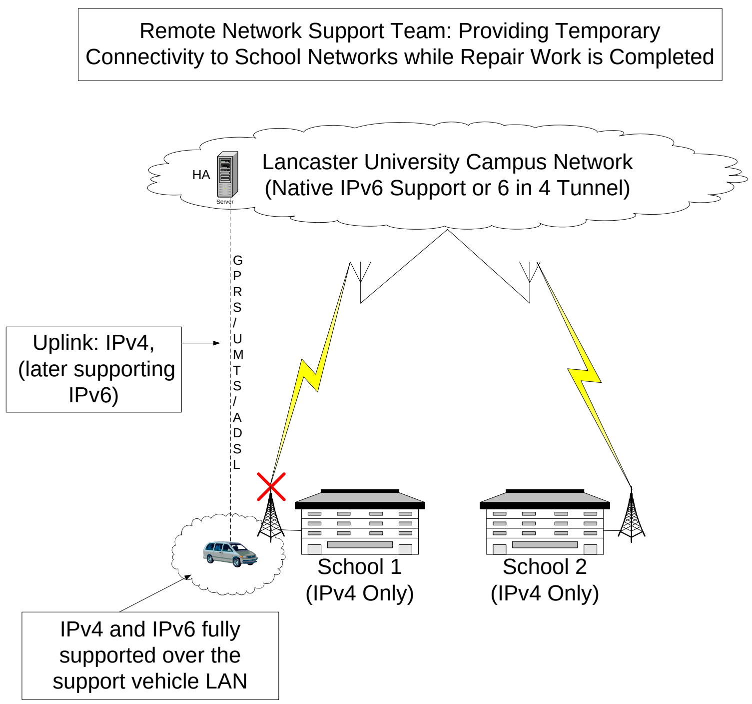


**Figure 4 Example of Remote Network Support**

We position the mobile router in the network support team's vehicle in order to utilise a number of available interface types (e.g. GSM/GPRS/UMTS, wired or 802.11) to connect back to the University campus network (via CANLMAN) and the wider Internet. In addition, the mobile routers provide an on-site temporary 802.11 hotspot, to ensure the support team members can move freely around the network site.

When carrying out maintenance and upgrades to the CLEO network it would be advantageous for the Remote Network Support team to be able to access information about the underlying connectivity they are receiving. To accomplish this, we have developed an application called the "Mobile Access Router (MAR Monitor)". The MAR Monitor constantly monitors all available interface types, determines the attainable throughput for each and translates these readings into a list of application types available to the user.

The core functionality of the MAR Monitor is based around it's ability to poll the MAR via SNMP to retrieve information about each of it's interfaces. The information the application can retrieve is obviously only restricted by what the SNMP MIBs on the MAR will support, but at present we have chosen to retrieve information on the following network characteristics at each interface:

- Throughput
- MTU of the Interface
- No. of Overall Packets Dropped

The MAR Monitor application is designed to run on a laptop PC which is connected directly (via Ethernet cable) to the Mobile Access Router. To permit remote monitoring, the application supports PDA based clients which connect to the vehicle LAN (and MAR Monitor) via the MAR's wireless interface (see Figure 5).

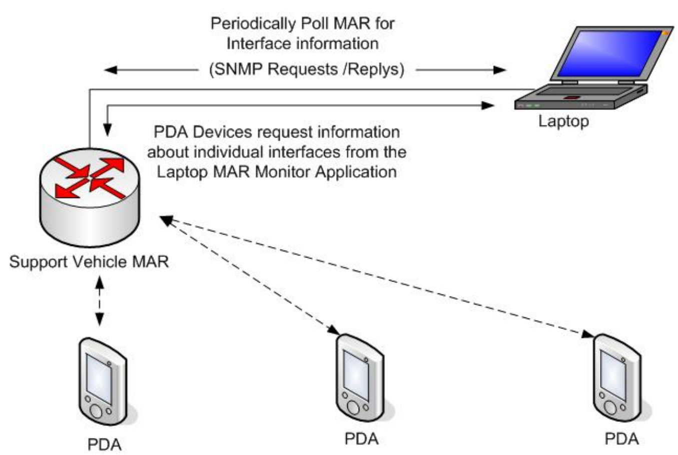


**Figure 5 How the MAR Monitor works**

This PDA support enables individual team members with a greater level of manoeuvrability while they carry out their duties (e.g. repair / realign a microwave antenna). In order to achieve this the application running on the laptop acts as a server to a PDA based application, providing it with the data it retrieves from the MAR interfaces. This approach was taken (as opposed to having the PDA application also poll the MAR) for efficiency reasons. The process of polling the router is (in terms of a PDAs capabilities) a relatively heavyweight task, rather than repeat the process for every PDA in the network, it is more efficient to forward the specific interface information on to the PDAs once it has been retrieved by the application running on the laptop. Also, due to the screen size available on a PDA, it is only viable to display information about one MAR interface at a time, meaning the PDA based application need only request information on one interface at any point in time. Using this method also ensures that the router does not need to process increasingly more data in the form of SNMP requests as more PDA terminals join the network.

Figure 6, Figure 7 and Figure 8 show screenshots of the main MAR Monitor screen, details of the MAR Ethernet interfaces and details of the MAR 802.11 access point respectively.

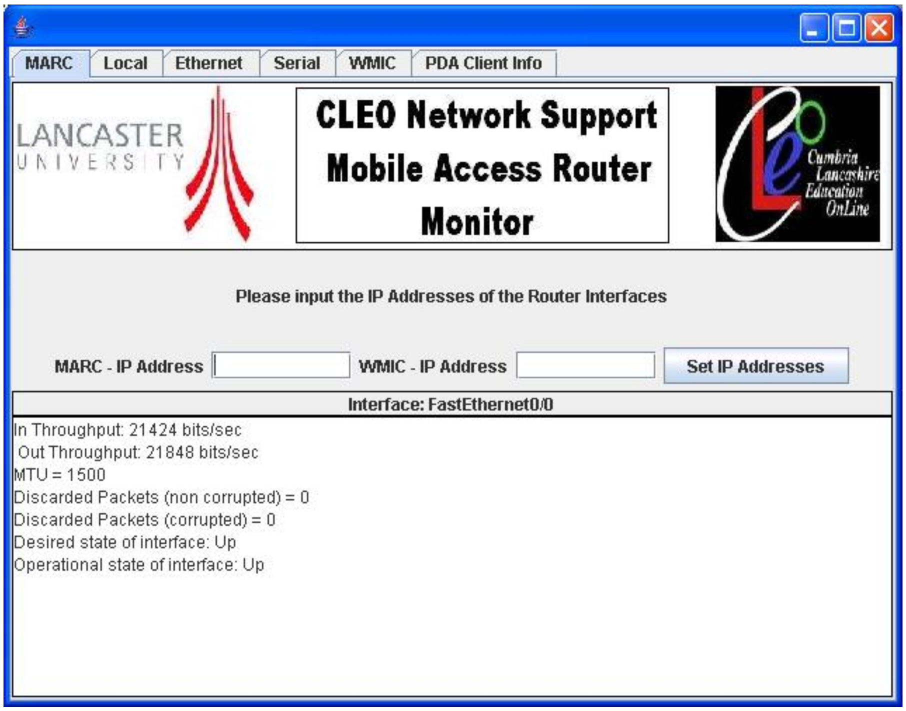


**Figure 6 MAR Monitor Main Screen**

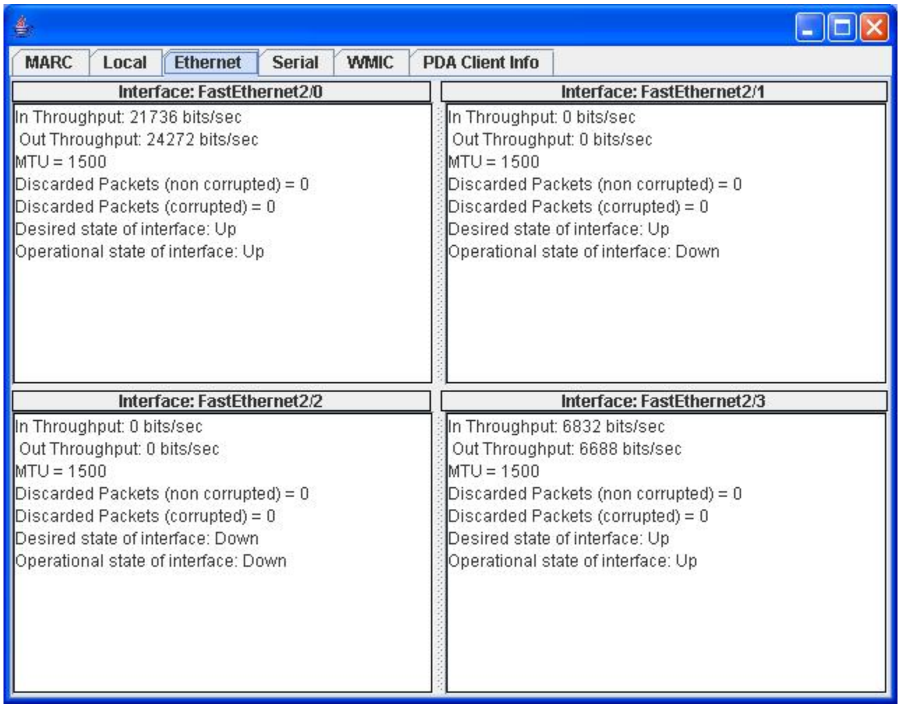


**Figure 7 Ethernet Interfaces on the MAR**

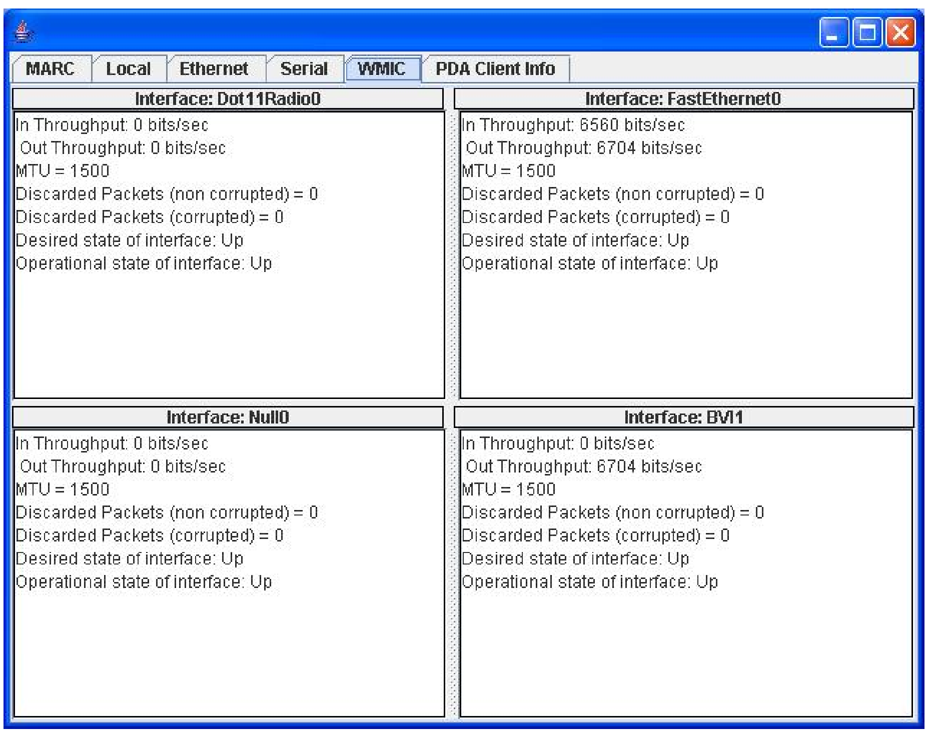


**Figure 8 802.11 Access Point on the MAR**

Figure 9 shows what the PDA interface of the MAR monitor application looks like.

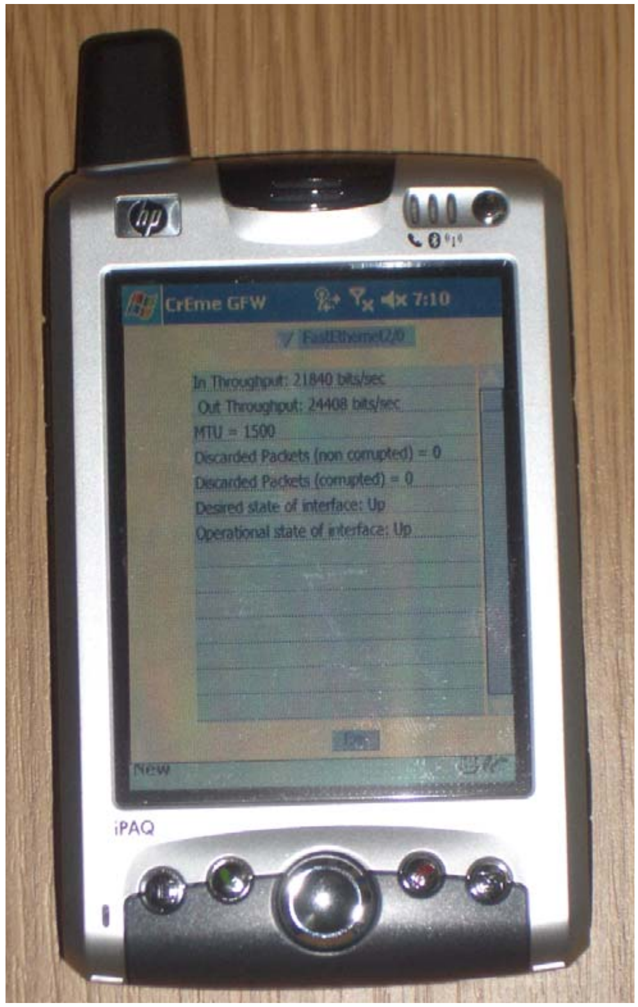


**Figure 9 MAR Monitor PDA Client**

# 4 Mobile Library

The concept of a mobile library is nothing new. It consists of a large vehicle, often a converted truck or bus, filled with books, that visits remote locations allowing people to browse and borrow the books. In recent years, the concept of a mobile Internet booth has come to light. In a similar fashion to the mobile library, it visits remote locations offering Internet access.

The idea of this demonstrator is to combine both of the above and more: a mobile library offering Internet access as well as a library service to urban and remote areas of Cumbria and Lancashire. Since there is a limit to the amount of books one can store in a mobile vehicle, it is important to provide a virtual library service. Whether it is an education or public based library service, users would be able to search the library catalogue and read resources online. Books could be ordered from the library online or excerpts printed locally at the mobile vehicle. One can also imagine extending this service to include access to many libraries from one mobile station.

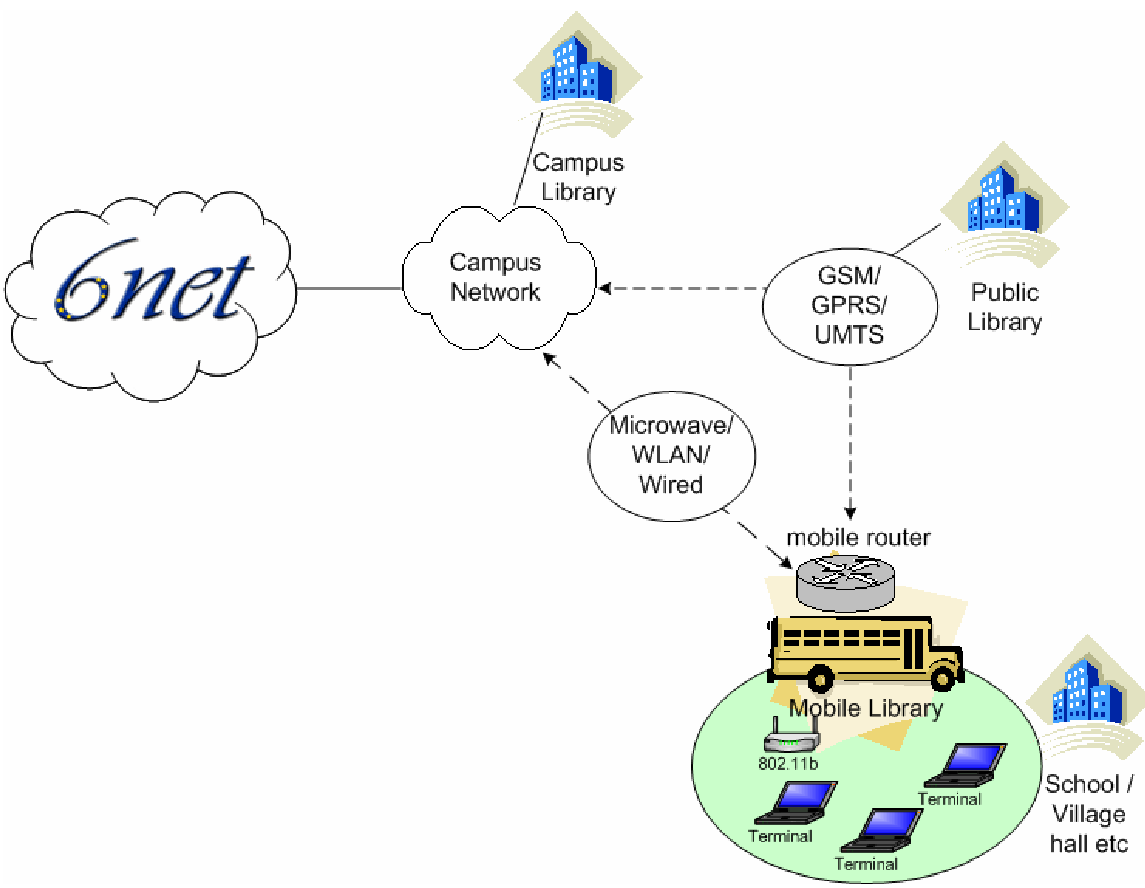


**Figure 10 Mobile Library Scenario**

The mobile library service can appear at many destinations such as schools, town/village halls, supermarkets, business parks etc. When reaching its destination, the mobile vehicle will be able to take advantage of any network connectivity provided by CANLMAN/CLEO. In areas where connectivity is not present, the vehicle will have to use public Internet access via GSM/GPRS/UMTS.

## 4.1 Technical Approach

It is easy to see how mobile router technology fits in with the concept of a mobile library. While the mobile router serves a LAN in and around the mobile library, it also provides uplink connectivity according to what is available at the current location of the mobile library. At certain locations (e.g. schools, business parks) the mobile library may be able to take advantage of wired network facilities or wireless hotspot coverage. At worst, the mobile library can fallback to using public GSM/GPRS/UMTS coverage.

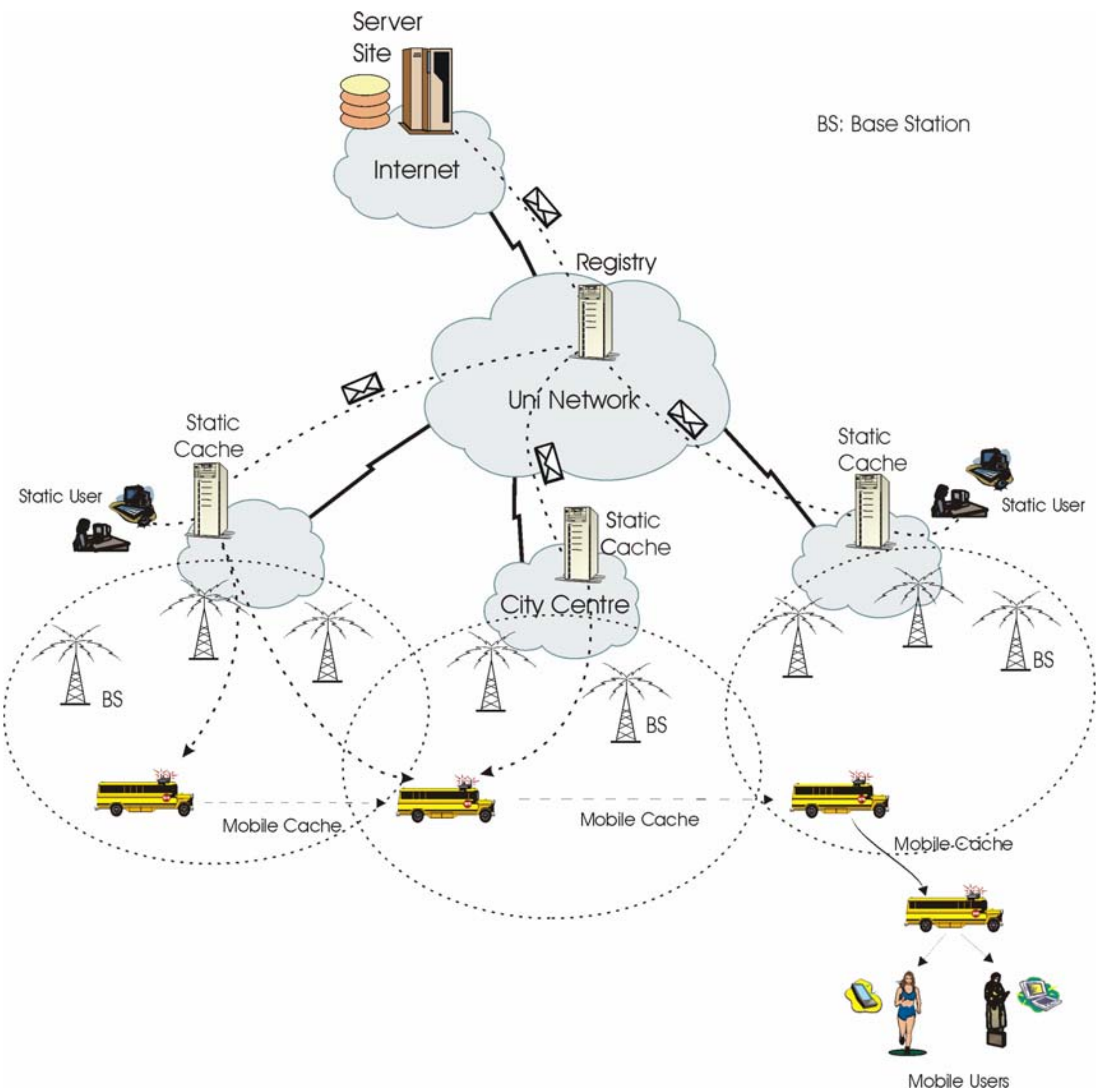


**Figure 11 Mobile Library Network Architecture**

Currently, the mobile library has to use GSM/GPRS when the vehicle is on the move. However, in the near future the CANLMAN network will be upgraded with WiMAX base stations (both for fixed and mobile stations) thus providing increased data rates for mobile libraries on the move.

This concept will be enabled by equipping a mobile library vehicle with a mobile router. The mobile library would be expected to source its network connectivity from the best available interface it has access to and supply content based on what the available network type can realistically support. This scenario throws up interesting and challenging exercises such as content based access control/filtering and mobile caching. With mobile caching, any pre-determined route and/or user access patterns can be input into a caching algorithm so that caching agents in the network can store information topologically close to the mobile library. By utilising previous usage logs etc, the mobile caching agents will allow the mobile library to use the bandwidth available to it in the most efficient manner possible by having cached information at the appropriate time and location.

The mobile library vehicle will be equipped with one mobile router providing Internet access (and thus access to virtual library services). The vehicle will also be equipped with fixed terminals (i.e. PCs or laptops) and an 802.11 access point for users to be able to move freely arounf the vehicle whilst using laptops or PDAs. The vehicle will also be home to a mobile caching agent (laptop or PC).

When a vehicle reaches its destination, the users can get into the bus and use the library and Internet facilities provided by the computers inside the vehicle. Mobile users can also access these facilities via the wireless hotspot that is projected from the vehicle. All user requests are intercepted by the mobile cache. If there is no connectivity, the mobile cache serves the user requests with the files already in the cache

While the vehicle is moving it may or may not be connected to the Internet via CANLMAN or public GSM/GPRS/UMTS. Each time the vehicle is connected, it informs the registry about its current location and its cache hits and misses. In addition, it tries to download any files requested since it was last connected.

Each vehicle consists of

- Books, magazines etc.
- Computer terminals
- Printer
- Cache for dealing with user requests and downloading
- Mobile router including 802.11 access point

The mobile cache aims to satisfy the needs of the users as much as possible. The users may be students, tourists, shoppers etc. Hence the kind of requests can differ considerably. The mobile cache can deal with all types of files including videos, web pages, online papers etc. Users can make their requests prior to the arrival of the bus, increasing the chance of their request being cached.

The cache relies on the idea that it will get strong connectivity on the way to its destination (?). The mobile cache gets its list of files to download from the registry. In the presence of sufficient connectivity, the mobile cache assumes that when it attempts to download a file, cooperative static caches will send the requested data from the closest source hence decreasing the amount of waiting time.

Within the timeframe of the 6NET extension, our mobile library scenario has only reached the stage of a lab prototype. The full system is still being designed to include an inter-cache communication protocol, cache replacement algorithms and real-time vehicle administration and location mapping.

We have designed a web service to allow users to make their requests before the arrival of the library service. Using this service, the users are able to

- view contents of a specific mobile library
- or find the location of a specific mobile library
- get timetables and follow the route of each mobile library.

Based on the information given, the users will be able to make more rational decisions about their requests.

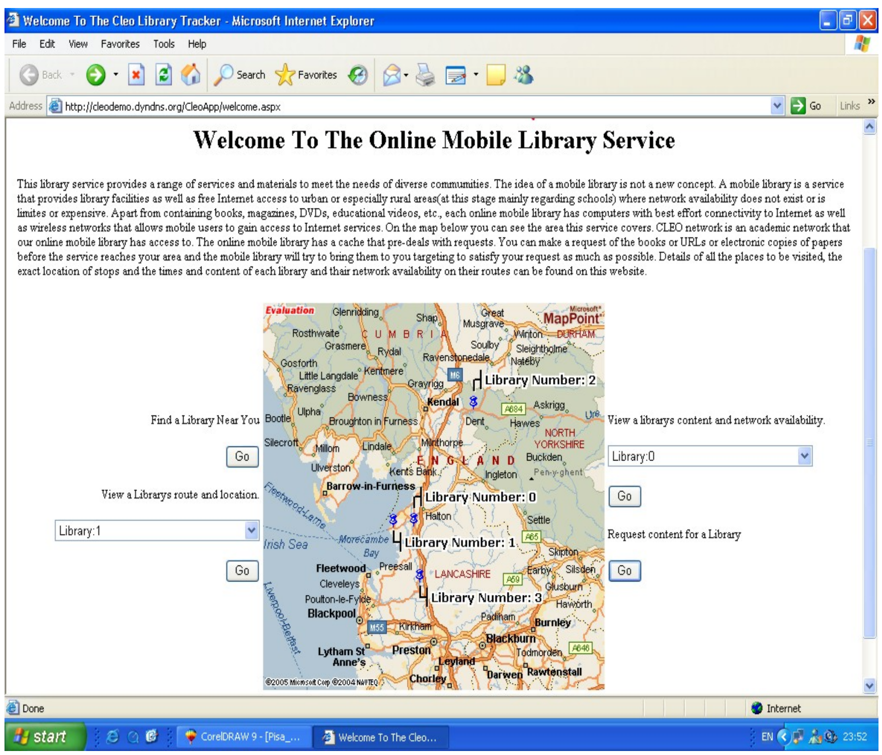


**Figure 12 Mobile Library Web Interface (1)**

The web service is able to show the exact location and the route of a mobile library on a real map including the coverage areas of the wireless networks close to the mobile library. The web service pulls the location (via GPS coordinates) and content information from the mobile libraries and updates the map accordingly. Every time a mobile library changes its content or location, it is reflected on the web service so that the users can get the latest information about the mobile libraries.

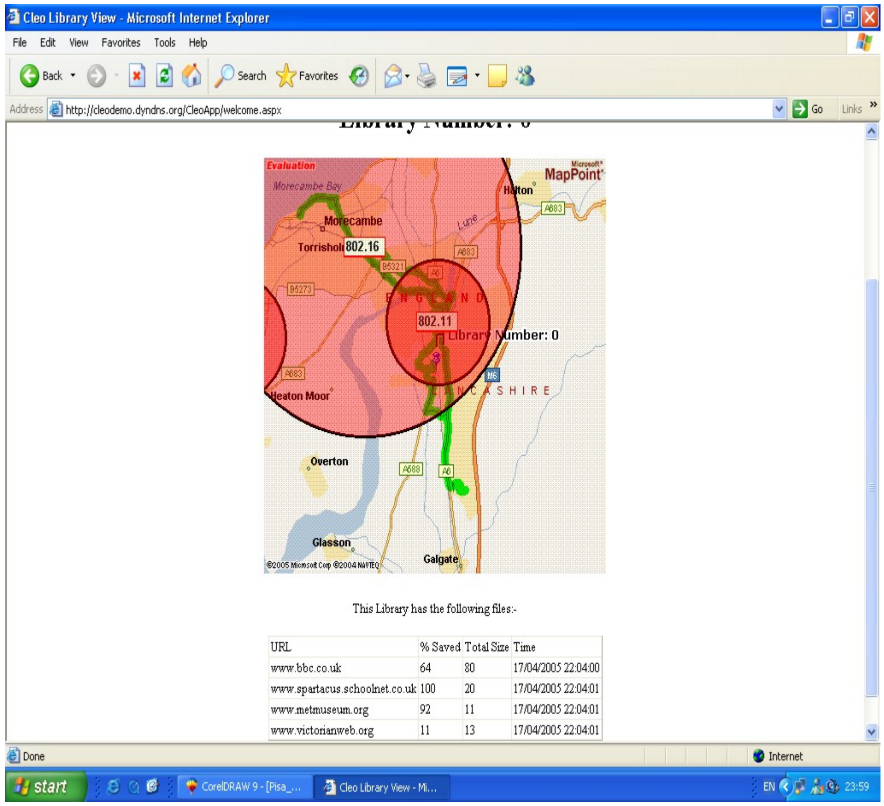


**Figure 13 Mobile Library Web Interface (2)**

In order to increase the chances of the requested content to be downloaded into the mobile cache, the users can make their requests prior to the arrival of the mobile library to their area. Using the forms filled in by the users, the mobile cache can pre-fetch the data before arriving to its destination and make more informed decisions about the users' requests in that area, i.e. making presumptions about the type of content (e.g. sports, news, etc. ) generally requested by the people living in that area.

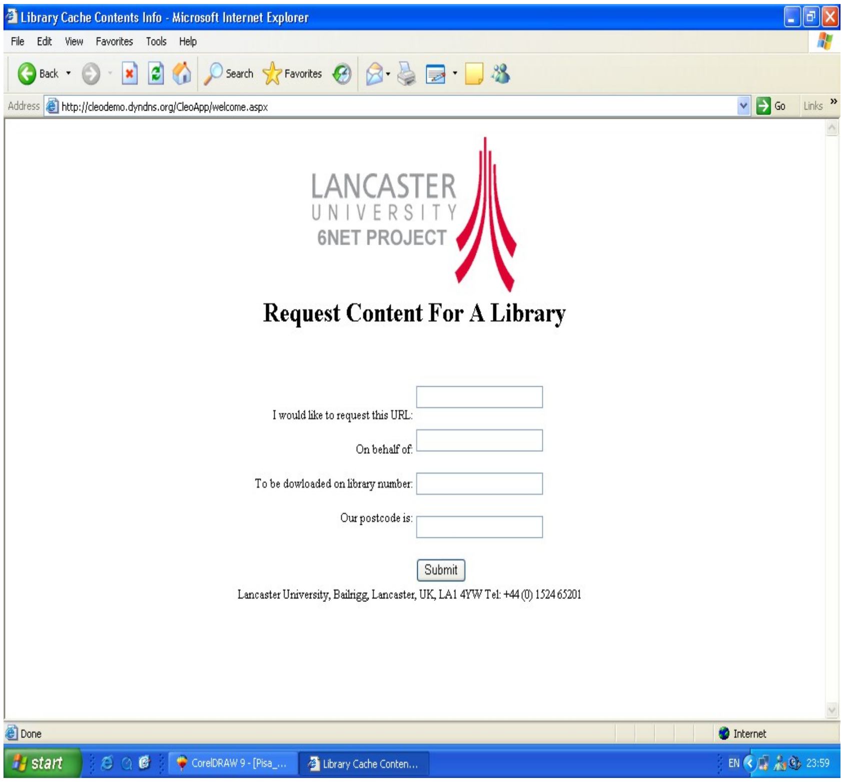


**Figure 14 Mobile Library Web Interface (3)**

# 5 Mountain Rescue

The purpose of this demonstrator is to determine how well Mobile IPv6 and the basic network mobility (nemo) protocol fare when utilised in environments that are highly mobile. We have identified the domain of mountain rescue services as ideal for this task. 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 Cockermouth mountain rescue team, we will examine the feasibility of using mobile routers to provide them with an on-mountain data networking solution.

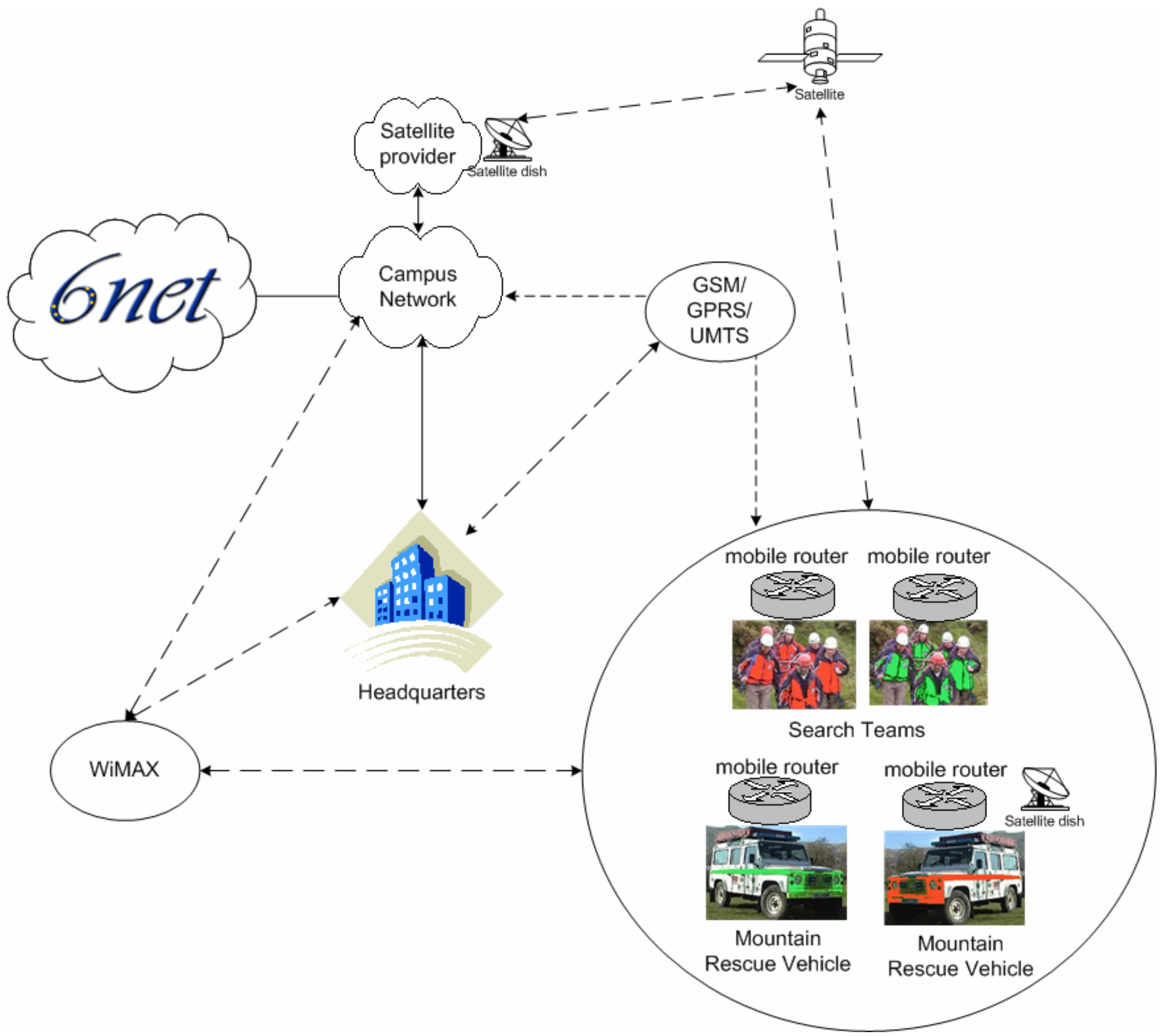


**Figure 15 Mountain Rescue Scenario**

## 5.1 Technical Approach

Integrating mobile router technology into the existing mountain rescue operational procedures is very challenging. Not only do we have the problem of providing optimum connectivity in remote mountainous regions, but also of catering for several communicating entities within a command hierarchy. Even a simple search will consist of several volunteers of a single rescue team spread across a wide area. The volunteers need to communicate with each other and their mobile response vehicle, which in turn will need to communicate with its home base and other entities such as ambulance services and the RAF (Royal Air Force). For large searches the situation is more complex as there may be several rescue teams trying to work in coordinated fashion.

The users of the real system that we will develop will be the Cockermouth mountain rescue team. The user base will most likely be expanded to include other mountain rescue teams within the Cumbria region.

We envisage a network hierarchy as follows:

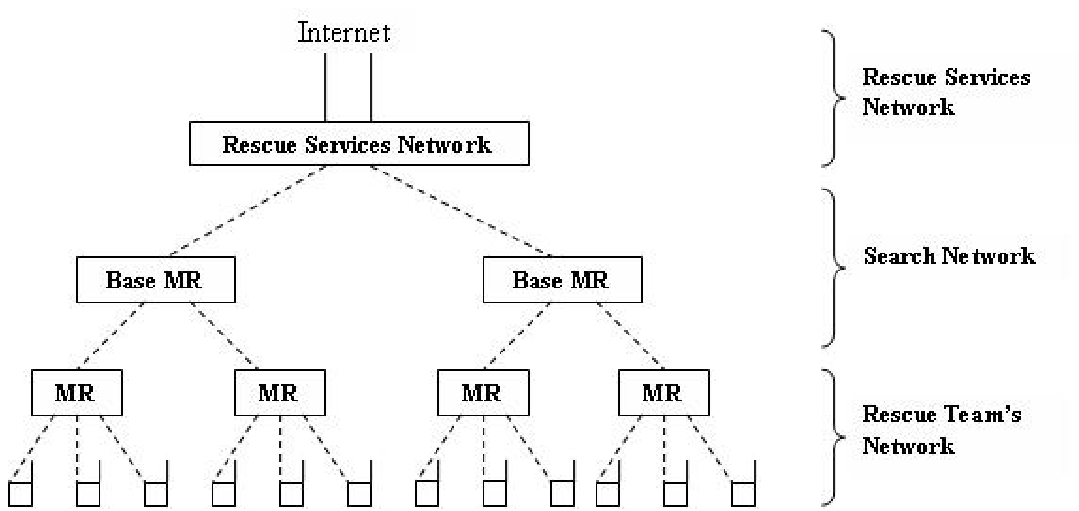


**Figure 16 Network Hierarchy relating to Rescue Services Organisation**

In Figure 16:

- “Rescue Services Network” refers to the fixed Local Area Network (LAN) located at the rescue services headquarters.
- “Search Network” refers to the network of MARs, most likely located in the base vehicles of the search teams.
- “Rescue Team's Network” refers to the network of MARs located with individual search teams out on the mountainside.
- The leaf nodes represent individual search members with their PDA devices.

In a typical search operation, each search team involved will be assigned to a base vehicle and, in turn each individual search member will be assigned to a search team. This leads to an obvious hierarchical relationship as depicted in Figure 16. However, these relationships are loose in that base vehicles, search teams, and individual search members may change their points of attachment as they move around during the course of a search.

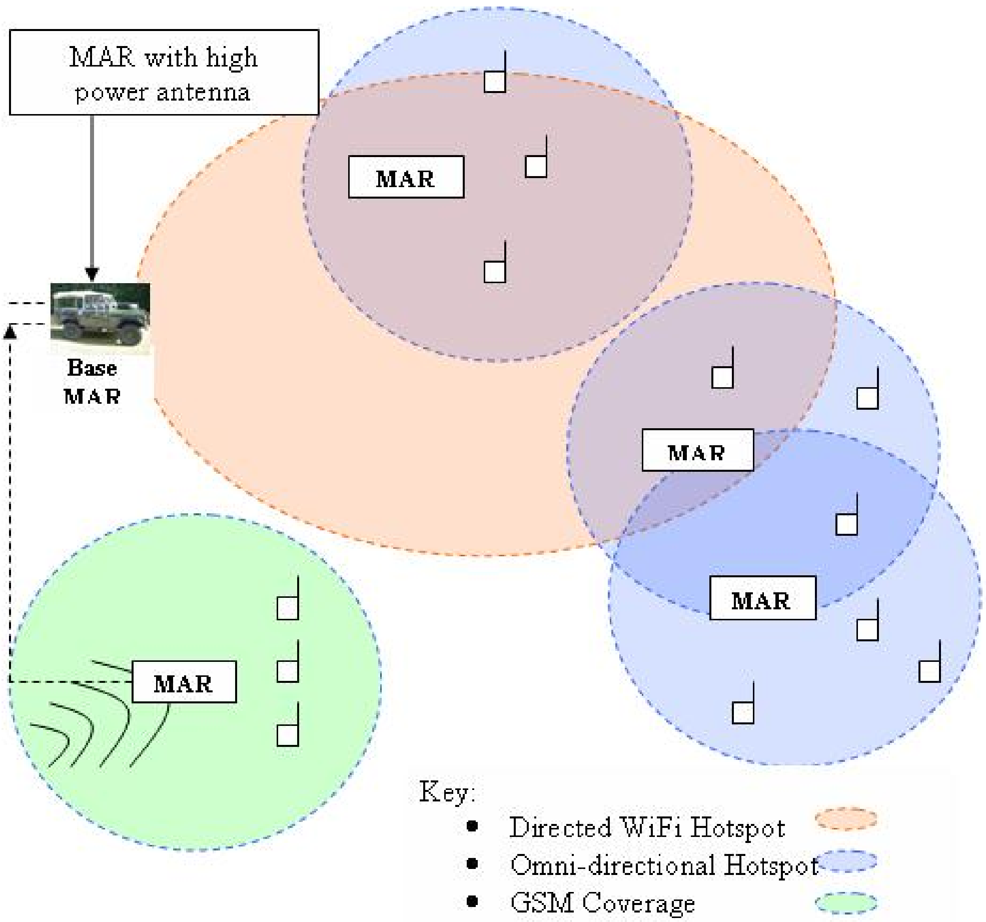


**Figure 17 Example Connectivity Map for One Rescue Team**

Figure 17 illustrates an example network infrastructure for the mountain rescue mobile network. In this envisaged solution, interconnectivity between each of the individual rescue teams can be achieved via numerous methods. One method (illustrated in the Figure as a red cloud of connectivity) is via a "base" MAR located on one of the all-terrain vehicles. Using high gain directional antennae we can project a hotspot of connectivity across an area being covered by the rescue team. This technique would be especially suitable in a situation where much of the overall teams' search efforts are located around one specific area.

The connectivity cloud presented in Blue represents the hotspot projected by each individual rescue team's MAR wireless interface card. This connectivity would primarily be used by any devices carried by the individual rescue workers, but could also be used by other MARs to chain connectivity through.

Finally, in an attempt to ensure that the rescue teams remain connected to the network for as long as possible the MARs, when losing all local connectivity links to the network, would attempt to find coverage via another, fixed, existing network (such as the GSM network).

For the actual demonstrator, we attempt to show the feasibility of using network mobility and the NEMO model for providing a mountain rescue team with the ability to network data between each of the team members, including those on the mountain, those in the vehicles and members back at the headquarters.

The demonstration involves replicating the types of nested mobile network topologies that could be expected when attempting to provide data networking between mountain rescue teams. To do this a cluster of mobile routers is arranged and manipulated to simulate the movement of rescue teams. Each mobile router will accept and provide network connectivity and will have one or more mobile nodes associated with it. The purpose of the demonstration will be to replicate network roaming, nested mobile networks and highlight any problem areas encountered.

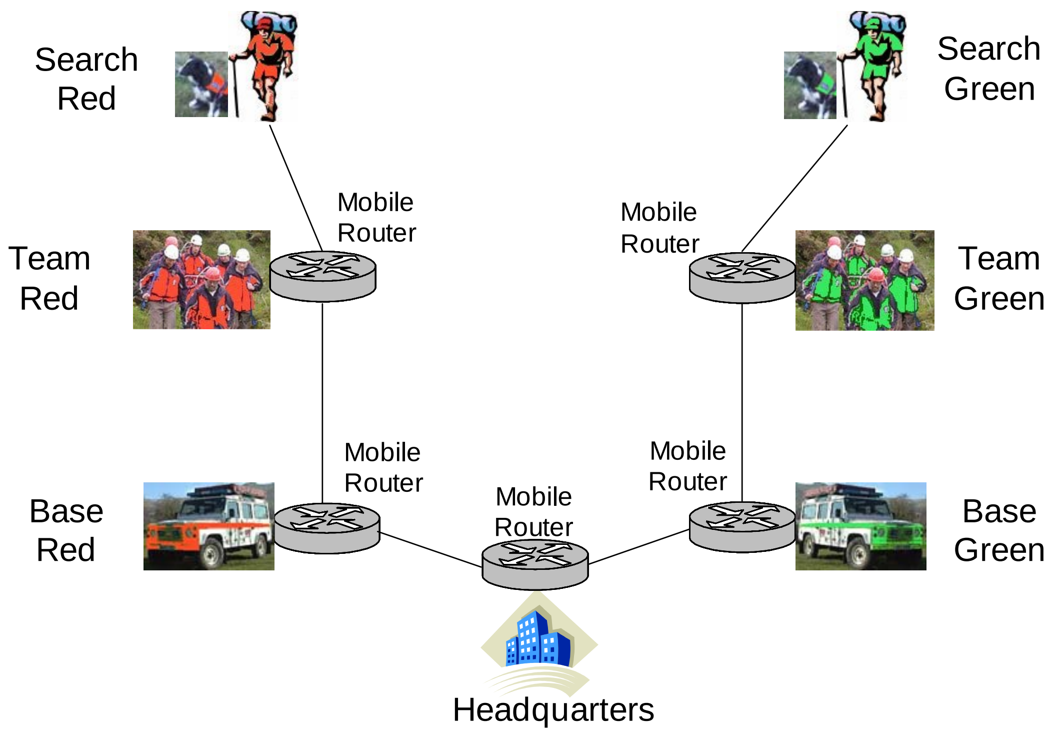


**Figure 18 Demonstration Setup**

The demonstrations at the GARR IPv6 event in Pisa and the Terena Networking Conference in Poznan, consisted of five Mobile Routers with two Rescue Teams, Green and Red linked by a common headquarters (see Figure 18). Simple continuous ICMP echo requests were sent between laptops representing the two individual search members of Green and Red. The echo requests and replies were monitored as the base vehicles and teams were moved around in a pseudo-random manner. Handover times (the time when echo replies were received again after movement had taken place) were up to 30 seconds during the demonstrations at Pisa. However, we managed to improve this to around 4 seconds a couple of weeks later in Poznan.

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