The Integration of Ad-hoc (MANET) and Mobile Networking (NEMO): Principles to Support Rescue Team Communication

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ABSTRACT

The concept of combining MANET and NEMO protocols in order to optimally support Nested NEMO scenarios is a relatively new idea that is attracting a lot of attention within the IETF NEMO WG. This combination has been termed MANEMO, which until now has stood to describe the process of running a MANET protocol between local Mobile Networks in a Nested NEMO topology, to optimise local packet delivery within the Nested structure. However, in this paper we highlight the mutual benefits that can be attained by combining MANET and NEMO technologies, not just by incorporating a MANET protocol into a Nested NEMO scenario but also by augmenting the capabilities of a MANET scenario through the introduction of NEMO. This subtle distinction leads us to define two separate instances of MANEMO, respectively NEMO-Centric MANEMO (NCM) and MANET-Centric MANEMO (MCM). The focus of our work at Lancaster University is on this latter instance of MANEMO, MCM; this work is based around the development of an on-mountain data networking solution for a mountain rescue team.

Keywords: NEMO, MANET, Mobility, Mountain Rescue, MANEMO

1 Introduction

Network mobility, although a relatively new concept can provide benefits to many conceivable scenarios and domains. In many situations in real world mobile computing, mobile nodes can often move in clusters (which means that whilst the cluster as a whole is mobile, in relation to one another they are in fact relatively static). Hence the mobile nodes' mobility can be aggregated and handled as one mobile network, this is made possible through the use of a Mobile Router (MR). Network mobility is applicable to many different mobility scenarios, because of this it is difficult to generate a single network mobility solution that can support all of the scenarios that a mobile network may be used in. At present the only standardised network mobility solution is the NEMO Basic Support (NEMO BS) protocol. NEMO BS was designed to fully support the most basic network mobility scenario (supporting consistent communication with a single mobile network that is roaming across different access networks.) However, with network mobility, scenarios can become massively more complex than with node mobility, as independent mobile networks can attach to other mobile networks (forming what is known as a nested mobile network). When nested mobile networks begin to form, NEMO BS can still theoretically be used to support these scenarios but because of the way the protocol operates, they quickly become extremely inefficient [1].

To counteract these inefficiencies, it has been suggested that a solution could be devised from incorporating MANET protocols into the nested NEMO scenario, this would permit unaltered NEMO operation whilst the mobile network roams as a single entity, but then also to use a MANET routing protocol for optimised local packet delivery within the nested NEMO network. This solution, combining the properties of MANET and NEMO protocols has been named as MANEMO. The purpose of this paper is to present the background and rationale that lead to the inception of the MANEMO solution and to present what we feel should be a 2-part definition of the MANEMO problem domain. In addition, we present the ongoing MANEMO related research that is being carried out at the University of Lancaster, specifically with reference to the Mountain Rescue Network that we are currently developing. Finally we introduce an optimisation technique that we are developing to work in conjunction with our MANEMO solution that provides optimisations by utilising the structured movement of the mountain rescue team.

The remaining structure of the paper is as follows, in Section 2 we provide some background information on Network Mobility and NEMO in general, Section 3 we introduce MANEMO and the notion of two distinct MANEMO scenarios (NEMO-Centric and MANET-Centric). In Section 4 we introduce the Mountain Rescue Network solution. In Section 5 we introduce an optimisation scheme called oMCM that we have designed to optimise the MANET-Centric MANE-MO based Mountain Rescue Network solution. In Section 6 we conclude the paper and provide thoughts on further work.

2 NEMO Overview

Leading on from the standardised technique developed for providing IP mobility to end hosts (Mobile IP [2] and Mobile IPv6 [3]), network engineers quickly identified many real world scenarios where clusters of end hosts were mobile, but relatively static in relation to one another. Examples of these scenarios include Access networks on public transport, Personal Area Networks and Vehicle based networks. In an effort to develop solutions that could support these scenarios, the IETF formed the NEMO Working Group (NEMO WG). After in depth analysis of the network mobility problem domain, the NEMO WG decided to approach the task of developing solutions in numerous stages. Rather than attempt to produce a single solution which would solve all conceivable uses of network mobility, the working group decided to first standardise a solution to the basic scenario and then with this milestone completed they would continue to work on producing solutions for more complex scenarios such as multihomed and nested NEMO scenarios [4].

2.1 NEMO Basic Support

The NEMO Basic Support protocol (NEMO BS) [5] is what the IETF NEMO WG entitled their first standardised solution to the network mobility problem and it is now an RFC. NEMO BS is considered an extension of MIPv6, with the major difference being that the HA intercepts packets for an entire network prefix and forwards them on to a Mobile Router (MR). This process ensures that Mobile Network Nodes (MNNs) within the NEMO are consistently reachable at the same IPv6 address (an address formed from the MRs Mobile Network Prefix (MNP)) irrespective of the MRs location. This solution facilitates the incorporation of mobile networks into the existing Internet infrastructure because it only requires the HA and the MR to be aware of the network's mobility. The MNNs and the Correspondent Nodes (CN) that they communicate with can remain unaltered.

2.2 NEMO Extended Support

In addition to the basic scenario, numerous other scenarios exist within the network mobility domain that require a more optimised solution to the problem domain than that which is provided by NEMO BS. Examples of these scenarios include:

- Multihomed NEMOs: Where a NEMO has multiple connections to send packets over in order to support load balancing or a redundant fall-back connection in case the primary connection is lost.
- Nested NEMOs: Where a roaming NEMO connects to another NEMO to gain network connectivity.
- Route Optimisation (RO) for the NEMO BS scenario: Such as a MIPv6-style RO mechanism whereby the dogleg route between the CN and the MNNs via the HA is optimised by updating the CN with the MNN's actual location.

These additional work areas and any other work areas that arise within NEMO that augment or differ from the functionality described by NEMO BS are termed as NEMO Extended Support. From these additional areas of work, we will be specifically introducing the problems created by Nested NEMO scenarios, as these scenarios were the initial catalyst behind the research into MANEMO and they highlight where the initial motivation to develop MANEMO arose from.

3 MANEMO Concept

The MANEMO (MANET-NEMO) concept has developed from the requirement to optimise local packet delivery paths within a Nested NEMO structure. However, this convergence of the two technologies can be mutually beneficial to one another and thus benefit both NEMO based scenarios and MANET based scenarios; the authors of this paper identify these separate instances as NEMO-Centric and MANET-Centric MANEMO.

3.1 NEMO-Centric MANEMO (NCM)

NEMO-centric MANEMO describes the scenario where numerous, disparate NEMOs converge to form a Nested NEMO network. In this scenario, if the NEMOs are using NEMO BS to maintain connectivity, packets sent between 2 NEMOs within the nested structure will traverse a highly inefficient route via each of the HAs of the NEMOs that are in the path between the source and the destination NEMOs. This routing sub-optimality is known as Pinball Routing (or Multiangular Routing) and is illustrated in Figure 1. The illustration shows how for a packet to be sent from Node A on NEMO 1 to Node B on NEMO 2, the packet must first be tunneled through the destination NEMO onwards to it's HA (HA1) at which point it is decapsulated and sent back to NEMO 2 via HA2 (back along the same path it travelled out to HA1).

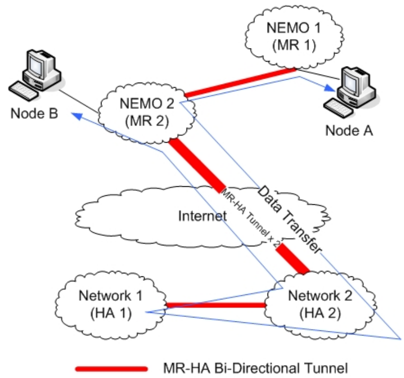

Figure 1: Example of Nested NEMO Route Sub-Optimality

This is obviously a highly inefficient process and so accordingly, a number of solutions to optimising this situation have been proposed as part of the IETF NEMO Working Group [6] [7]. The concept of combining MANET and NEMO was suggested as one possible solution, it was born from the observation that when the NEMO Mobile Networks converge in the same location to form a nested NEMO structure, this structure itself (locally) is actually a mobile ad-hoc network of NEMO mobile networks. Therefore, local delivery can be best performed between NEMOs in the Nested NEMO structure using a MANET routing protocol (extended to support network prefixes). Although no specific draft proposal was ever submitted to the NEMO WG, the possibility of combining MANET and NEMO in this manner was mentioned in the NEMO WG RO Space Analysis draft [8] and a slightly more detailed example was published at the IASTED Networks and Communication Systems conference [9].

The outlined scenario based around optimising nested NEMO structures is what we identify as NEMO-Centric MANEMO (NCM). We define a NEMO-Centric MANEMO scenario as being one in which the NEMOs in their typical state follow the NEMO BS model, i.e they are distinct mobile networks that typically roam across access networks in a non-nested structure. However, in the event of a roaming NEMO attaching to another NEMO (or possibly another Nested NEMO), packet delivery within the nested structure is optimised through the use of a MANET protocol. The optimisations this technique affords can come in two conceivable forms. Firstly in the case of local delivery (where packets originate from one NEMO within the nested structure and are destined for another NEMO within the same nested structure) it allows the packets to be routed directly to the appropriate NEMO without visiting any HAs or leaving the nested structure. Secondly, packet delivery to a NEMO within a Nested NEMO from a source that is outside the nested structure can also be optimised with this technique. Instead of blindly forwarding packets to every HA of every NEMO that must be traversed within the Nested NEMO, the NCM protocol could register the address of the Top Level Mobile Router (TLMR) (i.e the MR in the Nested NEMO that is connected directly to the access network). This way the HA could forward all packets destined for the NEMO registered with itself directly to the TLMR, and then allow the local MANET routing to ensure the packet is accurately delivered from the TLMR onwards.

3.2 MANET-Centric MANEMO (MCM)

MANET-Centric MANEMO (MCM) describes the scenario where a collection of NEMOs are by default part of an Ad-hoc structure and for them to move away from this structure is the non default case. In this situation it is the MANET protocol that will perform the bulk of the routing and the NEMO protocol that is engaged in the specialised case (vice-versa to the NEMO-Centric scenario). This specialised case occurs when a NEMO has disconnected from the Ad-hoc structure it originated in and therefore uses NEMO BS tunneling to tunnel packets back into the Mobile Ad-hoc Network swarm. This general model is illustrated in Figure 2, notably for descriptive purposes, from here onwards we identify the Mobile Ad-hoc Network swarm as a whole as a MANEMO.

The main distinction between a MANET-Centric and a NEMO-Centric MANEMO approach arises when we consider the location of HAs and the Home Networks in general. With NEMO-Centric MANEMO, a HAs role and its subsequent location follows the same model as with NEMO BS, however with MANET-Centric MANEMO it is intended that the Ad-Hoc structure (the MANEMO) is considered the Home Network of each of the NEMOs that belong to it. This distinction represents a big change in the overall conceptual model, but it doesn't massively alter the fundamental role of the HA itself. Essentially the duty of the HA should still be to tunnel packets to and from the MR, the fact that the bulk of the traffic will be sourced from or sent to nodes located on the Home Network shouldn't effect the HAs operation. When considering the location of HAs in this model we identify two distinct scenarios, which affect the possible solutions:

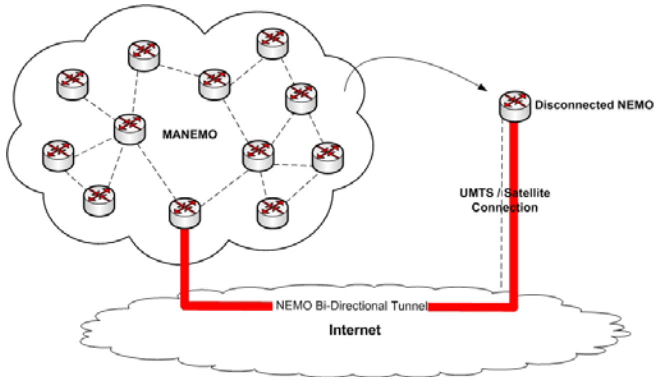

Figure 2: MANET-Centric MANEMO, General Model

1) Grounded MCM: This represents the simplistic model whereby the MANEMO (i.e. the MANET of NEMOs) has a permanent fixed point of connection to the Internet (such as a Head Quarters or a static vehicle with a satellite uplink) and therefore this anchor point can be used as a permanently reachable gateway back into the MANEMO. An example of this model is presented in Section 4 where we introduce our work on the Mountain Rescue Network. In this model, all the HAs for every NEMO would be located at this anchor point, this would enable a NEMO that becomes disconnected from the MANEMO to initiate a bi-directional tunnel with a HA located at the anchor point. If the HA then advertises a route within the MANEMO to the external NEMO, it can then forward packets to and from the NEMO and thus maintain the NEMO's connection to the MANEMO as a whole.

2) Non Grounded MCM: This represents the more complex model whereby the MANEMO can have multiple, changing points of connection to the Internet. which is much more difficult to support. With the general MCM model, the MANEMO itself can conceivably have multiple points of attachment to the Internet and these points of attachment may also change at any time. In this situation we have no fixed anchor point which we can use to enable NEMOs to tunnel back into the MANEMO. Therefore in order to produce a successful solution to this problem, external NEMOs must be able to somehow determine the current anchor points of an existing MANEMO. One conceivable solution to counteract this problem would be to enable NEMOs which become anchor points to dynamically assume the role of a HA and manage external connections for the duration it has an external connection. As you will see in Section 4, whilst our Mountain Rescue Network scenario does have a statically located HQ and therefore can be theoretically solved using a Grounded MCM solution, supporting a non-Grounded MCM model may make our solution more robust. For this reason we have incorporated support for dynamic HAs into our optimisation proposal (oMCM) detailed in Section 5.

4 Mountain Rescue Network

Mountain Rescue is a challenging scenario to attempt to produce a data networking solution for; however the potential rewards to a mountain rescue team of successfully implementing a solution would be numerous. A mountain rescue team with a reliable and efficient means of sharing data on the mountain would be able to share location information, possibly initiate voice conversations (benefiting from the multihop nature of the proposed solution), share images and crucially a successful solution would also allow the search coordinators to make more informed decisions when conducting a mountain rescue mission. In this section we introduce the work being carried out at Lancaster University (in colaberation with the Cockermouth mountain rescue team [10] who are based in the Lake District in the north of England) that is aiming to provide an infrastructureless, data networking solution in a mountain rescue domain based on the concept of MANEMO (specifically MANET-Centric MANEMO (MCM)).

4.1 The Mountain Rescue Network Model

The overall model we propose is based around the concept of each mountain rescue worker and each of their All Terrain Vehicles supporting a NEMO (using a MR). Each of these MRs will support a purpose built MCM protocol, using MANET style routing for communicating within the Ad-Hoc/on-mountain structure and using NEMO style routing whenever they roam onto a third party access network. The NEMO bi-directional tunnel will be used to send packets back and forth to the Ad-Hoc structure (MANEMO) and thus allow the disconnected NEMO to remain a part of the inter-communication between team member NEMOs whilst hiding their true network location. Each of the mountain rescue workers belong to separate groups called “search parties”, these groups consist of around five rescue workers (can be greater or fewer though) who in cooperation with each other, search the areas they are designated together. The primary, infrastructureless communication model is designed around the use of both short range and long range wireless interfaces. Short range interfaces are intended to be used between each of the individual search party members, because each search party member is relatively immobile in relation to one another. Longer range wireless interfaces will be used to interconnect each of the distinct search parties and All Terrain Vehicles. We suggest this approach because longer range interfaces are more expensive and require bulkier hardware. Therefore we reduce their usage to being located on the All Terrain Vehicles (and possibly being carried by one of the search party members). If a rescue team member’s mobile router loses its connection to the rest of the mountain rescue network, then it may attempt to reestablish a connection via a 3rd party access network (i.e. cellular network (using GPRS) or Satellite network). These connectivity types are considered to be fallback options, as they incur additional costs and overhead. In this situation, the mobile router uses the NEMO Basic Support protocol (NEMO BS) to tunnel across the access network and back into the mountain rescue network. The bi-directional tunneling approach adopted by NEMO BS allows the NEMO to hide its external address and permits continued communication, ensuring that all of its nodes appear to still be part of the MANEMO.

4.2 Implementation Considerations

As discussed in section 3, our solution is based upon the concept of MANEMO, and will therefore incorporate some form of MANET routing protocol and the NEMO Basic Support protocol into the overall solution. Our intention is to only alter the NEMO BS protocol where necessary and to implement an existing standardised MANET routing protocol. We feel that the MANET domain is already flooded with routing protocol suggestions and that specifying a new, scenario specific protocol would provide no real benefit to the computing community as a whole. The situations in which the MANEMO concept may be used are widely varied, so it would be restrictive to enforce the use of a specific MANET protocol. Our solution will be designed to reflect this and it will be our intention to decouple the MCM protocol from any one specific MANET protocol. However, whilst we feel the choice of which MANET routing protocol to use in between the NEMO networks should be decoupled, we believe that Proactive MANET routing protocols (such as OLSR [11] and TBRPF [12]) are more ideally suited to supporting MANEMO models. This is because Proactive MANET routing protocols most accurately suit the store and forward functionality of a conventional router. The MANEMO model incorporates the use of Mobile Routers which support numerous mobility unaware devices, these devices will generate packet transfers with no consideration for the underlying network. Therefore the use of any MANET routing protocol which does not maintain accurate, up-to-date routing tables could cause potential problems. For example, if a Reactive MANET routing protocol were used, packets arriving from the many different devices attached to the Mobile Router could quickly fill up it’s buffers whilst it awaited the completion of the on-demand route discovery process, which could lead to packet loss for many different flows.

Figure 3 illustrates how the proposed model is composed of a number of different search parties, All Terrain Vehicles and the rescue team headquarters. Each of the search parties are subsequently made up of a number of search party member Mobile Networks. In addition each PAN and All Terrain Vehicle Mobile Network has a number of devices connected to it. We have chosen to utilise Mobile Networks in this manner in order to support two important scenarios:

1) To support the use of PANs and VANs.

A mountain rescue worker is the perfect candidate for Personal Area Network (PAN) technology. Typically an individual rescue worker could benefit from carrying many electronic devices, such as a GPS location device, video camera (web cam) and environment sensors (i.e. heart rate monitors and temperature sensors). Crucially, supporting an IPv6 PAN

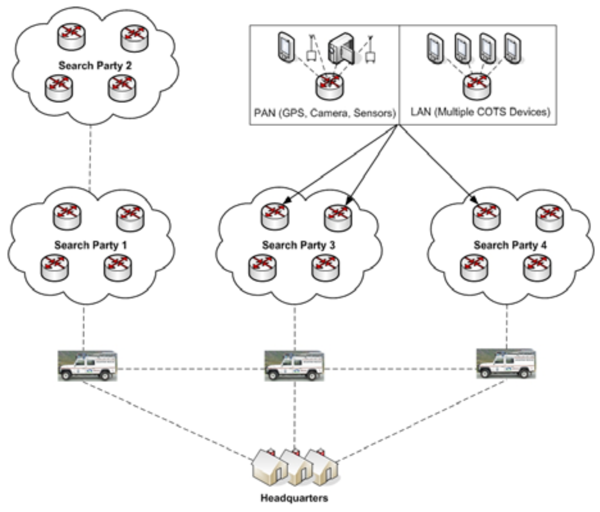

Figure 3: Proposed Mobile Network to Support Mountain Rescue Workers

between these devices would allow them to be remotely interfaced with and provide the search coordinators with further extensive information to help them organise their missions. For example, in freezing conditions, remote coordinators could monitor the temperature of the water retained in the rescue team member's skin to ensure that any individual that is recording temperatures close to those that would induce frostbite are requested to return down from the mountain. In addition to the advantages NEMOs can provide to the individual rescue team members, equipping the All Terrain Vehicles with similar mobile networks can provide additional benefits to the rescue team as a whole. Again the advantages attainable revolve around the remote monitoring and interaction with devices, in this case located within the vehicle forming a Vehicle Area Network (VAN).

In the case of both the PANs and the VANs, the devices connected to them remain relatively static in relation to one anothers. By using NEMOs in this situation we can hide the devices mobility from the devices themselves, this means that the devices can be COTS products which don't require any modification. If we were to try and support this direct addressability functionality using a host based mobility technique (such as a typical MANET routing model), each device would be required to support the mobility protocol (which would mean its code would have to be augmented). Aggregating all the devices in the PAN / VAN under one network prefix also means that less routing information need be transmitted. Rather than advertising the location of each of the devices to every other device in the mountain rescue network, we need only advertise the location of a single prefix. This drastically reduces the overall amount of signalling performed.

2) To support the sporadic introduction of COTS devices into the network.

The default/ideal solution proposed to support the mountain rescue team assumes that each of the mountain rescue team members has a MANEMO enabled mobile router which supports their PAN of wireless enabled devices. However, there may be instances when this model may not be attainable (i.e. if a team member's mobile router breaks and no replacement can be sourced). In this situation, it would be highly advantageous for a mountain rescue team member to have a contingency method for connecting to the Mountain Rescue Network to ensure they are able to continue receiving important information related to the search and rescue mission. In the mountain rescue network, any wireless Commercial Off The Shelf (COTS) PDA device with IPv6 support would be able to connect via one of their team mates' mobile routers. Rescue team members connected to the network in this manner would conceptually be considered as another device (Node) on their team mate's PAN. This would enable the rescue team member to continue receiving information and communicating with the rest of the rescue team, only they would no longer be able to support their own PAN and therefore their devices would no longer be present on the network.

5 Optimising the Mountain Rescue Network MCM Model

In addition to the MANEMO definitions outlined thus far, we propose the development of a solution which introduces optimisations to the MCM model by further abstracting away from the underlying routing architecture. This abstraction is designed to specifically capitalise on the team based operations of the mountain rescue team. As outlined in Section 4.1 the mountain rescue team perform their search and rescue missions as a number of distinct search parties. This approach is also adopted by many other institutions such as the fire brigade and the military and is therefore applicable to many scenarios which may benefit from the introduction of a data networking solution. In order to improve the overall efficiency and manageability of routing throughout the Mountain Rescue Network, we propose the use of a technique based on the concept of identifying each of these physically dispersed local area MANETs as individual Autonomous Systems (ASs) and abstracting away from the underlying MANET protocol running in each search party when performing inter search party transfers. This model we propose is called "optimised MCM" (oMCM), conceptually this model is designed to provide our solution with beneficial properties similar to those provided by the abstraction approach adopted by Border Gateway Protocol (BGP) [13]. However the implementation of our model must be significantly different to the current version of BGP (BGP-4) in order to take into account mobility and other problems specific to the Mountain Rescue Network model.

The oMCM technique of abstracting away from individual team members and instead routing via entire search parties would provide our solution with many advantages, including:

- Abstraction away from the internal routing performed within each search party.
- Aggregation of NEMOs within a search party - thus

reducing the overall size of route information shared across the network.

- Management of search party's external connections.

Figure 4 illustrates the general model proposed by optimised MANET-Centric MANEMO (oMCM), the crux of this approach is based upon the ability to identify which NEMOs should be aggregated together to form a distinct Autonomous System (AS). In the Mountain Rescue Network scenario this distinction is based upon physical aspects (i.e. NEMOs are a part of the same AS if they reachable over local area wireless connections only, this includes over multihop local area wireless connections). However scenarios may exist where the members of each AS are decided upon using a different criteria. For the purpose of presenting oMCM in this paper, we will concentrate on the mountain rescue scenario. Figure 4 shows a typical situation with the mountain rescue scenario, where each search party is geographically dispersed and each is therefore its own distinct AS. In this situation, Inter-AS traffic would be routed to the appropriate AS using oMCM whilst Intra-AS routing would be performed by the MANET routing protocol implemented throughout the MANEMO. Similar to BGP, we propose that oMCM utilises Border Routers that are designated within each AS which establish connections with other Border Routers in other ASs and share Inter AS route information. Again however, because of the mobility aspects, Border Routers in oMCM must be dynamically assigned their role because different NEMOs within an AS may at any time gain or lose an external connection to the wider network or to an Access Network. As well as maintaining and propagating Inter-AS route information, Border Routers also maintain accurate information about other Border Routers within their AS to ensure transit traffic is routed efficiently out of the AS. With the oMCM model it is also important to consider what process should be followed if two distinct ASs converge. A number of different outcomes to this situation can be proposed, this remains an ongoing topic in our research.

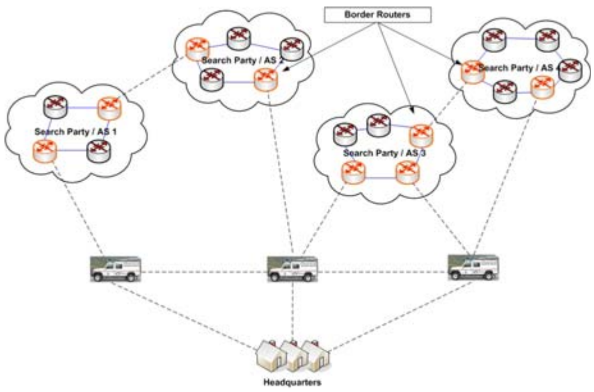

Figure 4: oMCM

6 Conclusion

The purpose of this paper has been to introduce both the concept of combining MANET and NEMO technologies, to produce what has been termed MANEMO solutions and to introduce the scenario that we are generating a MANEMO solution for. In addition we have highlighted what we believe are two distinct approaches to MANEMO which we have termed NEMO-Centric and MANET-Centric MANEMO. Finally, we presented optimised MCM (oMCM) which provides optimisations based on the observation that the mountain rescue team operate in a team based manner because of their operational structure. This structure allows us to aggregate NEMOs together as conceptual ASs based on which search party they are a member of. We are currently in the early stages of developing a working MCM solution based on the concepts presented in this paper.

7 Acknowledgement

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