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Host Identity Protocol based NEMO solutions: An evaluation of the signaling overhead

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***Abstract*—With the goal of solving shortcomings of MIPv6, alternative protocols such as HIP have been proposed by the research community. In the same way as for MIPv6, solutions to cover NEMO scenarios based on HIP have been worked out. However, there is little agreement on which the best way is to handle NEMO scenarios when using HIP. In this work we analyze different HIP based NEMO solutions and define mathematical models for their analysis. These models are utilized for evaluating the signaling overhead of HIP based NEMO protocols in order to provide insight in the specification of the features a HIP based NEMO solution should fulfill.**

***Index Terms*—Network Mobility, HIP, signaling overhead**

I. Introduction

RECENTLY, alternative solutions for managing the mobility have been defined to overcome main limitations of MIPv6: lack of security support and suboptimal routing. One of the most significant solutions is the Host Identity Protocol (HIP) [1].

The HIP protocol is an end-to-end (e2e) security association establishment protocol that aims at integrating security, multihoming and mobility management. The cornerstone of HIP is the separation of nodes location and identifier by means of introducing a new namespace, named Host Identity (HI), for identifying nodes. The protocol defines a Base Exchange (BEX) to establish a Security Association (SA) together with a signaling exchange to update this association through UPDATE messages. Due to its characteristics, it can be exploited to support mobility in an elegant way compared to the *de facto* MIPv6 solution.

Besides the usage of HIP to manage the mobility of single hosts, solutions that outperform the MIPv6 based NEtwork MObility (NEMO) Basic Support protocol (NEMO BS) [5] to address NEMO scenarios have been proposed: [2], [3], [4]. Each of these protocols define different approaches being little agreement on the best way to handle this scenarios. Therefore, this work presents an evaluation of the aforementioned outstanding HIP based NEMO solutions. In order to do so, a mathematical model is worked out which is utilized to compute signaling overhead. Our goal is to provide additional criteria to handover performance to give insight in the specification of the features a HIP based NEMO solution should fulfill.

II. HIP based NEMO protocols

The provision of NEMO support based on an e2e protocol is not straightforward. One of the main issues to be addressed is how nodes located inside the NEMO, Mobile Network Nodes (MNNs), are reached. Being MNNs identified by their HIs, whether MNNs are reached by means of their globally routable and reachable locators, or whether MR's globally routable and reachable IP address is utilized should be determined. Furthermore, an additional entity to enable MNNs reachability may be utilized, the RendezVous Server (RVS).

Another issue when covering NEMO scenarios using e2e mobility management protocols is the manageability. In large NEMOs managing independently all e2e associations between MNNs and correspondent nodes (CNs) will result in an increased complexity. Consequently, delegation of signaling rights between the MNNs and the MR is assumed by the HIP based NEMO protocols. However, as confidential data is generated during the e2e HIP association establishment, how these data is maintained unrevealed when delegation of signaling rights is applied should be solved. That is, security related issues arise related to delegation.

A. The IETF solution

The solution proposed by the IETF for solving NEMO scenarios [2] does not consider the utilization of new entities to provide reachability of MNNs.

First, MNNs register themselves in the MR. After this registration phase, MNNs delegate their signaling rights to the MR to authorize the MR to perform signaling exchanges on behalf of them. In order to do so, the MNN provides an authorization ticket to the MR.

As this solution recommends a link-local or unique local address space in the NEMO, the MR has to carry out address translation, from public addresses to private addresses and vice versa.

Regarding mobility management, when the MR changes its point of attachment it sends a NOTIFY message to all MNNs in the NEMO informing about its locator change. This information is used for notifying layers above IP layer the handover process. The MR also performs an UPDATE exchange with every CN associated with a MNN. As the UPDATE exchange is triggered by the MR but MNN's HIT

is placed as the source node, a new message type (PROXY-UPDATE) is defined for distinguishing this update process from an e2e update process carried out between the MNN and the CN. Figure 1 shows the flow chart of this solution.

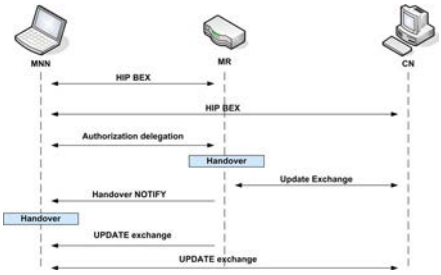

Fig. 1. IETF flow chart

B. Optimized IETF solution

This solution [3] is an extension of the IETF solution. Main goals of this solution are to minimize the signaling sent over the wireless link, and the mitigation of renumbering events, not sacrificing Route Optimization advantages. In order to do so, this approach proposes utilizing on-the-path signaling proxies located in the wired network to reduce wireless bandwidth consumption.

When a MNN enters the NEMO, it authorizes the MR to carry out signaling purposes on behalf of it, while the MR further authorizes a signaling proxy. When the MR handoffs, it carries out a single UPDATE exchange with its signaling proxy. This signaling proxy further notifies the received update information to the CNs.

As CNs may also use wireless access technologies, this solution also considers the scenario where CNs delegate their signaling rights to a proxy in the fixed network. In this way, when the MNN changes its locator or decides to rekey, it exchanges update messages with the signaling proxy of the CN instead of the CN itself. Figure 2 shows the flow chart of this solution.

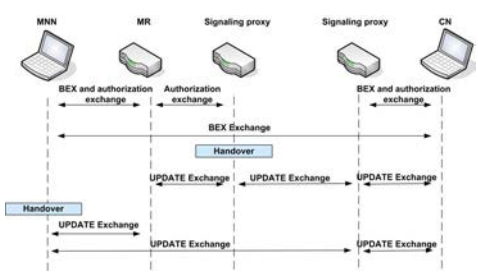

Fig. 2. Optimized IETF flow chart

C. The HIP-NEMO solution

Another oustading HIP based NEMO solution is the defined in [4], named HIP-NEMO. This approach defines an entity, the mobile RVS (mRVS), which has not only the role of an MR but also of a RVS. As in nature it is a mobile entity, the mRVS itself is registered in a RVS. In order to provide global reachability, MNNs will be registered in the RVS by the mRVS. It is worth pointing that this solution is the only approach covering the scenario where the Initiator (the node that initiates the communication) is in the outside network.

In this solution MNNs own globally routable and reachable addresses. However, the mRVS performs an address translating process for each packet. When the mRVS changes its point of attachment it acquires a new prefix and assigns a new topologically correct IP address to each MNN, but no renumbering takes place in the NEMO. The MR sends an update message to the CNs associated with the MNNs and to the RVS with the new prefix. Updating mRVS's prefix with a single message results in updating the locators of all MNNs that are behind the mRVS and registered in the RVS. Notice that although a globally routable addressing scheme is defined for MNNs, the reachability of MNNs is based on mRVS's IP address instead of MNNs'. Figure 3 shows the protocol flow chart.

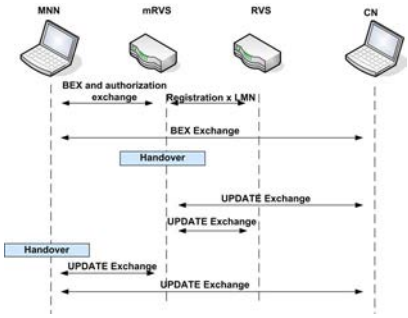

Fig. 3. HIP-NEMO flow chart

III. Modeling HIP based NEMO protocols

In this section we define the mathematical models based on previous works [2], [6] for analyzing HIP based NEMO solutions in terms of the signaling overhead, which is a relevant parameter for evaluating signaling protocols.

The total signaling overhead for a generic HIP based NEMO protocol consists of: Φ_{SA}, $\Phi_{UPDATE_{MR}}$ and $\Phi_{UPDATE_{MNN}}$. Φ_{SA} is the total signaling cost of the HIP association establishments, where the initialization overhead ($\Phi_{SA_{init}}$) and e2e SA establishment overhead ($\Phi_{SA_{e2e}}$) are considered, $\Phi_{UPDATE_{MR}}$ is the signaling overhead of NEMO mobility management when the MR changes its point of attachment and $\Phi_{UPDATE_{MNN}}$ is the signaling generated by the MNN when it updates its associations.

Signaling overhead contributions associated to mobility events are related to how often these mobility events occur. Therefore, in order to consider these rates, the residence time in a network has to be taken into account. We define T_{rMR} as an exponentially distributed parameter with mean value $1/\lambda_{rMR}$ for modeling the residence time of the NEMO in a certain network, and T_{rMNN} as the time between UPDATE messages generated by the MNN with mean value $1/\lambda_{rMNN}$.

Regarding scalability issues, the average number of nodes is introduced in the mathematical formulation. N_x denotes theses parameters, where x denotes each note type: MNN, CN,

RVS or CN's proxy. It is worth pointing that whenever a user requests a communication establishment with a different CN, a new HIP association has to be established. Thus, we define a Poisson distribution model for connection query arrival modeling, with mean value λ_{SA}. Consequently, the average number of CNs per MNN is given by $N_{CN} = \lambda_{SA} T_{rMNet}$, where T_{rMNet} is the residence time of the MNN in the mobile network.

The distance in terms of number of hops between nodes should be defined in order to introduce scenario characteristics. D_{MNN-CN} is the average number of hops between MNNs and CNs, while D_{MR-RVS} s the average number of hops between the MR and the RVS.

With the aim of studying the impact of the protocol in the network, transmission costs are taken into account while processing costs in the endpoints are not considered [6]. These weights are denoted as ρ_x, where x denotes wireless (W), local (L), core (C) or wireless local (WL).

Packet sizes are also specified in the model, S_{xi}, where x stands for packet type and i is given for the packet number.

For the sake of simplicity, we consider a single hop between every MNN and the MR, and between the MR and its point of attachment. The CN and the RVS are located in local area networks, in a two hop distance from the core network.

A. The IETF solution model

In order to have MNNs registered in the MR, an initialization signaling is required which is modeled by means of the following expression:

$$\phi_{SA_{init}} = \phi_{SA_{MNN-MR}} = N_{MNN}\rho_{WL}(S_{I1} + S_{R1} + S_{I2} + S_{R2}) \quad (1)$$

Whenever a MNN requests a communication with a new CN, a HIP SA is established between the MNN and the CN. In addition, delegation of signaling rights between the MNN and the MR is carried out providing the MNN an authorization ticket to the MR. Notice that this ticket is only valid for a single HIP SA, as it is derived from the keying material agreed e2e. Consequently, the signaling overhead associated to ticket delivery, $\phi_{SA_{ticket}}$ is also modeled. Therefore, the signaling overhead of the e2e HIP association establishments is given by:

$$\phi_{SA_{e2e}} = \phi_{SA_{MMN-CN}} + \phi_{SA_{ticket}} \quad (2)$$

where $\phi_{SA_{MNN-CN}}$ is the HIP SA establishment signaling cost between the MNN and the CN:

$$\begin{aligned}\phi_{SA_{MNN-CN}} = & \\ & N_{MNN}[(D_{MNN-CN} - 3)\rho_C + \rho_W + \rho_L + \rho_{WL}] \\ & \times\lambda_{SA}(S_{I1} + S_{R1} + S_{I2} + S_{R2}) \end{aligned} \quad (3)$$

and ϕSA_{ticket} is denoted by:

$$\phi_{SA_{ticket}} = N_{MNN}N_{CN}\rho_{WL}\lambda_{SA}S_{ticket} \quad (4)$$

Regarding the mobility management of the NEMO, whenever the MR changes its point of attachment, it carries out an update exchange with the CN and sends a notify message to the MNNs. The signaling overhead is computed as shown next:

$$\begin{aligned}\phi_{UPDATE_{MR}} = & \\ & N_{MNN}N_{CN}\lambda_{rMR}[(D_{MNN-CN} - 3)\rho_C + \rho_W + \rho_L] \\ & \times(S_{U1} + S_{U2} + S_{U3}) \\ & N_{MNN}\lambda_{rMR}\rho_{WL}S_{NOTIFY} \end{aligned} \quad (5)$$

When a MNN changes its address due to mobility events inside the NEMO it sends UDPATE messages. In addition, if this MNN decides to rekey its association, UDPATE messages have to be sent in an e2e basis. This UPDATE exchange should create a state in the MR for carrying out the NAT process, thus, it is necessary to notify the newly acquired address to the MR. Next, the related signaling overhead is modeled:

$$\begin{aligned}\phi_{UPDATE_{MNN}} = & \\ & N_{MNN}N_{CN}\lambda_{rMNN}[(D_{MNN-CN} - 3)\rho_C + \rho_W + \rho_L + \rho_{WL}] \\ & \times(S_{U1} + S_{U2} + S_{U3}) + \\ & +N_{MNN}\rho_{WL}\lambda_{rMNN}(S_{U1} + S_{U2} + S_{U3}) \end{aligned} \quad (6)$$

B. The Optimized IETF solution model

In this solution the CN first registers itself in its signaling proxy. During this registration the CN also delegates its signaling rights to the proxy using a self-signed certificate in the exchange. Therefore, the initialization signaling overhead is computed as:

$$\phi_{SA_{init}} = \phi_{SA_{CN-proxy}} + \phi_{SA_{MNN-MR}} + \phi_{SA_{MR-proxy}} \quad (7)$$

where $\phi_{SA_{CN-proxy}}$ is the signaling overhead of the HIP association establishment and authorization exchange between the CN and its proxy, computed as:

$$\phi_{SA_{CN-proxy}} = N_{CN}\rho_L(S_{I1} + S_{R1} + S'_{I2} + S_{R2}) \quad (8)$$

and $\phi_{SA_{MR-proxy}}$ is the signaling overhead associated to the delegation of signaling rights process between the MR and its proxy, which is driven by:

$$\phi_{SA_{MR-proxy}} = N_{MNN}\rho_W(S_{I1} + S_{R1} + S'_{I2} + S_{R2}) \quad (9)$$

where S'_{I2} is the packet where the certificate chain is placed. The expression of $\phi_{SA_{MNN-MR}}$ equals to (1), but the certification chain is considered when computing the length of the I2 packet instead of the ticket. In the same way as the IETF solution model, whenever a new HIP association is requested the required signaling denoted with $\phi_{SA_{e2e}} = \phi_{SA_{MNN-CN}}$ which equals to (3) is included.

When the NEMO carries out a mobility event and changes its point of attachment, it notifies the new address to its signaling proxy. Afterwards, this signaling proxy forwards the update to CNs' proxies. Next, the expression of this signaling cost is shown:

$$\begin{aligned}\phi_{UPDATE_{MR}} = & \\ & \rho_W\lambda_{rMR}(S_{U1} + S_{U2} + S_{U3}) + \\ & +N_{CN-proxy}[(D_{MNN-CN} - 3)\rho_C]\lambda_{rMR}(S_{U1} + S_{U2} + S_{U3}) + \\ & +N_{CN}\rho_L\lambda_{rMR}(S_{U1} + S_{U2} + S_{U3}) \end{aligned} \quad (10)$$

where $N_{CN-proxy}$ is the number of signaling proxies of CNs. In this solution, whenever the MNN decides to update the e2e association due to mobility, it sends update messages to CNs' signaling proxies instead to CNs. Each signaling proxy forwards received messages to the CNs. In addition, it also performs an update exchange with the MR. The expression for this signaling is shown next:

$$\begin{aligned}\phi_{UPDATE_{MNN}} = \\ & N_{MNN}\rho_{WL}\lambda_{rMNN}(S_{U1}+S_{U2}+S_{U3}) + \\ & +N_{CN-proxy}[(D_{MNN-CN}-3)\rho_C+\rho_W+\rho_{WL}] \\ & +N_{CN}\rho_L\lambda_{rMNN}(S_{U1}+S_{U2}+S_{U3})\end{aligned} \tag{11}$$

C. The HIP-NEMO solution model

In this solution MNNs are registered in the RVS in order to provide reachability from the outside network. Consequently, the initialization signaling overhead of the HIP association establishment is expressed as follows:

$$\phi_{SA_{init}} = \phi_{SA_{MNN-MR}} + \phi_{regRVS} \tag{12}$$

where ϕ_{regRVS} denotes the registration overhead of MNNs in the RVS. Notice that the mRVS is in charge of performing this registration, consequently, the signaling overhead of the process is computed as:

$$\phi_{regRVS} = N_{MNN}[(D_{MR-RVS}-2)\rho_C+\rho_W+\rho_L](S_{I1}+S_{R1}+S_{I2}+S_{R2}) \tag{13}$$

where $\phi_{SA_{MNN-MR}}$ equals to (1) and the e2e HIP association establishment between MNNs and CNs ($\phi_{SA_{e2e}} = \phi_{SA_{MNN-CN}}$) is computed following the expression (3).

When the NEMO changes the prefix where it is reachable at, the mRVS updates the information in the RVS. In addition, the mRVS informs the CN about the new location of the MNN. The signaling load generated as a result of changing the prefix of the NEMO is the following:

$$\begin{aligned}\phi_{UPDATE_{MR}} = \\ & N_{MNN}N_{CN}[(D_{MNN-CN}-2)\rho_C+\rho_W+\rho_L] \\ & \times\lambda_{rMR}(S_{U1}+S_{U2}+S_{U3}) + \\ & +N_{RVS}[(D_{MR-RVS}-2)\rho_C+\rho_W+\rho_L] \\ & \times\lambda_{rMR}(S_{U1}+S_{U2}+S_{U3})\end{aligned} \tag{14}$$

Although this solution does not consider isolated update messages sent by the MNNs, if the MNN decides to rekey its associations for instance, the signaling cost of these events would be the following:

$$\begin{aligned}\phi_{UPDATE_{MNN}} = \\ & N_{MNN}\rho_{WL}\lambda_{rMNN}(S_{U1}+S_{U2}+S_{U3}) + \\ & +N_{MNN}N_{CN}[(D_{MNN-CN}-2)\rho_C+\rho_W+\rho_L+\rho_{WL}] \\ & \times\lambda_{rMNN}(S_{U1}+S_{U2}+S_{U3})\end{aligned} \tag{15}$$

IV. Analytical Results

In order to specify residence times for the MR and MNNs, we assume a fluid flow mobility model [1]. For the sake of simplicity, we consider squared cells with perimeter $l(m)$ and node velocity $v(m/s)$ moving in uniformly distributed directions in the range $[0, 2\pi]$. In addition, we assume that the population density of the nodes in a cell is $\rho(nodes/m^2)$. Therefore, the cell crossing rate is given by [1]: $R_{cross} = \frac{\rho v l}{\pi}$.

Regarding the association updating frequency, we consider that mean values of residence times are modeled by cell crossing rates. Therefore, the time between UPDATE message sending by the MNNs and the MR is the following: $\frac{1}{\lambda_{rMR}} = \frac{1}{\lambda_{rMNN}} = \frac{1}{R_{cross}} = \frac{\pi}{\rho v l}$

Based on previous works [7], [8] we assume the following values for defining the coverage areas (m) and velocities of nodes (Km/h): $l_{NEMO_{access}} = 5000, v_{NEMO} = 60, l_{NEMO} = 360, v_{MNN} = 4.824$. We also consider that the density of the MNNs in the cells is $\rho_{MNN}(nodes/m^2) = 0.002$ [9] and that the density of NEMOs in the wireless access cell is $\rho_{NEMO}(NEMO/m^2) = 0.0004$.

For the HIP protocol, we assume the mandatory cryptographic suite [1]. Therefore, next values are considered for HIP packet sizes (Bytes): $S_{I1} = 40, S_{R1} = 656, S_{I2} = 852, S'_{I2} = 996, S_{R2} = 212, S_{U1} = 184, S_{U2} = 84, S_{U3} = 88, S_{ticket} = 95$. We consider that the rate of new HIP association establishment process is represented with a Poisson process with mean value $\lambda_{SA} = 0.4$ [6].

Regarding proportionality constants that model the transmission costs in different link types we consider the following values: $\rho_W = 4, \rho_C = 2, \rho_L = 1, \rho_{WL} = 1$ [9]. Selected values for the number of hops are $D_{MNN-CN} = 35$ and $D_{MR-RVS} = 17$.

1) Initialization and HIP association establishment signaling overhead: For computing the signaling cost associated to the HIP association establishment for initiating the scenario, we have considered up to 100 MNNs and single CN.

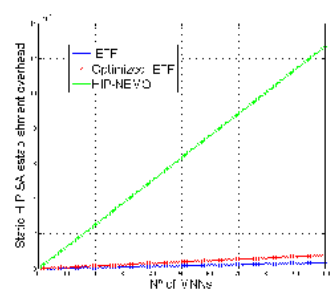

Fig. 4. Number of MNNs vs initialization signaling overhead

Figure 4 shows that the protocol that requires the highest amount of signaling is HIP-NEMO, generating more than 97% of signaling compared to the IETF solution. This is because unlike the IETF approach, MNNs in the HIP-NEMO solution are registered one by one in the RVS to be reachable from the Internet.

2) NEMO mobility management signaling overhead: In order to evaluate the signaling overhead when the MR changes its point of attachment, generated bytes per handover of the MR are computed. We assume that up to 100 MNNs are present and that each MNN is connected to up to 100 CNs. Figure 5 shows the signaling overhead when the MR changes its point of attachment. The resultant signaling overhead of the

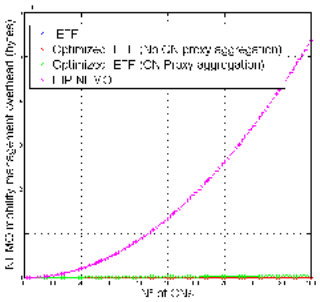

Fig. 5. Number of CNs vs MR's handover signaling overhead

MR's handover by the IETF and the HIP-NEMO solutions is almost the same and significantly higher than the signaling of the Optimized IETF solution. The functional difference between IETF and HIP-NEMO solutions resides in the update exchange performed by the MR with the RVS notifying the new prefix.

In order to study the impact of aggregating the signaling in a single proxy for the CNs, we have considered the scenarios where all the CNs have delegated their signaling rights to the same signaling proxy, and the scenario where each CN has its own signaling proxy. Figure 6 shows this effect.

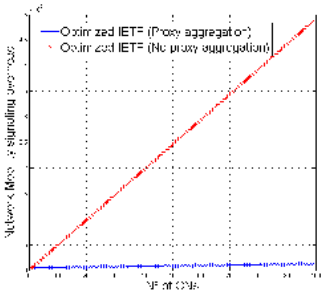

Fig. 6. Number of CNs vs NEMO management overhead

Results demonstrate that the signaling overhead can be reduced in 96% if a single signaling proxy is present. However, the scenario where several signaling proxies are present is considered more realistic because signaling proxies are required to be on-the-path and connections are likely to be established with CNs located in different geographically distributed networks.

V. Conclusions

In this work we have analyzed HIP based NEMO solutions [2], [3], [4] to present the different approaches each solution defines for addressing NEMO scenarios. We have also provided analytical models fitting each HIP based NEMO solution. These models are a basic tool for evaluating and comparing the different solutions. Therefore, being little agreement on which the best way to handle this scenarios is, our goal has been to provide insight in the specification of an efficient in terms of signaling overhead HIP based NEMO protocol.

From the study, we can conclude that registering the MNNs in the RVS to have them reachable from the outside network results in significant signaling overhead. So, a trade-off between MNNs reachability and the amount of signaling is required. If reachability of MNNs is selected, the IP address to be stored in the RVS as the location of the MNNs has to be defined. Notice that the addressing scheme of the mobile network is involved in this issue. If MNNs are reachable in their globally routable IP addresses, renumbering will take place increasing significantly the signaling to update the location in the RVS. On the other hand, if private addressing is used in the mobile network, address translation has to take place in the MR. So, when the MR changes its point of attachment, a single HIP update exchange is required with the RVS, but a state per HIP association is demanded.

We have also observed that delegating signaling rights to a proxy on the wired network is interesting to reduce the signaling overhead, but the on-the-path requirement makes difficult its implementation. In addition, the on-the-path requirement of the MR's signaling proxy is challenging because the mobile nature of the network requires complex security frameworks to manage the right delegation.

In conclusion, as a trade-off is required for defining aforementioned issues, the NEMO scenario characteristics and user demands will be the basis to design the functionalities of the most suitable HIP based NEMO approach.

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