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NAT-MANEMO: Global Connectivity for MANET Node by Using NEMO and NAT

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Deployment as a post-disaster recovery network has been considered as a typical application of MANET, but MANET is still not widely deployed. One problem deterring MANET adoption is addressing for MANET nodes and their global connectivity. This paper provides a novel IP address usage and operation scheme for the global connectivity of the node in MANET based on NEtwork MObility (NEMO) and Network Address Translation (NAT). We are focusing on address assignment and usage of the care-of-address of a Mobile Router using NAT to provide topologically correct address. We conduct comparative analysis on related work and our proposed solution in terms of 1) the access network involvement, 2) ease of address allocation, and 3) modification to the current specification. The result shows that our proposed solution fulfills all the requirements for the solution of MANET global connectivity issue.

1. Introduction

This paper is motivated by the need to support to deploy instant and temporary network infrastructure with cooperation among mobile nodes in emergency situations such as post-disaster operation. In post-disaster situations, the environment of IP communication is quite different from normal operation. For example, existing infrastructure such as base station of mobile cell-phone, fixed telephone line, or wired Internet connectivity is not available because of disaster. However there is a requirement of communicating in the rescue worker while it is under such compromised conditions. Normally, a private wireless medium may be used to communicate during rescue work; it is often not available because of the distance between the people or the size of coverage area. Moreover, since time resource before the rescue work is limited, the deployment time of the network should be short and operational difficulty should be removed. **Fig. 1** shows a typical topology of the network in disaster situation. Note that a lot of IP node presents here, and requires the connectivity for between among the nodes, and also to the Internet.

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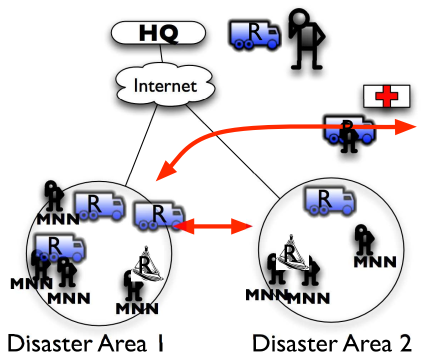

Fig. 1 Rescue work in disaster affected area with lots of mobile nodes.

Considering these situations, Mobile Ad-hoc Network (MANET) can be suitable solution, providing an auto-configured, self-organized network. However, because of the requirements of routing protocol for all of node in MANET, it raises the scalability issues of the number of nodes[1]. Moreover mobility functionality for MANET node is required that comes from the characteristics of wireless node[2]. Mobile IP (MIP)[3] and NEtwork MObility (NEMO)[4] are the solutions for the mobility related requirements.

Moreover, in order to operate a MANET autonomously, dynamic address and prefix assignment for the node is required. However, the problem of providing the connectivity for MANET node from the Internet is pointed out[5].

To satisfy these requirements, MANET for NEMO (MANEMO) was proposed[2]. In MANEMO, a Mobile Router (MR), which provides network mobility, has the ability to communicate on a multi-hop basis. The goal of MANEMO is to provide global connectivity while the nodes around the MR are moving and form a multi-hop topology in a wireless network. Thus it is expected that the mobile router will act as a MANET node while providing the connectivity to Mobile Network Node (MNN).

MANEMO can be a solution of the nested NEMO problem[6)7)], and the global reachability problem for MANET node[8)]. The focus of this paper is to solve the problem of global reachability for MANET nodes, especially targeting the method of address assignment and usage of care-of-address (CoA) of MR.

Our contribution in this paper is that we propose novel IP address usage and operation scheme that achieves the following:

(1) less modification to the component and functionality than other proposal,
(2) ease of address allocation,
(3) less access network involvement.

Our proposed solution uses NAT to provide a topologically correct address for the care-of-address of MR. It eliminates the nested NEMO problem while NEMO provides global connectivity for the client MNN. Since our proposed solution, using NAT, requires the modification only in MR, it achieves less modification to existing network infrastructure than other proposals, that uses tunnel or prefix delegation.

The remainder of this paper is structured as follows. In Section 2, we show our requirements for the solution of MANET global connectivity issue. In Section 3, we describe the problem that we are trying to solve in this paper. In Section 4, we show our proposed solution to tackle the problem. We evaluate the proposal with qualitative analysis in several criteria in Section 5. Finally, in Section 6, we conclude the paper.

2. Requirements

In this section, we set requirements for the solution to be applied to the disaster recovery networking with MANET.

Req-1 The MANET shall be set up as soon as possible when a disaster happens so that nodes inside the MANET can immediately start or resume the communication.
After a disaster happens, rescue workers start to move to the affected area as soon as possible. They requires the communication just after moving, therefore installation time should be short.

Req-2 The MANET nodes shall be addressable with permanent identifier from the nodes inside the Internet.
Not all the network among several disaster areas are connected to the same subnet. It's better to locate a disaster assistance headquarters outside of each disaster area in order to cover multiple disaster areas. Nodes in headquarters should be reachable to the node in MANET.

Req-3 The on-going session shall be continued even when the IGW and Mobile Router change the point of attachment to the Internet.
Each node would move in various ways: there are several locations in disaster situation, headquarters, the affected areas, ambulance, refuges, and road to the another place. If the IP prefix assigned to each location is different, the node changes their IP addresses during the movement. Some application such as VoIP requires the handover functionality under these situations.

Req-4 Modifications to existing networks shall be kept minimum because the disasters happens infrequently.

Req-5 The overhead on the wireless link should be kept low.
Since the resources of a wireless link are limited, the overhead of control packet exchanged between mobile nodes should be minimized, and the packet overhead caused by encapsulated headers should be minimized.

Req-6 Redundant routing path, which may be caused by hierarchical arrangement of Mobile Routers inside MANET, shall be avoided.
Since the application used in rescue operation requires low packet delay, the selected routing path for the communication should be minimized.

Req-7 Modification to the current NEMO[4)] specification should be minimized.
Since the deployment of post-disaster recovery networking covers multiple operational organization, the modification to the current NEMO specification should be minimized if we consider the deployment cost of the solution.

3. Problems on Providing Global Connectivity for MANET Node

In order to satisfy the requirements described in Section 2, the node in MANET should have an address that is unique and reachable from the Internet. However, existing protocols such as NDP (stateless address auto-configuration)[9)], DHCP[10)], DHCP-PD[11)] do not satisfy the MANET requirement because these protocols "as is" could not deal with dynamic, multi-hop and distributed nature of MANET[5].

There are several approaches to tackle this issue, **NAT-based approach**, **Prefix delegation-based approach**, and **NEMO tunnel proxy-based approach**.

3.1 NAT-based Approach

Using Network Address Translation (NAT)[12] provides freedom of assignment of the addresses in a MANET node[13][14]. A MANET node can use any address, including private address, and this un-routable address is translated at the border of MANET and the Internet. This approach satisfies Req-1 and Req-4, however traditional NAT keeps the state of each translation, which is triggered by the packet traversal on NAT device. This state information results in a single point of failure and the prevention of redundant NAT devices[15].

3.2 Prefix Delegation-based Approach

Prefix delegation-based address auto-configuration for MANET node have been discussed in IETF[5]. The goal of this approach is to provide topologically correct address in each MANET node with the interaction of a gateway node that connects to the Access Router. Border Router Discovery Protocol (BRDP)[16] is based on prefix delegation from access network to optimize the route path, and provides topologically correct address for CoA of MR. MIRON[17] is also a solution using prefix delegation model, even though the solution focuses the nested NEMO problem. However, the assignment of topologically correct address for all MANET nodes is hard: the address (prefix) is owned by Access Router, therefore whenever IGW disconnects from the network, Access Router should deactivate this prefix. It causes a prefix flapping problem into the access network. This is because state information should be kept in the access network. This violates Req-4.

3.3 NEMO Tunnel Proxy-based Approach

The tunnel proxy-based approach is proposed for the solution of nested NEMO problem. However, the approach using NEMO can also solve the problem on global connectivity for MANET node.

Unified MANEMO Architecture (UMA)[8] is proposed as a solution of global connectivity issue in MANET node, that is using NEMO. It uses IGW as tunnel endpoint for all of MR in MANET, considering Authentication, Authorization and Accounting (AAA) structure for every MANET node. Light-NEMO[18] is a solution that is targeted at the nested NEMO problem. The IGW provides proxy functionality with advertising their CoA to MR inside nested NEMO clouds, and MR uses this CoA as an alternate CoA to solve the problem of redundant routing path among HAs. Although these solutions based on this approach are not intended to solve the problem of global reachability in MANET node, they can solve this problem with additional functionality of the routing exchange among MRs.

4. NAT-MANEMO

In this section, we propose a new IP address usage and operation scheme, NAT-MANEMO, which solves the problem described in Section 3. In this solution, we use Network Address Translation (NAT) as a key functionality. Although NAT-based approach has several drawback (as show in Section 3), it works well if the scope of the effect of NAT is limited. In our proposed solution, address translation is limited to the address of MR, therefore packets from the end node (MNN) are untouched in this scheme.

4.1 System Overview

Fig. 2 shows system overview of our proposed solution, NAT-MANEMO. In this figure, AR is Access Router that provides global reachability, MR is Mobile Router, MNN is Mobile Network Nodes that attaches to MR, HA is Home Agent, CN is Correspondent Node located in the Internet, and IGW is Internet Gateway that is just an MR playing a special role. MR (IGW) and MNN are deployed after disaster at affected area and all the other parts are existing. The communication between MNN and CN is performed with the interaction of IGW, MR, and HAs based on the NEMO functionality.

4.1.1 Internet Gateway (IGW) Functionality

Whenever MR receives Router Advertisement message (RA) on its egress interface and gets a global routable prefix from an upstream router, it becomes an Internet Gateway (IGW) for the other MRs in MANET.

After changing the role, IGW must accomplish the following operation in addition to NEMO and MANET functionality.

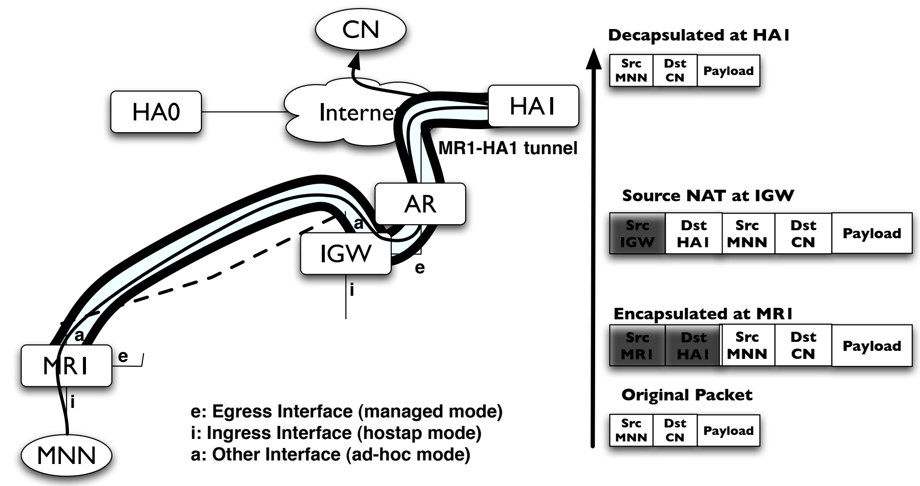

Fig. 2 Overview of NAT-MANEMO. MNN communicates with CN via MR1, IGW, AR, and HA1. HA0 is home agent of IGW, HA1 is home agent of MR1.

(1) Address translation (NAT)
Since each MR has no guarantee to have a global reachable address in our assumption, IGW should perform address translation (NAT) to provide the reachability of the node in MANET.

(2) Care-of-Address advertisement
An IGW should advertise its own CoA using the routing protocol. Instead of using the address of the interface in MR, MR uses this address as its CoA.

(3) The role of IGW advertisement
IGW also should advertise their role of IGW so that MR can recognize to operate NAT-MANEMO functionality. This operation is done by MANET routing protocol.

(4) Collect the address (Care-of-address) of MR
IGW should have an address list of MR in MANET in order to recognize the target of NAT. This operation is also done by MANET routing protocol.

(5) Create MR-HA mapping table
In order to translate the packet from HA to MR, IGW store the MR-HA entry when the Binding Update (BU) packet from MR is translated at IGW. This entry is validated while MR is in the routing table of IGW.

4.1.2 Mobile Router (MR) Functionality

(1) Use CoA of IGW instead of their own address
If MR receives CoA of IGW as a routing message and selects this router as IGW, MR uses this CoA as alternate care-of-address.

(2) New movement detection trigger at MR
Since CoA of MR is borrowed from IGW, movement detection[3], which is handover trigger at MR, is slightly modified. MR should detect the movement not only when CoA of MR is changed, but also selected IGW (or the address of IGW) is changed.

Once MR located under IGW that is notified by the advertisement message of IGW, MR try to register binding information to their HA. To generate binding update message, alternate CoA (Alt-CoA) option is used with the CoA of IGW.

4.1.3 Routing Protocol Operation

In NAT-MANEMO, every MR should run routing protocol to exchange their routing information among MRs. MR may have three wireless interfaces as shown in Fig. 2 and an ad-hoc interface is used to exchange the routing information.

Note that the routing protocol in here is not limited to any specific one. Optimized Link State Routing protocol (OLSR)[19] or Tree Discovery protocol[20] with Network In Node Advertisement (NINA)[21] are good candidate. IGW should have a database such as **Table 1** while the topology is as **Fig. 3**.

4.1.4 Addressing Consideration of MR

The ad-hoc mode interface can be configured with Unique Local Address (ULA)[22] or addressing model using unnumbered interface[23] in order to avoid to use global reachable address, which is our motivation, free to assign the topologically correct address at MR. This address is used as source address for original BU packet and bi-directional tunnel between MR and HA.

Although ULA and unnumbered addressing model does not have any global reachability itself, they can be reachable if IGW translate this address.

4.2 How NAT-MANEMO Works

To present above mentioned function, we use network topology as shown in Fig. 2.

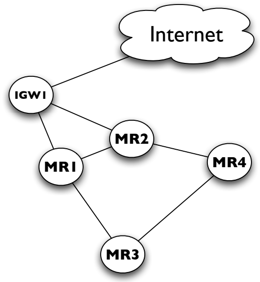

Fig. 3 Example of topology in MANET.

Table 1 Example of routing table at IGW1. IGW should have address list of MR in MANET.

Destination	Nexthop	#Hops
MR1/128	MR1	1
MR2/128	MR2	1
MR3/128	MR1	2
MR4/128	MR2	2

4.2.1 Topology Creation with MANET Routing Protocol

The first step is joining the network and creating a topology in MANET. MANET routing protocol is used to exchange the routing information among MRs (include IGW). When MR becomes IGW, IGW start to advertise their role of IGW and CoA that is obtained from Access Router (AR). MR can select this IGW as an exit point to the Internet. If there is multiple IGW in MANET, this selection is dependent on the metric of routing protocol.

4.2.2 Binding Update from MR

After detecting IGW at MR1, MR transmit Binding Update (BU) packet to their HA (HA1) by using Alt-CoA, which is obtained from IGW. When BU packet traverses IGW, IGW translates the source address of this packet, and record the MR-HA mapping entry in MR-HA table. Note that the payload of BU packet can be protected by IPsec.

4.2.3 Packet Processing at IGW

When the packet is traversed at IGW, IGW performs address translation in order to provide reachability in MANET. **Fig. 4** shows the alternation of the packet between MNN and CN.

- Outbound packet processing
  IGW performs NAT when it receives the packet sourced MR's CoA from MANET. If the source address field of the packet is in the routine table of IGW, IGW recognizes this address is MR's address, then it will be translated to the address of egress interface of IGW.
- Inbound packet processing
  When IGW receives the packet and if this packet comes from HA that is bound to the node in MANET, IGW performs NAT. If the source address field of the packet is in the MR-HA list at IGW, IGW translates the destination address of this packet to the CoA of MR.

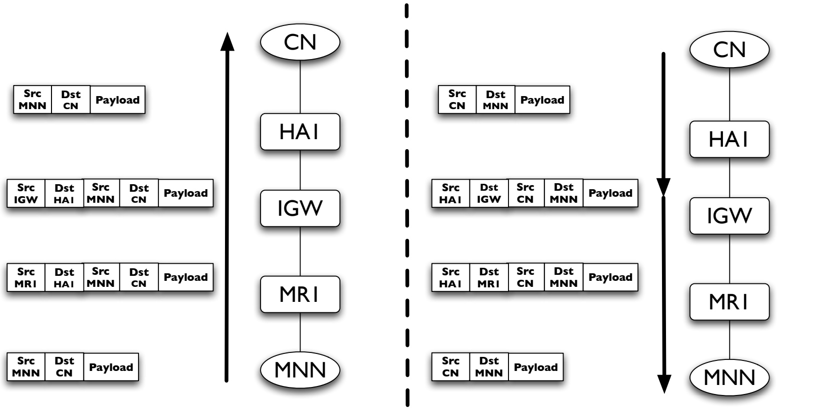

Fig. 4 Packet processing at IGW. Left: Outbound processing, Right: Inbound processing

The benefit of NAT-MANEMO is that only the packet, which source address is MR, is translated at IGW. Note that the packet transmitted by MNN is always encapsulated by their MR, the packet of application running under MNN does not change their original datagram. Therefore, it does not break the application transparency for MNN communication.

5. Evaluation

In this section, we evaluate the proposed solution with existing solution in terms of several criteria. As described in Section 3, the solutions for the global reachability issues for MANET node is categorized as shown in **Table 2**.

5.1 Evaluation Criteria

We consider the following criteria in order to evaluate our proposed solution.

Access Network Involvement

Table 2 Category of the proposed solution.

	Solution
Cat-1) NAT based	NAT-MANEMO
Cat-2) Prefix Delegation (PD) based	MIRON[17]
Cat-3) Tunnel proxy based	UMA[8], Light-NEMO[18]

Since our requirements for disaster networking consider minimum modification to existing network as described in Req-4, access network involvement, which includes any additional configuration for this network deployment or influence on the installation of MANET node, should be avoided.

NAT-based approach provides topology concealment, and it achieves to avoid the involvement of access network. Moreover, tunnel proxy based approach such as UMA[8], Light-NEMO[18], does not require any modification to access network either.

Prefix delegation (PD)-based approach such as MIRON[17] solves nested NEMO problem with assignment of topologically correct address, however since the support of access router is required, the modification to existing network is required. Moreover, as for the nature of MANET, since the node in MANET often moves and disconnects from access network, the delegated prefix for MANET may also be unstable. This makes additional load to the access router.

Table 3 Qualitative analysis of access network involvement.

Solution	Access Network Involvement
NAT-MANEMO (Cat-1)	O
MIRON[17] (Cat-2)	X
UMA[8] (Cat-3)	O
Light-NEMO[18] (Cat-3)	O

Ease of Address Allocation

Ease of address and prefix allocation is one of advantage of network operation. It satisfies Req-1 with auto-configuration or pre-configuration mechanism. PD-based approach requires interaction with access network to assign the address and prefix, therefore address should be allocated at access router. be a solution, however there is a drawback described in Section 3. Using Unique Local Address (ULA)[22] or unnumbered addressing model[23], which uses local owned prefix (e.g., Mobile Network Prefix) as a address of another interface, provides the freedom of these allocation, even though both themselves do not solve the issue of the global reachability without help of other functionality.

Provider independence achieved by the tunnel proxy-based approach allows using such private IP address in MANET node and also provides global reachability.

NAT-MANEMO also achieves the freedom of address usage for CoA of MR, it can be used ULA or unnumbered addressing model.

Table 4 shows the summary of the analysis for these criteria.

Table 4 Qualitative analysis of ease of address allocation.

Solution	Use of ULA	Use of topologically incorrect address (e.g., MNP)
NAT-MANEMO (Cat-1)	O	O
MIRON[17] (Cat-2)	X	X
UMA[8] (Cat-3)	X	O
Light-NEMO[18] (Cat-3)	O	O

Modification to the Current Specification

Using NEMO as a solution of global reachability issue is the motivation of MANEMO[24][8]. On the other hand, NEMO itself has a problem[6] in nested case if we consider our requirements (Req-5, Req-6). There are quite a lot of solutions that target on this problem. However if we consider the deployment in the world, modification of the solution should be minimized according to the Req-7.

PD-based approach is not required to modify the current specification. Just turn on the functionality on MR and IGW and Access Router (AR) are enough.

NEMO tunnel proxy-based solution also provides the optimization for the problem described in Section 3, however the modification to the standard NEMO extends over several component. In Light-NEMO[18] and UMA[8], modifications to MR and HA are required.

NAT-MANEMO only requires the modification to MR. That is, using NAT achieves minimum modification to the entity in the network. This is because the characteristic of NAT itself provides the virtualization as if node in MANET is connected to access network directly.

Table 5 shows the summary of the comparison for these criteria.

Table 5 Required modification to the NEMO functionality component.

Solution	Modification
NAT-MANEMO (Cat-1)	MR
MIRON[17] (Cat-2)	MR
UMA[8] (Cat-3)	MR, HA
Light-NEMO[18] (Cat-3)	MR, HA

5.2 Discussion

Table 6 Requirement achievement.

Solution	Req-1	Req-2	Req-3	Req-4	Req-5	Req-6	Req-7
NAT-MANEMO (Cat-1)	O	O	O	O	O	O	O
MIRON[17] (Cat-2)	X	O	O	X	O	O	O
UMA[8] (Cat-3)	O	O	O	O	O	N/A	X
Light-NEMO[18] (Cat-3)	O	O	O	O	O	O	X

Table 6 shows the satisfactory for the requirements with analyzed proposals. All of proposals are based on NEMO, and achieve the solution of global reachability problem in MANET node. However, the requirement described in Section 2 is achieved only by NAT-based approach, which is our proposed solution. The highlight of advantage of NAT-MANEMO and correspondent requirement are as follows.

- Provider independent address can be used. It relaxes the reservation and allocation of the prefix(es) when the point of attachment of MANET is changed frequently (Req-1).
- NEMO provides the solution for the global reachable addressing issue in MANET node (Req-2).
- NEMO provides session continuity. (Req-3)
- NAT provides topology concealment and it reduces the modification of existing network (Req-4).
- MANET routing protocol eliminates the redundant path in wireless network (Req-5)
- Using topologically correct address for CoA of MR achieves the optimized path among HAs (Req-6).
- Modification to the current MIPv6/NEMO specification only affects the behavior of MR. (Req-7)

According to Table 6, tunnel proxy-based approach also satisfies most of the requirement that NAT-MANEMO does, however it requires the modification in two components, at least, because tunnel is composed by two entity (tunnel endpoints) and modification of one side affects the other. On the other hand, NAT-MANEMO requires only MR-side modification because NAT involves only one component in the network.

The approach taken in our proposed solution uses NAT for the communication of MR. It keeps the transparency for the application in end node (MNN). NAT itself has several drawbacks and history in the Internet, especially in IPv6 protocol. The previous research[15] indicates the possible problem and the requirement for the functionality of NAT. Moreover, NAT can be considered as a method of locator identifier separation (LCID): translated address represents locator in the network, original address represents identifier in the limited location. Of course tunnel also provide the same functionality, the involvement is much more than NAT as we have already described. Further study is required to confirm the harmless and possibilities of NAT with additional evaluation. We decided to address it in future work.

6. Conclusion

We propose a novel solution, NAT-MANEMO, for the global reachability issue of MANET node, and analyze the proposed solution with existing approach. The aim of NAT in this paper is using topologically correct address for CoA of Mobile Router. We found that existing approaches have already solved the problem themselves, however our proposed solution achieves the followings: 1) less modification to the component and functionality than others, 2) ease of address allocation and 3) less access network involvement. Consequently, the proposed solution fulfills the all the requirements that we should consider for the solution of our disaster recovery networking scenario.

As for future work, we plan to extend the evaluation of this solution with the implementation of software, and show the proof of concept with regard to

NAT effect. We also hope to perform the quantitative analysis with in-field experimentation for the reason of the deployment.

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