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A Study on NEMO-partially DMM based E2E Seamless Data Integration Transmission Scheme in SOC Public Infrastructures

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Abstract

Nowadays, distributed mobility management (DMM) approaches have been widely adopted to address the limitations of centralized architectural methods to support seamless data transmission schemes in wireless sensor networks. This paper deals with the end-to-end (E2E) integration of Network Mobility (NEMO) basic support protocol in distributed wireless sensor network systems in structural health and environmental monitoring of social overhead capital (SOC) public infrastructures such as bridges, national highways, tunnels, and railroads. The proposed scheme takes advantage of the features of both the NEMO basic support protocol and partially distributed network-based DMM framework in providing seamless data transmission and robust mobility support. The E2E seamless data transmission scheme allows mobile users to roam from fixed-point network access locations and mobile platforms (i.e., vehicles such as cars, buses, and trains) without disconnecting its current sessions (i.e., seamless handover).

Keywords: *E2E, SOC public infrastructures, partially DMM, NEMO, seamless data transmission*

1. Introduction

The decentralized or distributed wireless sensor architectures have been widely adopted for deployment and become a robust solution for the limitations imposed by centralized and hierarchical mobility management schemes for heterogeneous wireless networks. The centralized and hierarchical mobility management architectures lead to well-known bottlenecks and single-point of failure issues when data traffic increases significantly. In addition, the centralization of both the control and data plane functions at the central mobility anchor introduces scalability issues and sub-optimal routing paths between the mobile nodes (MNs) and their corresponding nodes (CNs) [1].

To optimize such distributed wireless sensor architectures, various mobility management schemes and optimizations have been developed to support the performance of DMM functionalities. The DMM key concept is to decouple the control and data plane functions and distribute the mobility anchors among network entities and deploy closer to the MNs [2][3]. DMM based wireless sensor architectures provide a promising scheme to address a rapidly increasing volume of data traffic over mobile networks as the scheme alleviates

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the allocation of network resources and the data traffic is better distributed among the network entities, thus improving the network system scalability and reliability. These advantages make DMM an appropriate model for designing robust wireless sensor architecture for structural health monitoring (SHM) of SOC public infrastructures [4][5].

The NEMO basic support protocol on the other hand refers to client-based mobility (i.e., router) of an entire network (i.e., mobile network) aiming to address the transparent internet access requirement from moving vehicles [6]. The mobile access router (MAR) in this case takes care of the mobility management that includes mobility signaling and tunnel setup on behalf of all the mobile network nodes (MNNs) connected to the mobile network. However, NEMO inherits the limitations exhibited by the standard mobile internet protocol version 6 (MIPv6) in addition to having its own drawbacks. Thus, NEMO optimizations will be essential to alleviate its performance whenever utilized in data transmission schemes for the SHM system of SOC public infrastructures (e.g., bridges, national highways, tunnels, railways).

This paper deals with the integration of NEMO to support the E2E seamless data transmission for partially distributed wireless sensor architecture on SHM of SOC public infrastructures. It aims to leverage the advantages of the NEMO protocol for moving users and vehicles and partial DMM solutions in enhancing the mobility handovers and signaling capabilities. This transmission scheme will be designed to provide connectivity for devices from fixed geographical locations as well as for mobile platforms. It will allow mobile devices to move between fixed access point locations and mobile platforms while keeping its ongoing sessions, that is, without involving in the signaling operations for the handover procedures.

The rest of this paper is organized as follows: Section 2 outlines the related works; the design for the seamless data transmission scheme in SHM systems for SOC public infrastructures is presented in Section 3; the discussions on the comparative analysis among data transmission schemes were discussed in Section 4; and the concluding remarks in Section 5.

2. Related Works

Mobility management will be essentially important for the design of a robust data transmission scheme for SHM of SOC public infrastructures. The NEMO basic support protocol is an extension of the standard MIPv6 that enables entire networks (i.e., moving vehicles) to move between heterogeneous wireless access points while maintaining its network connectivity. The IP addresses of the MNNs belong to the mobile network prefix (MNP) which is anchored at the home agent (HA) of the MAR [6]. Contrary to MIPv6, the MAR takes the role of the MN in performing the mobility management functions such as sending binding updates. The MNNs attached to the MAR were not aware of the network's mobility as it receives data packets only from the MAR.

The flow of data traffic in NEMO is depicted in Figure 1 where IP packets from CNs were tunneled through the HA to the MAR before being delivered to the MNN. Using the standard routing, the MNN sends data traffic back to the CN through the same bidirectional tunnel from the MAR to the HA.

Aside from the inherited limitations of NEMO basic support protocol from the standard MIPv6, it also provides its own drawbacks as it does not provide seamless connectivity. Incorporating route optimization mechanism in NEMO may affect its performance in vehicular situations and results in longer handover latency. The traffic flow path traversed by data packets sent by the correspondent nodes (CNs) to the MNNs may result in suboptimal routing since the data packets need to go through one or more bidirectional tunnels between the HA and the MAR (i.e., CN and the mobile network were topologically close and were far away from the HA). In addition, since all data packets going to or from the mobile network are required to pass through the HA, it creates a bottleneck. Moreover, encapsulating data packets that go through one or more bi-directional tunnels results in header overhead or increased data packet sizes which increase fragmentation chances and reduce bandwidth efficiency. The number of encapsulation and decapsulation processes also requires additional processing at the HA and MAR which can increase the handover latency. Furthermore, additional delays can be incurred by router discovery procedures which also include obtaining a Care-of Address (CoA) and HA registration as the MAR moves from one network to another. Thus, in order to address the limitations of the NEMO protocol, various optimizations were designed and proposed.

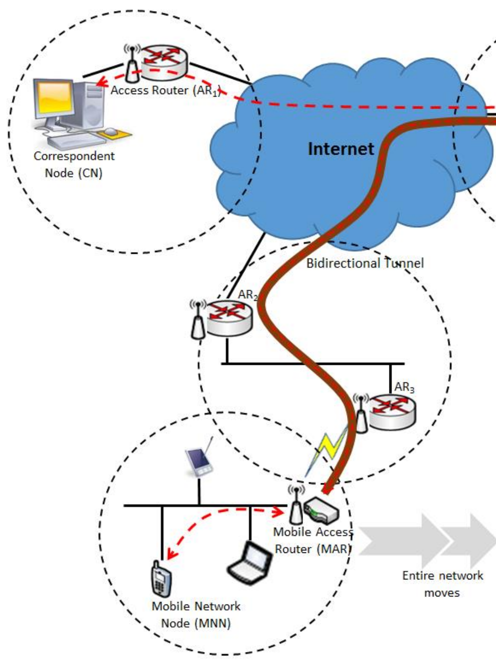


Figure 1. NEMO Basic Support Protocol General Architecture

The NEMO handover efficiency can be enhanced through optimistic Duplicate Address Detection (DAD) which aims to reduce address configuration delays in the successful DAD case as well as to reduce disruption as much as possible in the failed DAD case [7]. It has introduced a new address state "Optimistic" which will be used to mark an available for use address and has not completed a DAD process.

The NEMO-enabled Proxy MIPv6 (N-PMIPv6) architecture proposed in [8] has fully integrated the mobile networks into the localized mobility domains (LMDs). In this architecture, the MNNs will be provided with connectivity either from fixed locations or using mobile platforms such as vehicles (e.g., trains, buses, etc.). MNNs can also be able to move between fixed locations and mobile platforms, thus, better integration of mobile networks has been achieved. While roaming between fixed and mobile platforms, MNNs keeps the same IP address. Since the N-PMIPv6 is based on the PMIPv6 mobility management which is a network-based approach; it has addressed the limitations incurred by the host-based mobility management protocols. However, the NPMIPv6 inherits the drawbacks of centralized architectures which will be crucial in the implementation of structural monitoring for SOC public infrastructures.

The NEMO enabled PMIPv6 mobility management support for efficient information transmission in SHM systems for SOC public infrastructures also incurs the limitations exhibited by centralized architectures for wireless sensor systems [9]. Although the scheme has allowed mobile devices to roam between mobile network platforms and fixed-mobile access gateways (MAGs), the routing of packets, location discovery, handover management, and other mobility management processes were handled by central entities (i.e., MAGs and local mobility anchors (LMAs)). Thus, this scheme also inherits the drawbacks that centralized wireless sensor systems have incurred.

To address the limitations of centralized mobility management schemes, the distributed mobility solution based on NEMO for mobile internet protocol (MIP) networks was proposed [10]. The scheme has taken advantage of the features of a fully distributed DMM model where the control and data planes were both distributed among the HAs. The mobility anchors (i.e., HAs) were placed closer to the edge of the network to enable optimal routing and reduce the delays. This scheme has been based on multiple HA concepts to provide optimal routing, no triangular routing, and no public key algorithm invocations whenever the MAR attaches to its home network. In spite of these features, the MNNs require additional signaling processes as they participate in the mobility management procedure as the architecture deployment is considered to be a host-based approach.

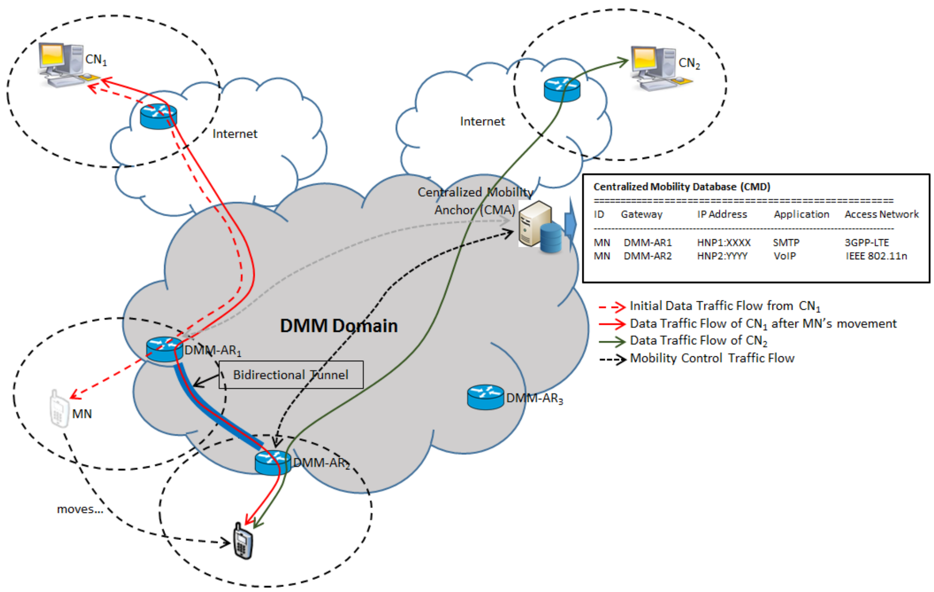
The partially distributed DMM model was utilized in the proposed information transmission scheme in [11] where the data and control planes were decoupled. The data plane was distributed in the mobility anchors placed at the edge of the network closer to the users while the control plane remains centralized and manages the mobility of MNs and routing of data traffic. The scheme has addressed the drawbacks incurred by fully centralized mobility management systems as well as the signaling overhead limitations of host-based protocols. However, this scheme does not provide NEMO support to allow an entire network to move between domains which is essential in SOC infrastructures where moving networks were common.

Thus, in order to address the issues being raised in the previous works, this paper leveraged the features of the NEMO basic support protocol to provide mobility support whenever an entire network moves between network domains. The proposed scheme will also allow the MNs to roam between fixed network domains and mobile network domains. This will be implemented through the utilization of a partially distributed DMM model where the control plane remains centralized to store the mobility sessions of MNs and control the routing of data traffic while the data plane is distributed (i.e., edge routers) and responsible for data forwarding.

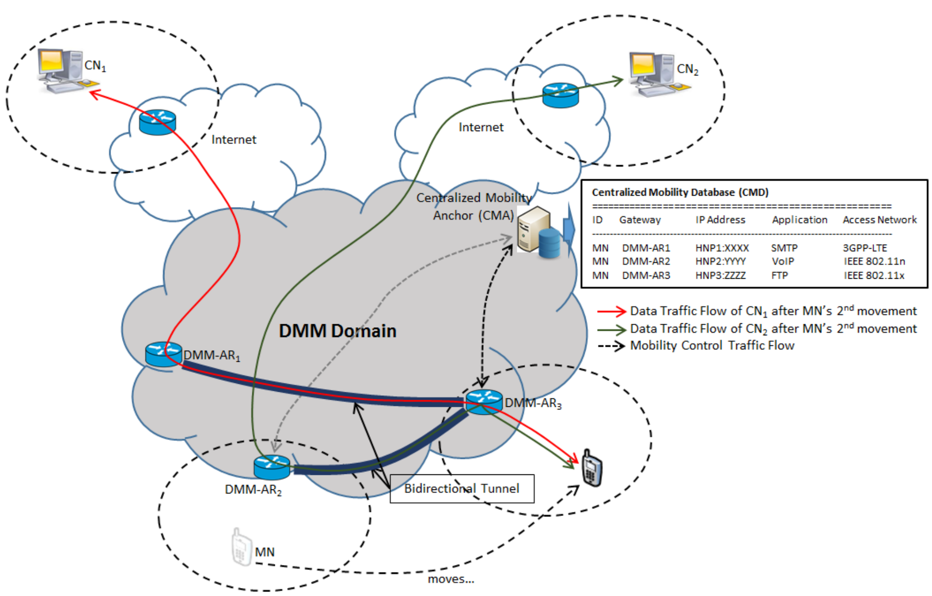
3. Design for the E2E Seamless Data Transmission Scheme

The proposed seamless E2E data transmission scheme for structural health and environmental monitoring of SOC public infrastructures will be based on the partially DMM architecture with NEMO basic support. The DMM based architectures were designed to minimize or even eliminate the limitations of centralized mobility management schemes through deploying mobility anchors at the edge of wireless networks making them closer to the mobile users [12]. The partially distributed mobility management architecture decouples the data plane from the control plane. The data plane will be responsible for all functions and processes that routes data traffic from one interface to another based on the control plane logic. The data plane is distributed in the mobility anchors which were located very close to the mobile user terminals (i.e., one hop) to provide optimal routing of structural health and environmental information. On the other hand, the control plane is kept centralized and was responsible for all functions and processes which determine which path to route the data traffic. The control plane conveys the required information in establishing and controlling network connectivity. It is responsible for handling seamless mobility handovers between access networks for user mobile terminals. In addition, the control plane is responsible for routing or determines how data traffic can be forwarded.

The partially DMM architecture is depicted in Figure 2 showing the distributed data plane and a centralized control plane. The MNs will not be involved in the location update and registration processes as the proposed approach is network-based and such responsibilities are allocated to the centralized mobility anchor (CMA) as part of the control plane. In Figure 2(a), the MN's movements will be detected and receive home network prefix (HNP) (i.e., HNP1) from the DMM – access routers (DMM-ARs) which are deployed closer to the users (i.e., first hop from the MN). The MN will receive its HNP2 whenever it moves its attachment to DMM-AR2 which is the new distributed access router. The DMM-AR2 requires information whether it is the first router the MN has attached to or there were other previous access routers that have been attached to and must be notified with the MN's movement.



(a) MN moves its attachment to DMM-AR$_2$



(b) MN moves its attachment to DMM-AR$_3$

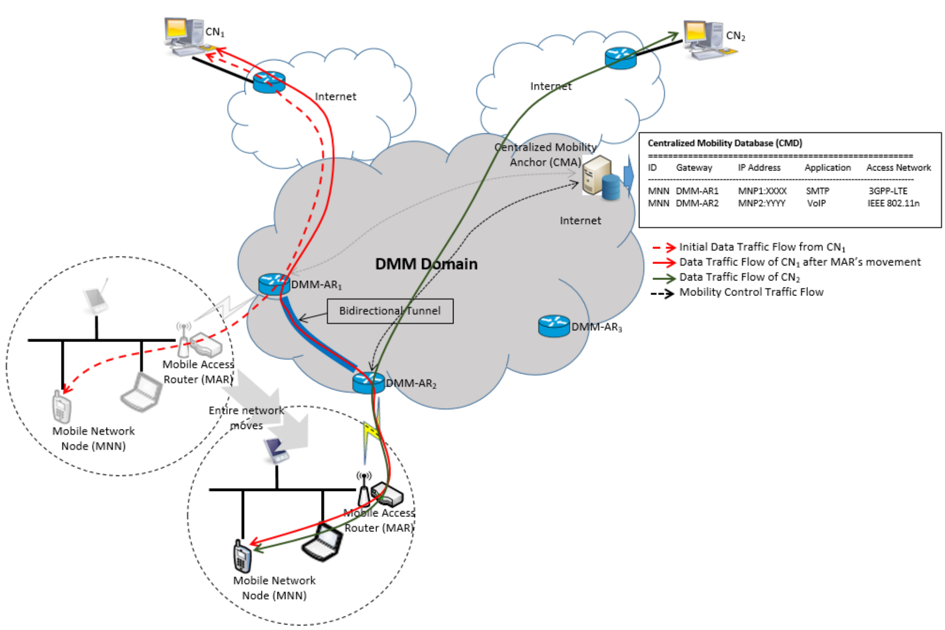
Figure 2. Partially Distributed Mobility Management Overview

The CMA (i.e., control plane) manages the centralized mobility database which is a global location database that maintains and updates the mobility information of the MNs as well as the data traffic routing tables. That is, whenever the MN changes its point of attachment to a new access router (DMM-AR2), the DMM-AR2 requests for MN's information from the CMA. The previous access router (DMM-AR1) and DMM-AR2 establish a bidirectional tunnel in order to forward the data traffic which was originally destined to MN's HNP1, thus, the MN continuously receives data packets from its ongoing sessions. The new sessions for the MN will be delivered to its HNP2.

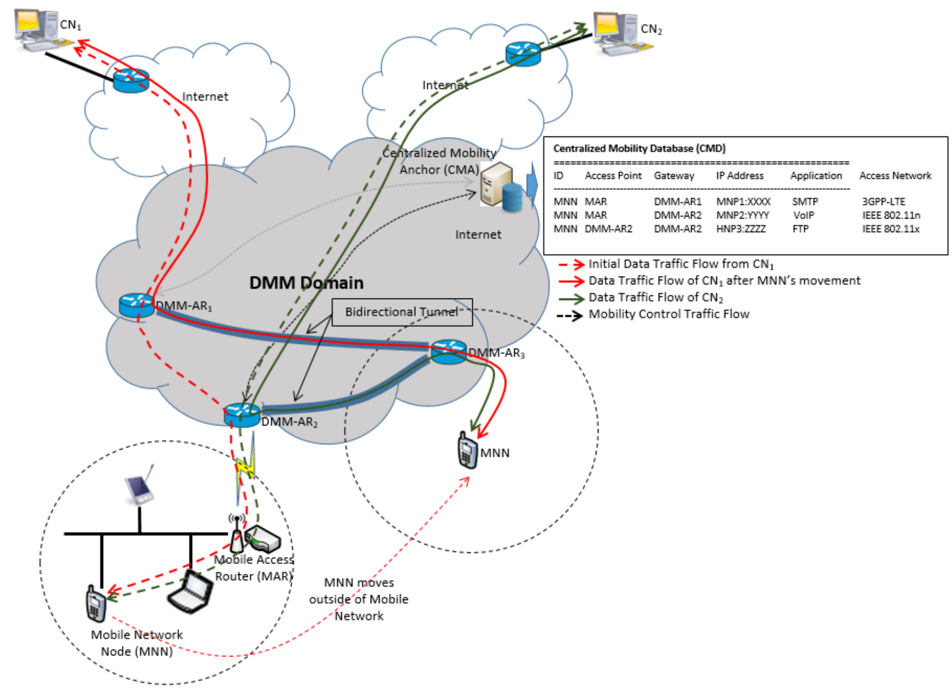
Whenever the MN changes its point of attachment to a new access router (i.e., DMM-AR3), it will receive its HNP3 where it can receive data packets from its new sessions as depicted in Figure 2(b). A bidirectional tunnel will be established by the DMM-AR3 and the previous access routers where previous sessions were still ongoing in order to provide the MN with continuous services.

The integration of NEMO basic support for the E2E seamless data transmission for distributed wireless sensor architecture on SHM of SOC public infrastructures is outlined in Figure 3. In this proposed scheme, a CMA is introduced that extends the mobility database that will be responsible for storing the MN's location context, allocation of HNPs for mobility management, and managing the routing paths for the structural and health and environmental data traffic. The routing of data traffic is forwarded through the mobility anchors (DMM-ARs) which are distributed through the DMM domain and are deployed closer to mobile users. In Figure 3(a), the mobile network is initially attached to DMM-AR1 where the MNN receives the data traffic from CN1 through the MNP1 acquired by the MAR from the CMA. Whenever the entire network moves its attachment to DMM-AR2, the MAR acquire a set of MNP2 and a bidirectional tunnel between DMM-AR1 and DMM-AR2 is established. The data traffic from the previous session of the MNN with CN1 will now be tunneled between the two distributed mobility anchors.

When the MNN moves outside of the mobile network domain and attaches to DMM-AR3, it directly receives a home network prefix (i.e., HNP3) from the CMA to be used for routing data traffic from its CNs as illustrated in Figure 3(b). Bi-directional tunnels will then be established between DMM-AR3 and the previously distributed mobility anchors (i.e., DMM-AR1 and DMM-AR2) in order that the previous sessions for MNN will be maintained despite its movement from the mobile platform to a fixed access point location platform.



(a) Mobile Network's Movement to a new Access Router



(b) MNN's Movement outside of the Mobile Network

Figure 3. NEMO-partially DMM Support for E2E Seamless Data Transmission

In this proposed mobility management support for seamless data transmission scheme of structural health and environmental monitoring of SOC public infrastructures, the MAR is configured with a new HNP every time it makes a handover and additional MNP to be used for the attached MNNs. Then, a bi-directional tunnel is established between the previous and new distributed mobility anchors in order to redirect data traffic for the MNNs. In general, the NEMO-partially DMM support consists of the following entities:

(1) The CMA which extends the central mobility management database to store the mobility information for each of the MARs and nodes within the DMM domain. It is also responsible for the routing decisions of data traffic and must be updated of every mobility change and anchoring of other network entities.

(2) The distributed mobility anchors that will be responsible for providing connectivity to the MARs and nodes. They will be responsible in E2E forwarding data traffic intended to the MNNs.

(3) The MAR is responsible for acquiring the HNP and MNP for its attached MNs.

(4) The MNNs can roam between mobile platforms through the MAR and fixed access point location platform through the distributed mobility anchors. The MNNs can be the devices used in vehicles or mobile devices of the users.

4. Discussions

This paper deals with the analysis of the integration of NEMO basic support for partially DMM based seamless data transmission for structural health and environmental monitoring of SOC public infrastructures. The qualitative analysis of the features of the proposed scheme in comparison with the different NEMO implementations was outlined in Table 1. The table describes each approach based on several factors such as topological architecture, the type of mobility management, granularity, network components, tunneling support, and MN modification. The comparison results laid out the advantages of NEMO-partially DMM support for seamless data transmission that provides optimized and distributed routing with centralized control but not requiring any protocol stack modification with the MN.

Table 1. Qualitative Analysis on NEMO Implementations

Features/NEMO Implementation	NEMO Basic Support [6]	NEMO enabled PMIPv6 [8][9]	NEMO-based DMM [10]	NEMO-partially DMM
Topological Architecture	Centralized	Centralized	Fully Distributed	Partially Distributed
Type of Mobility Management	Host-based	Network-based	Host-based	Network-based
Granularity	Macro mobility	Micro mobility	Micro mobility	Micro mobility
Network Components	HA	LMA, MAG	Distributed Mobility Anchor	Distributed Mobility Anchor, CMA
Tunnel Support	HA to Mobile Router	LMA to MAG	Previous Mobility Anchor to New Mobility Anchor	Previous Mobility Anchor to New Mobility Anchor
MN Modification	Required	Required	Required	Not Required

The decoupling of data infrastructures (delivery of critical structural and environmental information) from its control infrastructures (mobility management and routing decisions) in the proposed scheme has allowed more efficient mobility management, provisioning and allocation of network resources, optimized and distributed data traffic routing, and seamless handover management. The comparison analysis can show that DMM approaches generally boost seamless data traffic transmission specifically with a large volume of data traffic over heterogeneous mobile networks. The DMM’s capability in obtaining a new prefix for every handover while keeping their old prefixes allows the MNNs to maintain their ongoing sessions while roaming the DMM domain.

The proposed NEMO-partially DMM E2E transmission scheme addresses the signaling overhead and high-latency limitations in host-based mobility management support of NEMO-based DMM which is based in a fully distributed model. In addition, it addresses the drawbacks incurred by centralized mobility management schemes of NEMO-enabled PMIPv6.

5. Conclusions

This paper has presented an analysis of the integration of NEMO basic support for partially DMM based seamless E2E data transmission scheme for structural and environmental health monitoring of SOC public infrastructures over heterogeneous wireless networks. The scheme implements the separation of the data and control infrastructures in order to optimize the delivery and routing of critical structural and environmental information while providing NEMO based mobility support for MNs. It allows MNs to roam between fixed access point locations and mobile platforms without interruptions on their ongoing sessions and without being involved if signaling operations during handovers. Thus, the scheme is capable of providing seamless transmission of critical structural and environmental information which is essential in the monitoring of SOC public infrastructures, hence, guarantee public safety.

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