

# Signalling Cost Analysis of PDE-NEMO

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**Abstract**—A Personal Distributed Environment (PDE) is an example of an IP-based system architecture designed for future mobile communications. In a single PDE, there exist several Sub-networks hosting devices located across the infrastructure, which will inter-work with one another through the coordination of a Device Management Entity (DME). Some of these Sub-networks are fixed and some are mobile. In order to support Mobile Sub-networks mobility in the PDE, the PDE-NEMO protocol was proposed. This paper discussed the signalling cost analysis of PDE-NEMO by use of a detailed simulation model. The paper started with the introduction of the protocol, followed by the experiments and results and then followed by discussions.

**Keywords**—Mobile Network, PDE-NEMO, Signalling Cost.

## I. INTRODUCTION

THE emergence of new technologies in the mobile communication systems and also the ever-increasing growth of user demand have triggered researchers and industries to come up with a comprehensive manifestation of the up-coming fourth generation (4G) mobile communication systems. In the literature, users' personalisation and ubiquitous access seems to dominate the trend for future mobile communication systems.

"User centric" as the feature is known focuses more on the needs of the users. It is strongly believed that user centric will be the foundation in shaping the design of the 4G system as discussed in [1][2][3]. Other than that, it is also anticipated that in the 4G, the users will be provided with connectivity to heterogeneous wireless networks inter-working with one another. As a result, there will be a diverse services offered to the user.

The Mobile VCE project has defined the concept of a Personal Distributed Environment (PDE) of a user's devices, services and data. This concept enables a user to access services and data through a distributed set of terminal ubiquitously optimised for their application. These terminals, services and data that the user would access, form the user's "Personal Distributed Environment" [4].

In a single PDE, there will be Sub-networks interconnected with one another. In its architecture (refer to Figure 1), there will be a Device Management Entities (DMEs), which will control devices within a single PDE Sub-network and also provides universal co-ordination between the Sub-networks. A user might be at one time working in one of the Sub-networks, but may also utilise devices in other Sub-networks. More interestingly, in the concept of PDE, some of the Sub-

networks are also mobile. The scenario of a whole network becomes mobile deserves a special attention and need to be addressed appropriately.

Network mobility support will enable a network to change its point of attachment in the Internet without involving the nodes inside it. There are a lot of advantages that network mobility can offer, but the most important one is that it would reduce the signalling cost. This is due to the fact that only the node known as the Mobile Router will perform location update on behalf of the entire mobile network.

The PDE-NEMO Basic Support Protocol (PDE-NEMO) protocol is a network protocol designed to support Mobile Sub-networks mobility in PDE. The protocol is seen as essential in order to maintain reachability for all the nodes behind a Mobile Sub-network in a PDE. The protocol will be used whenever a Mobile Sub-network is formed and started to change its point of attachment in the infrastructure. There is a particular case when this Mobile Sub-network would attach itself to another Mobile Sub-network of the same PDE. This is known as convergence of Mobile Sub-networks in PDE. This protocol was also designed to handle the convergence of Mobile Sub-networks in the PDE.

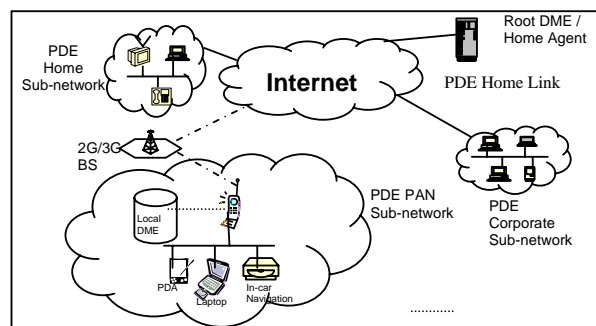


Fig. 1 PDE Basic Architecture

When a user moves away from a fixed Sub-network (e.g. his/her home), a Mobile Sub-network (in this case a personal area network (PAN)) will be created consisting of whatever devices the user retains. At this point, the Sub-network will start to change its point of attachment in the infrastructure. This process must be completed satisfactorily to ensure that the session continuity for all the nodes in the Sub-network is maintained.

The scenario outlined could be more complicated if the user and PAN, for example, enters a car and becomes mobile. In PDE, the vehicle itself is considered as a separate Sub-network maintaining its own devices, e.g. a Global Positioning System, car security system and digital radio

working in a collaborative way. In effect when the user enters the car, the two Sub-networks will merge, which is known as convergence in the PDE. Conversely when the user leaves the car, the two networks will separate, and this is known as de-convergence in the PDE. This paper considers the signalling cost analysis of PDE-NEMO using the two approaches proposed to handle the convergence and de-convergence of Mobile Sub-networks in PDE.

## II. OVERVIEW OF PDE-NEMO BASIC SUPPORT PROTOCOL

In order to support Mobile Sub-networks such as the PAN, a protocol known as the PDE-NEMO Basic Support Protocol, was developed. The protocol is actually an adaptation of the NEMO protocol discussed in [5] and uses the same mobility agents, i.e. the Mobile Router and the Home Agent as defined in [5]. On top of that, a new mobility agent known as Root DME was introduced.

Compared to NEMO [5], the Home Agent in PDE-NEMO does not advertise the Home Address of the Mobile Router to the infrastructure. Instead, the mechanism for other nodes in the infrastructure to locate the device in a PDE is carried out through the usage of SIP Uniform Resource Identifier (URI) as mentioned in [4]. For this reason also, the Home Agent in the PDE-NEMO does not have to intercept packets meant for a device in a Mobile Sub-network. This also helps to reduce signalling traffic in the infrastructure, as the Home Agent does not have to send gratuitous Neighbour Advertisement messages.

As in [5], the PDE-NEMO protocol also requires a Mobile Router to have a unique Home Address through which it is reachable when it is registered with its Home Agent. Whenever a Mobile Sub-network attaches itself to a new point of attachment in the infrastructure, it will request a Care-of Address from an Access Router or even a Mobile Router. After that, a Binding Update (BU) message consisting of the new Care-of Address will be sent to the Home Agent. Upon receiving the BU message, the Home Agent will update the appropriate records in the appropriate Binding Caches. Subsequently, the Home Agent will send a BU Acknowledgement to the Mobile Router.

Whenever a Correspondent Node sends a packet to a device within a Mobile Sub-network, the packet will be sent to the Root DME first at the PDE Home Link. The Root DME will find the most appropriate device to receive the packet. After that, the Root DME will locate the device by contacting the Home Agent. After the Home Agent finds the current location of the device, the packet will be encapsulated and tunnelled to it. At the other end, upon receiving the encapsulated packet, the Mobile Router will de-encapsulate the packet and then forward it to the intended device.

Imagine a user leaving his/her home for office (refer to Figure 2). As soon as the user breaks off with the home Sub-network, a Mobile Sub-network (PAN for example) with whatever devices he/she has on him/her would be created. Assuming he/she drives to work, there would then be another Mobile Sub-network in the user's PDE, i.e., his/her car (it is

assumed here that in the PDE, a car can be a Mobile Sub-network on its own). What would happen when the two Mobile Sub-networks belonging to the same PDE get together? This scenario is known as the convergence of Mobile Sub-networks in PDE.

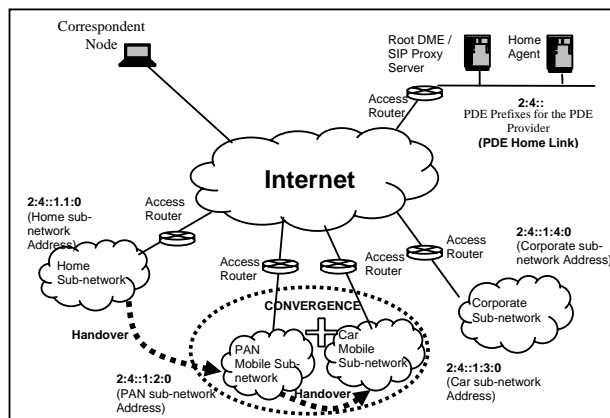


Fig. 2 Convergence of Mobile Sub-networks in PDE

In this research, there are two approaches presented to handle the scenario where two Mobile Sub-networks that belong to a PDE become converged. The first approach is known as the Nested Approach and the second approach is known as the Merged Approach. An overview of the two approaches is given below:

### **Merged Approach**

The two Mobile Sub-networks could be merged and form a single Mobile Sub-network. The incoming Mobile Sub-network will be disintegrated and devices will re-register to the other Mobile Sub-network.

### **Nested Approach**

In the Nested Approach, a nested Mobile Sub-network is created. In this research, only one level of nested Sub-networks is considered. However, the nesting methodology applied in this research can be used for multi-level of nesting.

## III. EXPERIMENTS AND RESULTS

In order to analyze the signalling cost of the PDE-NEMO using the two approaches discussed in the previous section, a simulation model as depicted in Figure 3 was developed. This model considers the comprehensive signalling exchanges which take place in each case and, in particular, the impact of varying the number of devices in each Sub-network. A simplified Gilbert Elliot Model was used to simulate a more realistic radio channel model. It introduces back to back packet loss in the radio channel. The simplified Gilbert-Elliot Model used in the simulation is an approximate characterization of the radio channel. It is sufficient to demonstrate the bursty errors that often faced by radio channel.

### A. Applying the Convergence Methods in the Simulation Model

The simulation model developed was designed to simulate a scenario whereby a user (along with his/her PAN Mobile Sub-network) has moved out of contact with an access router (AR) and has converged with another Mobile Sub-network and then after some time, de-converges again. In this paper, only the convergence of subnetworks belonging to the same PDE is considered. Figure 3 shows two Mobile Routers namely Mobile Router 1 (MR1) and also Mobile Router 2 (MR2) serving two different Mobile Sub-networks. In both Mobile Sub-networks, the mobility management is handled by the respective Mobile Router. As a consequence, the mobility of the Mobile Sub-network is transparent to the nodes behind the Mobile Routers.

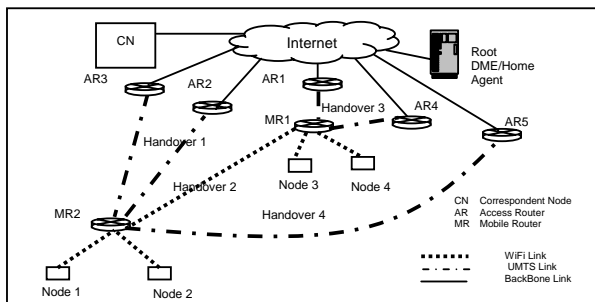


Fig. 3 Simulation Model

In the simulation model, a pre-planned route was set for the Mobile Sub-networks. In Figure 3, the convergence takes place in the second handover. It is assumed that at each handover, MR2 simply searches for another AR (also known as the detection and search processes as mentioned in [6]). If a new AR is found in range, the Mobile Router sets up a new path and exchanges information with the new AR.

Figure 3 shows that 4 handovers took place in the simulation. As mentioned in [6] the handover process can be divided into three phases namely detection, search and execution. The time taken for the handover process as reported in [6] is actually technology dependent i.e. different wireless cards have different handover times. The detection phase refers to the discovery of the need for the handover to be executed. Receiving a stronger router advertisement signal from the nearest router (even Mobile Router in this case) is one example. The second phase, i.e. the search phase, refers to the acquisition of the information needed to perform the handover. Lastly, the execution phase refers to the performance of the handover itself.

### B. The De-convergence Processes in the Simulation Model

After a certain time, the simulation model forces the converged Mobile Sub-networks to de-converge. In the simulation, the de-convergence process occurs during handover 4. For the Nested Approach this process is known as de-Nesting and for Merged Approach it is known as de-Merging. The de-Nesting process is actually the handover process of the child subnetwork away from the parent subnetwork. The same procedure for handover applies here as

mentioned in the earlier paragraphs of this section. The de-Nesting is actually a straightforward case of handover same as in the Nesting process. The time taken to complete the de-Nesting process is known here as de-Nesting time.

As for the de-Merging process, it is a process of reconstructing a Mobile Sub-network. The de-Merging process is more complicated than de-Nesting. The Mobile Router will initiate the de-Merging process. This is achieved through MR2 sends de-Merging signals to all the nodes. In the scenario, the user walk away from the current Mobile Sub-network he is attaching to and taking with him a number of devices. These devices are the devices that will actually respond to the MR2 de-Merging signals. The involved devices has to respond to the de-Merging signal as that is the strongest signal they could receive from any AR or Mobile Router which is a normal procedure for a handover as mentioned in [6].

### C. Cost Analysis Metrics Derivation

Within the context of this research, cost can be defined as a representative value (number) which refers to the overhead in terms of latencies or delays associated with mobility of Mobile Sub-networks in the PDE-NEMO. In this research, the analytical model focuses on the signalling and database lookup costs for the handover that is/are taking place during the convergence and de-convergence of Mobile Sub-networks in the PDE. The cost analysis was also discussed in [6], [7], [8], [9] and [10].

The signalling cost of a Mobile Sub-network in the PDE-NEMO basic support protocol has two major components namely: cost for path setup and cost for packet delivery. Both of these costs made up the signalling cost during the convergence and de-convergence of Mobile Sub-networks in the PDE.

The signalling cost depends on a variety of factors, such as network topology and location of entities. However in this research, the signalling costs used in the calculation of the performance analysis are based on the environment of the simulation model developed. In order to compute the performance analysis, the parameters shown below are used:

- $\gamma_{Nest}$  : Cost for path setup in the Nested approach
- $\gamma_{Merge}$  : Cost for path setup in the Merged approach
- $\psi_{Nest}$  : Cost of packet delivery in the Nested approach
- $\psi_{Merge}$  : Cost of packet delivery in the Merged approach

Let  $Cost_{LU}$  be the cost per unit time for location update, then:

$$Cost_{LU} = \frac{\gamma}{T_{rsdn}} \quad (1)$$

where  $T_{rsdn}$  is the residence time for a Mobile Sub-network. Let  $Cost_{PD}$  be the cost per unit time for packet delivery, and  $\omega$  is the rate of downlink packets (packets/sec) then:

$$Cost_{PD} = \omega\psi \quad (2)$$

Therefore, the total cost per unit time for packet delivery and location update is:

$$v = Cost_{LU} + Cost_{PD} \quad (3)$$

Which is formulated for the different approaches as follows:

$$v_{Nest} = \frac{\gamma_{Nest}}{T_{rsdn}} + \omega\psi_{Nest} \quad (4)$$

$$v_{Merge} = \frac{\gamma_{Merge}}{T_{rsdn}} + \omega\psi_{Merge} \quad (5)$$

In order to calculate the path setup and packet delivery costs, the database lookup and signalling costs need to be determined as well. Both costs are represented by the following:

- $\xi_{HA}$  : Cost of updating/querying a database at Home Agent
- $\xi_{MR}$  : Cost for updating/querying a database at Mobile Router
- $\ell_{int\ rnt}$  : Cost for sending a signalling or data packet over the Internet
- $\ell_{mobrtr}$  : Cost for sending a signalling or data packet between Mobile Routers

The signalling costs listed above include the switching/routing cost at all intermediate nodes, and also the cost for transmitting the packet through the communication links. The cost of updating/querying at the Home Agent was based on the actual processing speed at the Home Agent. This includes the queueing time of the packets at the Home Agent. Whereas, the cost for updating/querying at the Mobile Router was based on the actual processing at the Mobile Router. This also includes the queueing time of the packets involved at the Mobile Router.

TABLE I  
SIGNALLING COST PARAMETERS

Signalling Cost Parameters	Values
$T_{rsdn}$	150
$\omega$	0.01
$\ell_{int\ rnt}$	40
$\ell_{mobrtr}$	1

On the other hand, the cost of sending a packet over the Internet was actually derived from the actual time taken for the packet to travel the Internet in the simulation model. The time was then weighed against the time taken to send packet between the Mobile Routers as a ratio. The valued obtained were 40 for the  $\ell_{int\ rnt}$  and 1 for the  $\ell_{mobrtr}$ .

The total time taken to do the updating/querying was then weighed against the time taken for updating/querying at the Mobile Router as a ratio. This ratio was then used in the calculation. The ratio values obtained for the updating/querying the Home Agent and also the Mobile Router was too small as compared to the ratio values obtained for costs of sending a packet over the Internet and between Mobile Routers. Therefore, these values hardly have any affect on the delivery costs. The values of the parameters used in the calculation are as shown on Table 1.

Based on the Nested and Merged approaches algorithm discussed in section II, the expressions for location update and packet delivery costs for both approaches are derived as follows:

$$\gamma_{Nest} = \xi_{HA} + \xi_{MR} + 2\ell_{int\ rnt} + 2\ell_{mobrtr} \quad (6)$$

$$\gamma_{Merge} = n(\xi_{HA} + \xi_{MR} + 2\ell_{int\ rnt} + 2\ell_{mobrtr}) \quad (7)$$

$$\psi_{Nest} = \xi_{HA} + 2\xi_{MR} + \ell_{int\ rnt} + 2\ell_{mobrtr} \quad (8)$$

$$\psi_{Merge} = \xi_{HA} + \xi_{MR} + \ell_{int\ rnt} + \ell_{mobrtr} \quad (9)$$

Therefore, by using equations 4, 5, 6, 7, 8 and 9, the total cost for the different approaches are given by the following expressions:

$$v_{Nest} = \left[ \frac{\xi_{HA} + \xi_{MR} + 2\ell_{int\ rnt} + 2\ell_{mobrtr}}{T_{rsdn}} \right] + [\omega(\xi_{HA} + 2\xi_{MR} + \ell_{int\ rnt} + 2\ell_{mobrtr})] \quad (10)$$

$$v_{Merge} = \left[ \frac{n(\xi_{HA} + \xi_{MR} + 2\ell_{int\ rnt} + 2\ell_{mobrtr})}{T_{rsdn}} \right] + [\omega(\xi_{HA} + \xi_{MR} + \ell_{int\ rnt} + \ell_{mobrtr})] \quad (11)$$

#### IV. DISCUSSIONS

As mentioned in section III, within the context of this research, cost can be defined as a representative value (number) which refers to the overhead in terms of latencies or delays associated with mobility of Mobile Sub-networks in the PDE-NEMO Basic Support Protocol.

For the cost analysis, it was assumed that the signalling cost dominates with the database access cost was set to 0. All the parameters values within equations 10 and 11 were obtained from the simulation model developed. The values were then substituted into the equations to obtain the final results as shown in Figure 4 and Figure 5. The values for the cost of sending packets through the Internet and also between Mobile Routers were obtained after the actual times were measured from the simulation model

Figure 4 shows the effect of residence time on the signalling cost. It was observed that the signalling cost for the Merged Approach is greater than the Nested Approach. With the decreasing of the residence time, the cost for location update for the Merged Approach is relatively high compared to the Nested Approach, which results in a higher increase of signalling cost.

However, it was observed that both approaches have the same performance characteristics when the residence time decreases. From figure 4 it can be deduced that when mobility decreases, the signalling cost also decreases for both

approaches. This actually makes sense as the less number of handovers take place, the less number of signalling will take place.

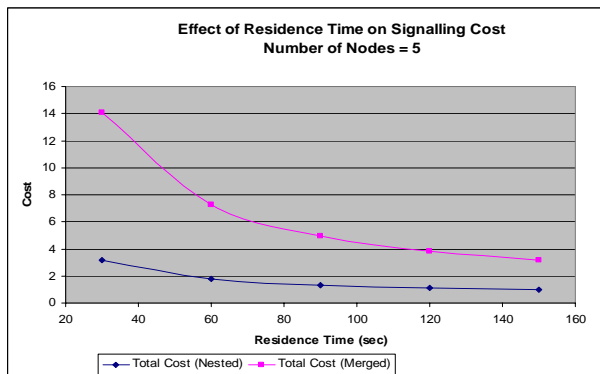


Fig. 4 Effect of Residence Time on Signalling Cost with Number of Nodes = 5

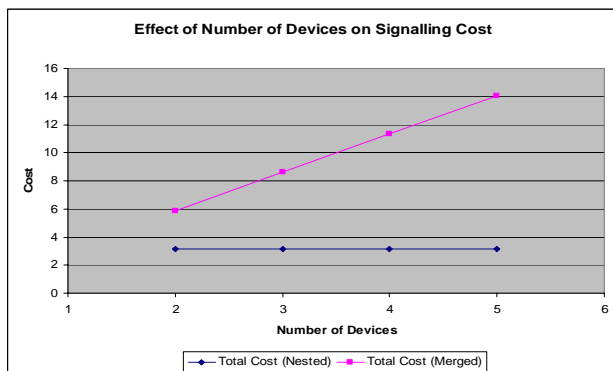


Fig. 5 Effect of Number of Devices on Signalling Cost

This applies to both the approaches proposed to handle convergence and de-convergence of Mobile Sub-networks in the PDE. The only different is that the Nested Approach will generate fewer signals as compared to the Merged Approach.

For the Merged Approach, as the number of devices increases, the signals involved also increases. The Nested Approach seems to alleviate this problem by performing a simple convergence process without involving the mobile hosts behind the Mobile Router during the convergence process.

On the contrary, in the Merged Approach, whenever the Mobile Sub-networks become converged, all the nodes behind the Mobile Router have to participate in the convergence process. As a result, the number of signalling packets increases as the number of nodes increases.

This is one of the drawbacks of the Merged Approach i.e. generating excessive signalling cost due to its mechanism. Besides increasing the signalling cost, the same mechanism also causes the handover delay for the approach to be higher than that of the Nested Approach as been discussed in section III. As a result, the packet ratio for the Merged Approach is also higher than the Nested Approach.

The fact that the Merged Approach generates more signalling cost as the number of devices increases is proven through figure 5. From figure 5, it was observed that, when the number of devices increases, the signalling cost for the Merged Approach also increases. The increment can be said as a linear relationship.

As for the Nested Approach, the signalling cost remains constant although the number of devices increases. This is due to the mechanism of the Nested Approach whereby only the Mobile Router is involved in the convergence and de-convergence processes. As a result, the number of devices behind the Mobile Router does not affect the overall signalling cost during the convergence and de-convergence process.

## V. CONCLUSION

In this paper, the signalling cost analysis of PDE-NEMO using the two approaches proposed to handle the convergence and de-convergence of Mobile Sub-networks in PDE have been discussed. The simulation model and its environment was also explained and followed by the discussion of the implementation of both approaches in the model. The cost signalling metrics used to evaluate both approaches were also presented together with its derivation. This was followed by the results of the evaluation.

As a conclusion, it is safe to conclude now that the Nested Approach is more favourable than the Merged Approach. With its simplicity in handling Mobile Sub-network convergence, shorter Nesting/De-Nesting time, lower packet loss ratio and also less signalling cost, it is hard to resist the benefit that the Nested approach has to offer.

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