Location Awareness in a Mountain Rescue Domain

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***Abstract*— Aiding the efficient collaboration and coordination of rescue teams is a challenging task especially in a heterogeneous mountainous region. Knowing the exact location of the rescuers during a mountain search and rescue mission can be of great value for the successful progress of the mission and help the mission coordinator in taking informed decisions. The devised Location Awareness System can provide, in a quasi real time manner, exact location information of the rescuers on the mountain, to the mission coordinator who usually stays at the headquarters to organize the operation. The mountain rescue domain poses many difficulties in the terms of network connectivity and thus feasible and effective connectivity options had to be identified and exploited by the developed system. Our collaboration with a real rescue team provided the grounds for analyzing the rescue mission's mobility patterns and requirements and for evaluating the system in a mountain rescue environment. The results from our tests show that our system can provide precise location information and also be able to recover from any connectivity loss either periodic or total.**

I. Introduction

Efficient coordination and collaboration in rescue missions is of critical importance as every minute matters. The knowledge of the exact location of each rescuer during a mission can be of great value for the mission coordinator who needs to take fast and informed decisions. The concept of location awareness gains more attention especially in search and rescue missions taking place in rural areas where the domain itself makes the coordination of a rescue team even more difficult.

The valley areas around the Lake District (Cumbria, Northwest UK) combine a nice setting of mountains and lakes that attracts many individuals for hiking, fell running and mountain climbing in a picturesque setting. However, the physical characteristics of the region, rapid changes in weather conditions, and occasional overconfidence of individuals can lead to accidents and people reported being lost or stuck with little or no knowledge of their precise location. It is a fact that since the area of the Lake District is designated as a National Park, it is mostly uninhabited, and the boundaries of each region are difficult to be recognized and known. Therefore, when one or more of the twelve Lake District mountain rescue teams are called for an emergency incident, their members often need to roam around their region trying to locate the casualty. The efficiency of this searching operation is time critical and the rescuers have to collaborate effectively to increase the possibilities of locating the casualty as fast as possible.

Our collaboration with the Cockermouth Mountain Rescue Team (CMRT) [1], which operates in the northwest area of the Lake District, demonstrates that knowing the exact location of each rescuer and their search parties during a mission can be of significant aid to the mission coordinator of the team. In the case of an emergency incident a call is made to the headquarters (HQ) of the CMRT, located at Cockermouth (Cumbria, Northwest UK), and the members of the team, which are mostly volunteers, are called to report to the HQ. When enough members of the team arrive at the HQ, they are split into independent search parties that are composed of a cluster of rescuers and all-terrain vehicles, are briefed on the incident, and dispatched to the area that it is most likely that the incident has occurred in order to locate the casualty. The mission coordinator of the team stays at the HQ and tries to remotely organize the rescuers and improve the efficiency and the accuracy of the mission. Currently, communication among the rescuers and the mission coordinator takes place using legacy 2-way radio. Rescuers often resort to using their personal mobile phones, which causes frustration since GSM coverage in the area is unreliable and they are personally billed for these calls.

At Lancaster University we have developed a Location Awareness System (LAS) that informs the mission coordinator of the exact location of the members of the team in a real-time manner when possible. Using the LAS during a mission, the mission coordinator can keep track of the rescuers and the search parties, and also keep a broad picture of the operation in order to take informed decisions in terms of which areas have (and have not) been thoroughly searched. The basic principle behind the system is the transmission of coordinates obtained from the Global Positioning System (GPS) from a client application that resides in lightweight devices that the rescuers carry, to a server application located at the HQ of the CMRT via the most suitable and available connectivity option. In turn, the server application receives all the GPS coordinates and plots them onto a map to inform the mission coordinator of the progress of the mission.

Defining viable connectivity options for the developed system can be challenging especially when taking into account the lack of fixed network infrastructure in the region. Therefore, the developed LAS, apart from the client and the server applications, contains a Communication Framework that includes multiple viable and prioritized connectivity options that can apply to the mountain rescue domain. Although this framework is specified for the requirements of the LAS, it can be extended and used by other systems or applications supporting operations in other domains.

The remainder of this paper is structured as follows. Section II provides an overview of the mountain rescue network which supports the LAS and tries to facilitate the networking needs of the team. Section III presents the architecture, design and implementation of the most significant parts of the LAS. Section IV describes the evaluation of the devised system and discusses results taken from field trials. Finally, Section V outlines our future plans regarding the further development of the system and includes a conclusion of this work.

II. Mountain Rescue Network

Providing the network to support a mountain rescue mission is a challenging task as it has to confront the concept of network and host mobility in an environment with little or no network coverage. Since the area that the CMRT operates in is mostly uninhabited, telecommunication providers have little incentive in providing a fixed network infrastructure that could be used to facilitate the devised LAS and many other networking requirements of the team, such as Voice Over IP (VOIP) calls or video feeds over an IP network infrastructure. Moreover, the physical characteristics of the environment result in higher installation and maintenance costs for a fixed network infrastructure.

U2010 is a European research project that is researching capable means for effective communication and access to information in aiding emergency and crisis situations [2]. Lancaster University's involvement in this project has enabled us to thoroughly examine and analyze the networking requirements of the CMRT. Our analysis indicated that the most viable means for providing a networking link between the rescuers and the HQ has to be provided, at least partially, from the team itself. This primary link should be specifically designed for the needs of the CMRT and should be financially and practically feasible to run. In addition, back up solutions have to be identified and utilized in the mountain rescue network when the primary connectivity option fails.

To reflect the outcome of our analysis, a mountain rescue network has been designed (Fig. 1) and is currently being deployed. The independent search parties that a mountain search and rescue mission includes can be envisaged as mobile ad-hoc networks (MANETs) that move independently to cover a geographical area whilst searching for the casualty. The rescuers of each party can be seen as the leaf nodes of these MANETs that are relatively immobile in respect to one another. The mountain rescue network provides connectivity among the devices within a MANET (i.e. among rescuers), and from the MANETs back to the HQ primarily with a wireless network that combines both short and long range wireless hotspots (depicted in Fig. 1). The short-range wireless hotspots (using e.g. 802.11a/b/g) are intended to cover the networking needs of each search party and are projected in the

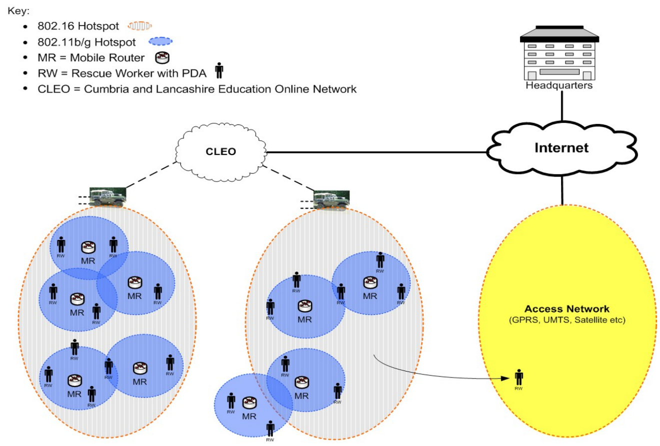

Fig. 1. The Mountain Rescue Network

area where rescuers roam from a mobile router that a member of each search party is carrying in a rucksack. For the needs of the LAS each rescuer is carrying a simple and lightweight WIFI enabled device (e.g. a PDA) that is covered primarily from this short-range wireless hotspot that relatively follows the general movement of the search party as it is carried from one of its members. Connectivity among these MANETs is provided by long-range wireless hotspots (using long-distance 802.11 or 802.16) projected from high-gain directional antennas attached to the all-terrain vehicles that are parked as close to the incident as possible. In turn, the all-terrain vehicles gain backhaul network access to the HQ of the team by relaying data to the nearest wireless point of presence (PoP) of the Cumbria and Lancashire Education Online network (CLEO), which is administered by Lancaster University.

The physical characteristics of the domain in conjunction with the constant and unpredictable movement of the rescuers introduces many difficulties in the wireless communication described above. The WIFI based networking model cannot guarantee the transmission of the data from the rescuer's device to the HQ either because a rescuer is not covered by a wireless hotspot or because the end-to-end connectivity is not apparent at a given point and thus application sessions are interrupted. Work is being carried out in our research group to confront the above problems basically with two, differently scoped, but complementary approaches. The first approach is to identify alternative access networks, such as UMTS, GPRS and Satellite (right side of Fig. 1) that the rescuers' end-devices can use to transmit data from the mountain domain to the HQ when they have insufficient WIFI coverage. The second approach is to combine network mobility protocols, such as the NEMO Basic Support Protocol [3], MANET protocols and Mobile IPv6 [4], to be able to retain mobile transparency to the users and applications inside the local network while the network is roaming, and also get global Internet presence for every device with minimum user intervention. Detailed information of how to apply these protocols to the mountain rescue domain are described in [5] and [6].

The described mountain rescue network has been designed, and ways to deploy it are currently being investigated with the main problem being identifying sufficient relay points to the

CLEO network around the CMRT search area. Apart from the LAS, the mountain rescue network is envisaged to support many networking needs of the CMRT, such as VOIP or transmitting video feeds or values taken from biomedical sensors to the HQ.

III. System Description

The LAS has been designed to aid the missions of the CMRT by tracking and monitoring the rescue workers during a mission. Fig. 2 illustrates a high level architectural diagram of the developed LAS. The architecture of the LAS consists of three conceptually distinct parts; the *mountain rescue domain*, that is the region that an incident can occur, the *HQ* of the team, and the Communication Framework, namely the *connectivity options* that can interconnect the two domains.

The basic principle behind the system is the transmission of GPS coordinates from small, lightweight and mobile devices that the mountain rescue workers will carry during a mission, to the server application that runs on the team's server at the HQ. Therefore, the application on the device that the rescuers carry, obtains GPS coordinates from the dedicated satellites constellation system and then identifies the best available connectivity option for the transmission of the coordinates to the server application. The LAS consists of a refined Communication Framework that includes the network connectivity options that are available, viable and feasible for the transmission of GPS coordinates. Finally, the server application at the HQ of the CMRT receives the GPS coordinates that are sent from the clients regardless of the connectivity option used, processes them and plots them onto a map to inform the coordinator of the progress of the operation.

A. Communication Framework

Generally, the potential connectivity options that could be used in a mountain rescue domain are limited due to the physical characteristics of the domain itself. In addition, as the domain lacks of full-coverage fixed network infrastructure the decision for defining appropriate connectivity options is harder.

Three significant communication options that seem viable for this domain are included in the devised Communication Framework (central part of Fig. 2). The first one is to transmit the coordinates via IPv4/IPv6 over the WIFI network using 802.11 and 802.16 interfaces, the second one is via IPv4/IPv6 using GPRS over the GSM network and the third one is via SMS over the GSM network. The client application is able to identify the availability of each of the connectivity options and then use them according to the following priority; WIFI, GPRS and SMS. This priority has been built by comparing and contrasting the connectivity options based on the following criteria ; availability, cost to purchase/set up, cost to run, speed, extensibility of the provided service, ability to follow evolution in terms of new network protocols, and practicality.

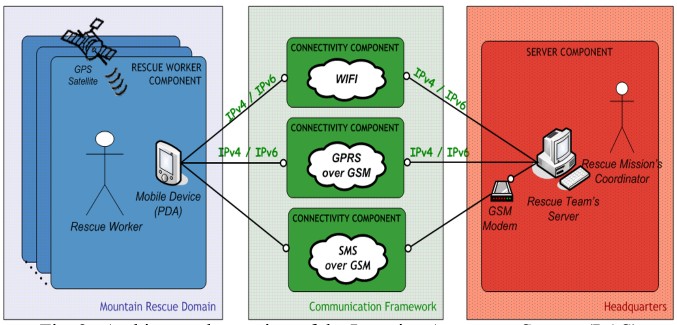

Fig. 2. Architectural overview of the Location Awareness System (LAS)

A full analysis of their prioritization cannot be provided here, but it can be briefly stated that the WIFI connectivity option gets the highest priority since it is most likely to be available as it is provided from the equipment that the rescue team carries (mobile routers and antennas) and follows the mobility of the team. Moreover, it is a connectivity option that although has a high cost to purchase the required equipment, it does not incur any data charges and can provide extensibility to the service since it is IP-based. In addition, taking into account that the WIFI network is provided, supported and administered by the CMRT and Lancaster University, we are able to use evolving networking protocols to support the concept of host and network mobility.

However, the presence of the WIFI connectivity option cannot fully confront the unpredictable movements of the members of each search party and cannot provide coverage overcoming all the physical impediments of the mountains. As a result, two additional connectivity options have been identified, namely GPRS and SMS, to provide redundancy for the transmission of the GPS coordinates. Although both additional connectivity options are based on the GSM coverage, each one provides different back-up mechanism as GPRS is generally connection oriented and IP based, whereas SMS is simple and connectionless.

Complementing WIFI with the GPRS option seems promising as GPRS relies on a different access network, the GSM network. A significant advantage of using GPRS is that it is an IP based solution that can follow, at least in theory, the evolution of IP based networks providing extensibility for the service offered. For example, although current UK GSM telecommunication providers support only IPv4 over their GPRS network, we carry expectations that they will migrate to IPv6 which can be used from our client applications. Moreover, as the GPRS connectivity component is made available as an IP based method, any newly developed IP based connectivity solution that a telecommunication company might follow will easily suit the architectural structure of LAS and be easily adapted and used by the client application. For example, if the telecommunication provider for the GPRS connectivity option upgrades its network to EGPRS (EDGE) or UMTS to provide higher bandwidth, this will not require any change to the design of our system as it will continue using the new connectivity component as an IP based option.

Finally, the devised Communication Framework includes as a backup connectivity option the transmission of GPS coordinates using SMS over the GSM network. This can be achieved as the defined message format (discussed in the following section) for transferring GPS coordinates is a fixed set of characters. Therefore, the SMS connectivity option can be used as it is generally simple, connectionless, does not require any set up fees and can be relatively cheap if used as a back up method.

B. Unified Message Format

An important feature of the Communication Framework is that it defines a Unified Message Format (UMF) that is used for the transmission of the GPS coordinates from the clients to the server regardless of the connectivity option used. This simplifies the procedures for the transmission, reception and processing of the packets both on the client and the server side.

Fig. 3 illustrates the UMF which includes nine text fields separated by a character delimiter. These fields include the connectivity option used for the packet being sent, the node ID of the device that sent the packet, a security code unique for each device and a sequence number for the packet being sent from that client. In addition, the message format includes a timestamp for the date and time that the packet was created and transmitted, a pair of GPS coordinates (with the character "º" being replaced with "@" as the former cannot be transmitted over SMS without using the extended character set that limits the number of characters that can fit into a simple short message) and finally a field for possible extensions.

The carefully designed and selected fields of the UMF, apart from simplifying the process of transmitting and receiving coordinates, include valuable data that can enable additional features to be supported. For example, the server application can authenticate the client that sent a packet, based on the values of the node ID and the security code fields with the use of a shared key infrastructure. Moreover, the server application can re-order out of sequence received packets based on the node ID and the sequence number of each packet. Such a rearrangement can become valuable when, for example, a client has sent an SMS message and then regained WIFI connectivity and sent another GPS update over it. It is likely that the later packet will arrive earlier than the SMS message and thus the server has to filter the presented information based on the fields of the received packets. In addition, an identification mechanism can take place as the node ID field of each packet maps to a certain device, which in turn and with the aid of a knowledge database in the HQ maps to a certain person. Therefore the server application can not only overlay the position of a rescuer onto a map, but also expose the person's identity which can be of valuable aid to the mission coordinator, when for example, trying to locate the closest rescuer with medical training. Finally, an extension field is included in the UMF, which is currently being used to identify if packets are transmitted in an online or offline manner (explained in the following section), but can also be used for any additional feature or extension.

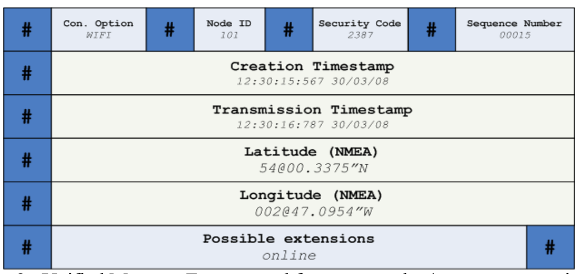

Fig. 3. Unified Message Format used for every packet/message transmitted from the clients to the server regardless of the connectivity option used.

C. Client application; design, implementation and features

The client side of the LAS is composed of lightweight and small end devices that are carried by the rescue workers during the mission. The aim of the application running on these devices is to obtain GPS coordinates, identify the best suited connectivity option according to the defined Communication Framework and use that option for the transmission of the GPS coordinates to the server application. Consequently, the client devices should be GPS, WIFI, GPRS and GSM enabled to be able to facilitate the CMRT's requirements and utilize the connectivity options. For the purpose of our research, HP IPAQ 6915 PDA devices are used running Windows Mobile 5.0 that in principle can support the requirements of the LAS.

Each of the client devices runs an application that is implemented in Visual C# using the .NET Compact Framework, libraries from the OpenNETCF SDK and calls to native dynamic link libraries of Windows Mobile 5.0. The application is multi-threaded to allow efficient implementation of concurrent activities, and its functionality is based on timers (e.g. sending coordinates at specific intervals) and events (e.g. the acquisition of GPS coordinates).

The client application displays various pieces of information to the rescuer separated in tab-pages, namely the Main tab, which is the main screen of the application (Fig. 4), the Client and Server tabs for settings regarding the client and the server, the Map tab for displaying a map to the rescuer marked with his\her location, and finally, the Info tab with information obtained from the GPS satellites. The Main Tab (depicted in Fig. 4), is the main screen that the mountain rescue worker sees during a mission. This screen presents real-time information for the current location of the rescuer, the number of satellites that the application can view and lock for the acquisition of the GPS coordinates, indications for the WIFI and GSM signal strength, the current connectivity option used and counters for the packets being sent from each connectivity option or stored for later transmission. The application can also display the walking speed of the rescuer holding a device or the driving speed of an all-terain vehicle, based on GPS data retrieved.

The client application is able to work seamlessly in two

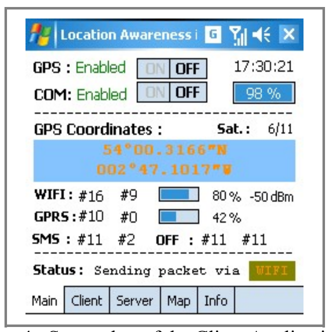

Fig. 4. Screenshot of the Client Application

basic modes; online mode and offline mode. The online mode includes the transmission of the coordinates when at least one connectivity option is available and usable. On the contrary, when no connectivity option is available the application works in offline mode, storing packets for later transmission. The transition from one mode to another is done automatically without any intervention from the rescuer, but does not restrict the two modes running at the same time if required. The decision whether a connectivity option is available and usable is based on a complex mechanism that takes into account the signal strength of the WIFI and GSM networks, the ability to perform a connection (for the IP-based connectivity options) and the monitoring of the actual transmission. Our current set of tests show that the client's complex mechanism works relatively well by basing its primary functionality on two IP-based connectivity options and sending SMS messages as a backup solution to increase the redundancy of the system.

The client application has also an efficient mechanism to constantly monitor and poll the IPv4/IPv6 TCP connections that are used, to keep them active and re-establish them in the background if required. When none of the IP-based options are available then the SMS connectivity option is used and this is monitored for its success. If the SMS transmission fails then the application enables the offline mode that stores packets in order to confront the lack of connectivity. The offline mode monitors the availability of the connectivity options and when connectivity is regained with at least one of them it sends the stored packets flagged as offline since they include the location that a rescuer has been in the past. This flag is used by the server application to distinguish the way online and offline packets are presented to the mission coordinator.

Another feature of the client application is the ability to modify on-the-fly the interval that is used for the transmission of the GPS coordinates. Thus, when a search party is in a vehicle more frequent updates are needed as opposed to when rescuers search a region on foot.

The client application includes powerful log functionality with valuable data being recorded frequently. Furthermore, the availability of each connectivity option is cross-referenced with a pair of coordinates and is logged to provide the data for building coverage maps and improving the coverage of the connectivity options if and when this is possible.

D. Server application; design, implementation and features

The main aim of the server application running at the HQ of the CMRT, is to listen for incoming packets that are sent from the clients regardless of the connectivity option used for their transmission. Then, it processes the payload of each arrived packet/message and plots the received GPS coordinates of the rescue members onto a map to assist the mission coordinator to track the progress of a mission and take informed decisions.

The server application is mainly implemented in Visual C# using the .NET framework and runs on the team's server located at the HQ. It is a multi-threaded application listening for TCP connections from many clients on its Internet-enabled interface. IP packets coming from either the WIFI or the GPRS connectivity option over the Internet will reach the server via this interface. In addition, the server has a GSM modem which receives all the SMS messages that are sent from the clients and forwards them to the server application for processing.

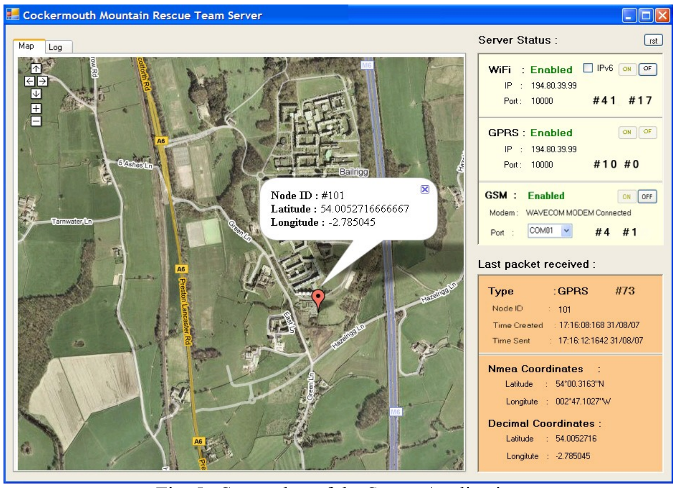

Fig. 5. Screenshot of the Server Application

An important part of the server application is to present the location of the rescuers in a coherent way plotted onto maps. Fig. 5 illustrates a screenshot from the server application which is divided into three distinctive parts; the Map, the Server Status, and information for the last packet received. The map functionality is currently implemented using Javascript that overlays useful information from the received packets onto a map using the Google Maps API, but work is being carried out for the use of ordinance survey maps of the region. The mission coordinator has the ability to see more information about the last packet/message received either by clicking on the point on the map or by examining the right bottom corner of the server application. Information about the received coordinates in NMEA and decimal format, as well as the connectivity option used for the transmission of a packet and timestamps for its creation and transmission are also available. Information about the current status of the server, the IP address/Port that the server listens to and counters for the packets received are also displayed at the top right corner of the application. In addition, a Log tab-page is available for a detailed description of every received packet.

The server application imposes thorough processing on the incoming packets to enable features such as authentication and identification of the clients, splitting merged TCP packets and re-ordering of the received packets since all of them follow the UMF. In addition, filtering also applies when the server application receives offline packets that are depicted differently than the online ones, since these packets contain location points that rescue members have been in the past. Finally, detailed log functionality has been implemented to enable offline studies of the mobility patterns of the team and to apply search theory techniques for improving the efficiency of future missions.

IV. Evaluation and Result Analysis

The evaluation of LAS included three distinctive phases based on the place the experiments were done; the lab phase, the campus phase and the on-mountain phase.

The lab and the campus evaluation phases were carried out at Lancaster University including a PC running the server application and a HP6915 PDA running the client application. During these two phases a person holding the PDA running the client application was roaming either around a building or around campus. In the lab phase an IPv6 802.11b network was created to emulate the WIFI network of the mountain rescue team and both the client and the server had a local-link IPv6 address. In addition the server application had an IPv4 public address listening to packets sent from the client device using the GPRS network. Numerous tests were done to evaluate how well the client application identified and utilized the available connectivity options. During this phase three issues regarding the hardware and the software of the client device were identified. Firstly, the chosen PDA had a cut down version of the IPv6 networking stack and therefore it was unable to get a global IPv6 address. Secondly, Windows Mobile 5.0 was not able to have two IP connections (WIFI, GPRS) available and hot swap from one to the other. Finally, a buggy operating system's behaviour was noticed when the application was using GPRS but then wanted to swap to the WIFI network. Various tests were done to clarify the cause of the observed behaviour and eventually it was decided that due to the hardware and operating system's limitations, different client devices had to be purchased since our software was verified to be running smoothly. In addition, it has been decided that the features of IPv6 and GPRS should be opted out from the third phase until the purchase of new end devices is completed.

While trying to find an alternative client device and since critical decisions for the exact mobile equipment to deploy the mountain rescue network (described in Section II) had still to be made, a mobile testbed has been created to enable us enter the third evaluation phase, the on-mountain phase. Fig. 6 illustrates the mobile testbed that includes a laptop running the server application with a USB GSM modem listening for SMS messages and an IPv4 address listening for packets coming over the WIFI link. Another laptop was used to act as an access point to provide the WIFI connectivity option. Finally, to emulate the networking link between the clients and the server two directional antennas were used that were each attached to a laptop respectively.

An on-mountain experiment was carried out using our mobile testbed for about one hour (limited by the batteries of our equipment) in the area of Buttermere (Cumbria, UK). During this experiment a person was monitoring the server application running on one of the laptops tracking the movements of another person who was roaming in a radius of 500m around the access point, holding the PDA with the client application. Table I presents results from the packets being transmitted either in the form of IP packets over WIFI, or SMS messages over the GSM in online or offline manner. Regarding the packets being transmitted over WIFI using TCP, it has been observed that only 7 out of 121 (approximately 5.8%) were lost, a remarkable percentage for a wireless network taking into consideration the physical characteristics of the environment and the mobility of the person holding the client device. Furthermore, it has been noticed that when the client application was identifying a broken TCP socket it was swapping to GSM, managing to minimize the packet loss. Regarding the SMS messages, it has been observed that two of them were not received from the server application, a behaviour that is accounted to the GSM provider. On the server side, the application was able to rearrange out of sequence packets and also split merged TCP packets, presenting on the map the movement of the person roaming. Generally it can be stated that the client application had transmitted GPS coordinates successfully in respect to the available connectivity option. Furthermore, the person monitoring the server application could track the movements of the person holding the PDA and although further tests have to be carried out, it can be stated that the developed LAS managed to provide the concept of location awareness in a mountainous domain.

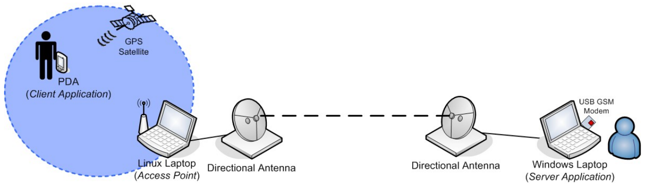

Fig. 6. Mobile Testbed developed for outdoor experiments

TABLE I
Results from the on-mountain evaluation phase

Connectivity option	**Client** (packets sent)		**Server** (packets received)	
	Online	Offline	Online	Offline
WIFI	121	18	114	18
SMS	42	9	40	9

V. Future Work and Conclusion

In this paper we have introduced the LAS to facilitate the concept of location awareness in a mountain rescue domain. Our hitherto results show that the developed system can track rescuers in a real-time manner and can be of great value to the mission coordinator of a search and rescue team. Our future work includes the further development of the LAS and the integration of search theory algorithms and network mobility protocols to increase its efficiency and support the rescue missions to a greater extent.

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