Mathematical Modeling and Simulation Study of Delay-Sensitive Algorithm to Enhance Quality of Service in Mobile Networks

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Abstract

The mobile networks play a vital role in the information and communication technology. There are two kinds of mobility supported by mobile networks such as host mobility and network mobility. The enhancement of Quality of Service (QoS) in NEtwork MObility (NEMO) environment is more complex than host mobility environment. One of the complexities in NEMO environment is routing of packets. The routing algorithms play a significant role in enhancing QoS. This necessitates looking into the weaknesses of existing routing algorithms. Based on the weaknesses, we have already proposed a Delay-Sensitive Routing for NEMO (DSRNEMO) to enhance the QoS in NEMO environment with respect to delay parameter. The objectives of this paper are to derive a mathematical model for DSRNEMO and to simulate the operations of DSRNEMO. The outcome of the mathematical model and simulation results show that the DSRNEMO gives better results than the existing algorithm, NEMO. Ultimately, this paper contributes to enhance the QoS in mobile networks.

Keywords*: Host mobility, network mobility, quality of service, delay-sensitive algorithm, mobile networks*

1. Introduction

The advancement in mobile networks is growing very fast that makes changes in the protocols and mechanisms used in the different layers of mobile networks. It is a great challenge for the service providers to update the advancement in the services offered to customers. The host mobility needs Mobile IPv6 [1] which enables the mobile hosts to move within the mobile wireless network regardless of its home location address [2]. The NEMO means NEtwork MObility that enables a whole network to move into another network. In other words, NEMO supports network mobility that is movement of an entire network. The NEMO Basic Support Protocol [3] allows a group of nodes as a network to roam around Internet [4]. While roaming into another network all the nodes of the visiting network connected under a single router. The visiting network router will be connected to the foreign network router. Now, all the communications between the foreign network and the visiting network are possible. The network mobility is inevitable in mobile platforms [5,6] such as bus, car, train, flight, etc.

Some of the existing Route Optimization (RO) mechanisms [7] had not concentrated on delay problem. The RO in NEMO environment has several issues [8]. The Delay-Sensitive Routing for NEMO (DSRNEMO) [9] concentrates on delay problem. The DSRNEMO is used to reduce the delay in establishing Route Optimization (RO) by effectively maintaining a table that stores information about whether a node supports RO or not. It reduces time taken for fall back procedure that in turn reduces excessive delay in establishing RO and to offer better QoSs to the customers.

This paper is organized as follows. Section 2 discusses the motivations to write this paper. Section 3 derives the mathematical model for DSRNEMO algorithm. Section 4 provides the simulation results of DSRNEMO and Section 5 explores the findings and interpretations. Section 6 concludes this paper and references are listed in Section 7.

2. Motivations

This section describes the related works and motivations to write this paper. Sahibzada Ahmed Noor et al., analyzed the NEMO route optimization [4]. They targeted network mobility issues from the scope of route optimization. Their aim was to explore route optimization schemes in NEMO. After discussing the need of route optimization in NEMO, available solutions are discussed and a quantitative analysis is provided.

Thomas Clausen et al., [8] discussed that the NEMO working group has developed a protocol suite, extending the notion of edge-mobility on the Internet to support network mobility. This implies that a set of nodes, along with their mobile router, changes their point of attachment and that traffic to these nodes is tunneled to be delivered through their new point of attachment. This mechanism is transparent to applications in that existing traffic to a node is being encapsulated and tunneled, regardless of where the network containing the destination node is attached.

Thierry Ernst et al., addressed some of the problems in the MIPv6 [10]. V. Devarapalli et al., describe the Network Mobility (NEMO) Basic Support protocol that enables Mobile Networks to attach to different points in the Internet [11]. The protocol is an extension of Mobile IPv6 and allows session continuity for every node in the Mobile Network as the network moves. It also allows every node in the Mobile Network to be reachable while moving around. Young Beom Kim et al., explained that, in nested mobile networks, the undesirable effects due to non-optimal routing tends to get aggravated, leading to excessively long packet sizes and transfer delays. In order to resolve the non-optimal routing problem, also known as ‘pinball routing problem’ in the literature, a new route optimization scheme where the care-of address in each binding update message is recursively substituted by the intermediate mobile routers in the mobile network is developed [12].

Jongkeun Na et al., proposed a unified route optimization scheme [13] that can solve several types of RO problems by using Path Control Header (PCH). In this scheme, Home Agent (HA) does piggybacking the PCH on the packet which is reversely forwarded from Mobile Router (MR). That enables any PCH-aware routing facility on the route to make a RO tunnel with MR using the Care-of address of MR contained in the PCH. By applying to some already known NEMO RO problems, he shows that his scheme can incrementally optimize the routes via default HA-MR tunnel through the simple PCH interpretation.

The goal of the network mobility (NEMO) management is to effectively reduce the complexity of handoff procedure and keep the mobile devices connected to the Internet. The customers not only need mobility but also quality. It is a great challenge for the service providers to offer Quality of Service (QoS) [14]. Vehicle is moving so fast that it may cause the handoff and packet loss problems. Both of the problems will lower down the throughput of the network. Assume that a packet is sent to a mobile node and found that MN doesn’t support the route optimization then there will be a fall back procedure. This process wastes time and creates unnecessary traffic [15, 16] as it has to find a node again that supports RO.

Yuh-Shyan Chen et al., propose a novel NEMO protocol for vehicular ad hoc network (VANET) [5]. There are different types of Internet applications and mobile network interfaces. The Internet applications are file transfer, telephony, video conferencing, etc. The

QoS requirements will vary from one application to another application [17, 18]. To overcome the above problems, the DSRNEMO algorithm has been proposed.

3. Mathematical Model

This section derives a mathematical model for the DSRNEMO to prove that it gives better results than the NEMO. It uses relations such as symmetry, transitivity, reflexivity and transitive closure [19]. Relations are set of tuples, so set operation can be applied. The intersection of two relations gives pairs satisfying both relations. The union gives pairs satisfying one-the union of "brother-of" and "sister-of" is "sibling-of". Complement gives pairs not satisfying both relations.

3.1 Composition

Definition: The composition of relations $R_1 \subseteq AxB$ and $R_2 \subseteq BxC$ is the relation $R_2 \circ R_1 = \{(a,c) \mid (\exists b)((a,b) \in R_1) \Lambda (b,c) \in R_2)\}$.

Lemma $R_1 \circ (R_2 \circ R_3) = (R_1 \circ R_2) \circ R_3$

The composition $R \circ R$ of R with itself is written as R^2. Similarly R^n denotes R composed with itself n times. Formally (by recursive definition) R_1= R, R^n = $R \circ R^{n-1}$.

The relation among various levels of mobile routers is shown in Figure 1. It is used as an example mobile network to describe the DSRNEMO algorithm.

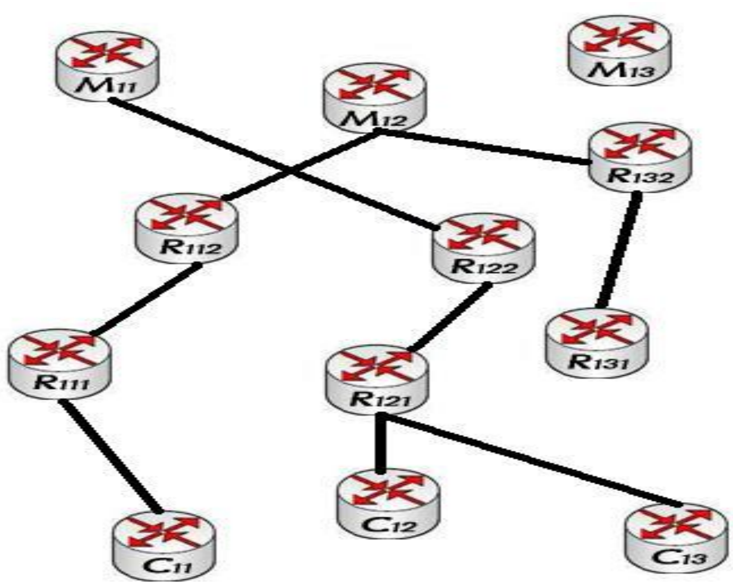


Figure 1. Mobile Network 1

The relation between different levels in Figure 1 is given below.

Relation between intermediate routers in level 1 and mobile nodes

	R_{111}	R_{121}	R_{131}
C_{11}	1	0	0
C_{12}	0	1	0
C_{13}	0	1	0

Relation between intermediate routers in level 1 and intermediate routers in level 2

	R_{112}	R_{122}	R_{132}
R_{111}	1	0	0
R_{121}	0	1	0
R_{131}	0	0	1

Relation between intermediate routers in level 2 and mobile routers

	M_{11}	M_{12}	M_{13}
R_{112}	0	1	0
R_{122}	1	0	0
R_{132}	0	1	0

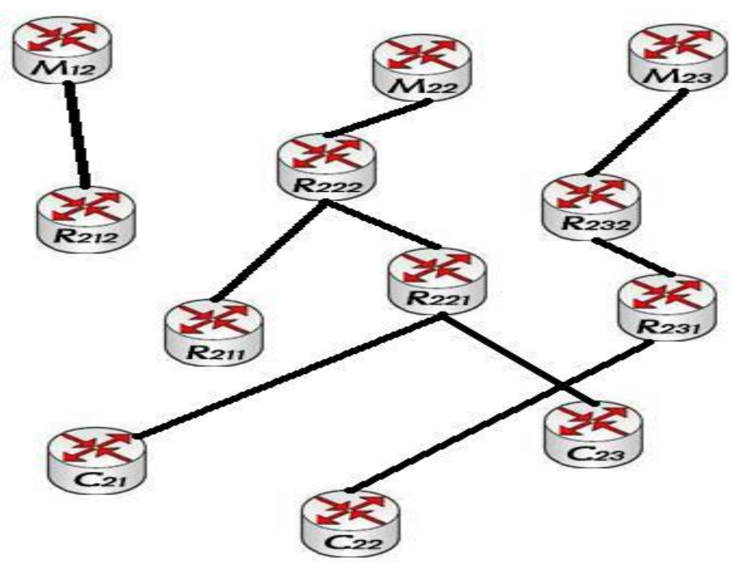


Figure 2. Mobile Network 2

The relation between different levels in Figure 2 is given below.

Relation between intermediate routers in level 1 and mobile nodes

	R_{211}	R_{221}	R_{231}
C_{21}	0	1	0
C_{22}	0	0	1
C_{23}	0	1	0

Relation between intermediate routers in level 1 and intermediate routers in level 2

	R_{212}	R_{222}	R_{232}
R_{211}	1	0	0
R_{221}	0	1	0
R_{231}	0	0	1

Relation between intermediate routers in level 2 and mobile routers

	M_{21}	M_{22}	M_{23}
R_{212}	0	1	0
R_{222}	1	0	0
R_{232}	0	1	0

CEM $= t_{11} + t_{12} + t_{13} + t_{21} + t_{22} + TP$

$$= \sum_{j=1}^{3} t_{1j} + \sum_{j=1}^{i-1} t_{2j} + TP \quad \text{.......................................(1)}$$

CPM $= t_{11} + t_{12} + t_{13} + TP$

$$= \sum_{j=1}^{3} t_{1j} + TP \quad \text{..(2)}$$

Where,

CEM = Cost for existing method to identify RO support.

CPM = Cost for proposed method to identify RO support.

TP = Time taken for connection of two TLMR (Top Level Mobile Router).

t_{ij} = Time

$TP \geq t_{ij}$, $t_{ij} > 0$

i = Max (j)

M_{ij} = Mobile router, R_{ijk} = Intermediate router, Cij = Mobile node

i = index for network, j = index for router, k = index for level

From (1) and (2), it is proved that the DSRNEMO takes less time to establish RO than the NEMO.

4. Simulation Results

A simulator for this research work has been implemented using Java. This simulator helps to compute the results for mobile networks with different levels of nesting. The computation results for both the NEMO and DSRNEMO are given separately and comparison is done. It is also represented using graphs.

There are two scenarios taken up for experimentation though the simulator can support many scenarios. Figure 3 shows the scenario 1 that represents mobile networks with the level of nesting as 1. The MN and MR represent the mobile network and mobile router, respectively. For example, MN1 and MN2 refer mobile network 1 and mobile network 2 and MR1 and MR2 refers mobile router 1 and mobile router 2.

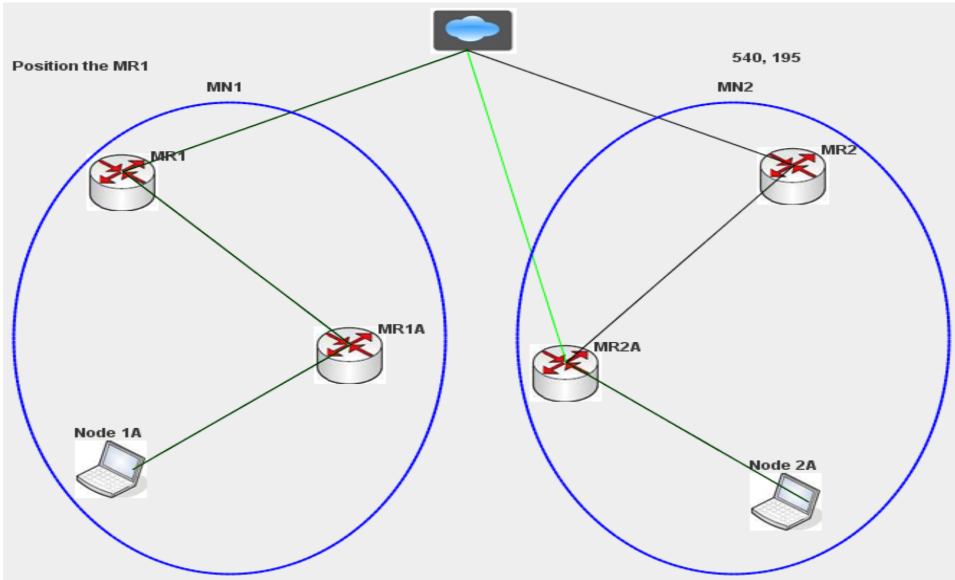
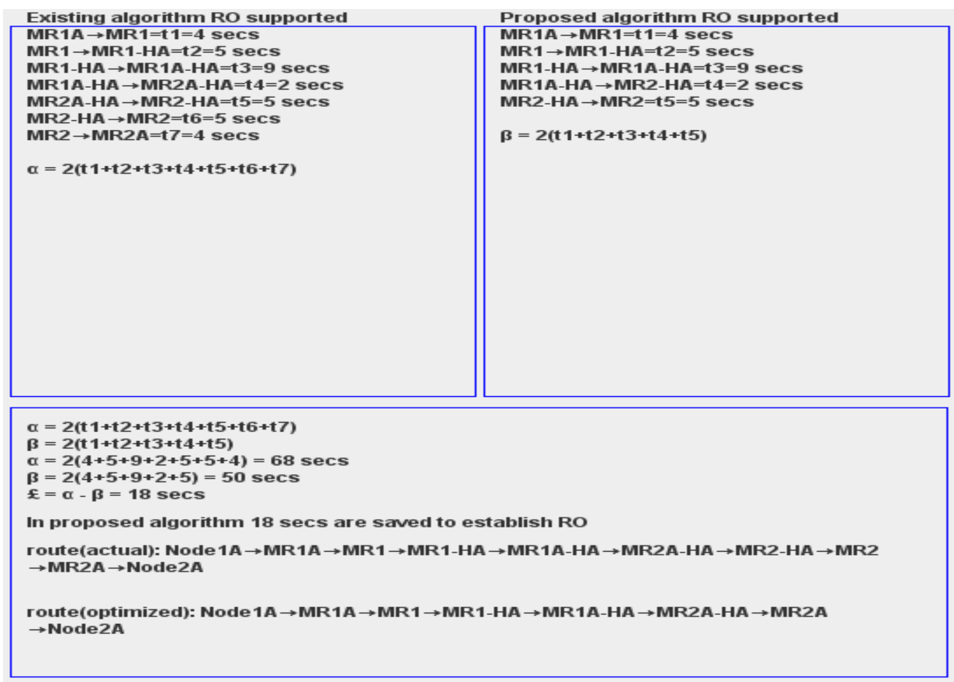


Figure 3. Mobile Network (Scenario 1)

Figure 4 shows the time taken to establish RO between MN1 and MN2. The total time taken to establish RO using NEMO is represented by ‘α’ and total time taken to establish RO using DSRNEMO is represented by ‘β’. The difference between the time taken to establish RO in NEMO and in DSRNEMO is represented in ‘£’.



Existing algorithm RO supported
MR1A→MR1=t1=4 secs
MR1→MR1-HA=t2=5 secs
MR1-HA→MR1A-HA=t3=9 secs
MR1A-HA→MR2A-HA=t4=2 secs
MR2A-HA→MR2-HA=t5=5 secs
MR2-HA→MR2=t6=5 secs
MR2→MR2A=t7=4 secs

α = 2(t1+t2+t3+t4+t5+t6+t7)

Proposed algorithm RO supported
MR1A→MR1=t1=4 secs
MR1→MR1-HA=t2=5 secs
MR1-HA→MR1A-HA=t3=9 secs
MR1A-HA→MR2-HA=t4=2 secs
MR2-HA→MR2=t5=5 secs

β = 2(t1+t2+t3+t4+t5)

α = 2(t1+t2+t3+t4+t5+t6+t7)
β = 2(t1+t2+t3+t4+t5)
α = 2(4+5+9+2+5+5+4) = 68 secs
β = 2(4+5+9+2+5) = 50 secs
£ = α - β = 18 secs

In proposed algorithm 18 secs are saved to establish RO

route(actual): Node1A→MR1A→MR1→MR1-HA→MR1A-HA→MR2A-HA→MR2-HA→MR2→MR2A→Node2A

route(optimized): Node1A→MR1A→MR1→MR1-HA→MR1A-HA→MR2A-HA→MR2A→Node2A

Figure 4. NEMO vs. DSRNEMO (RO supported)

Figure 5 clearly shows that the DSRNEMO gives better result in reducing the time taken to establish RO. The X axis shows the algorithms used and Y axis shows the time. For the scenario shown in Figure 3, the DSRNEMO saves 18 secs to establish RO which in turn enhances the QoS.

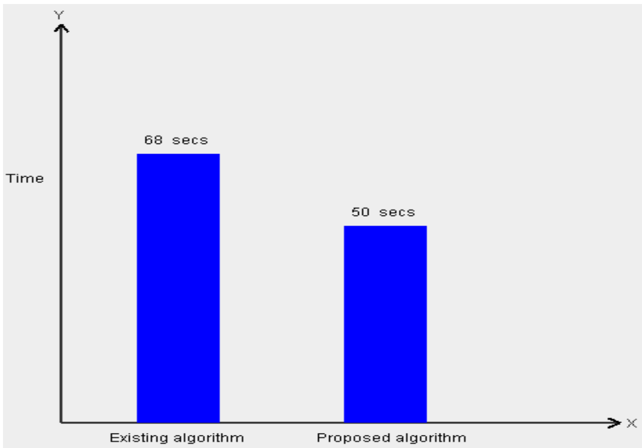


Figure 5. Graph Showing the Total Time Taken by NEMO vs. DSRNEMO (RO supported)

Even if RO is not supported, the DSRNEMO shows that the time taken to identify the MRs that do not support RO is less than the time taken by NEMO and significant amount of time is saved. For the scenario shown in Figure 3, the DSRNEMO saves 18 secs to identify that MRs do not support RO.

Figure 6 shows scenario 2 that represents mobile networks with the level of nesting as 3. Here, MR1 is a parent MR to MR1A; MR1A is a parent MR to MR1B and so on.

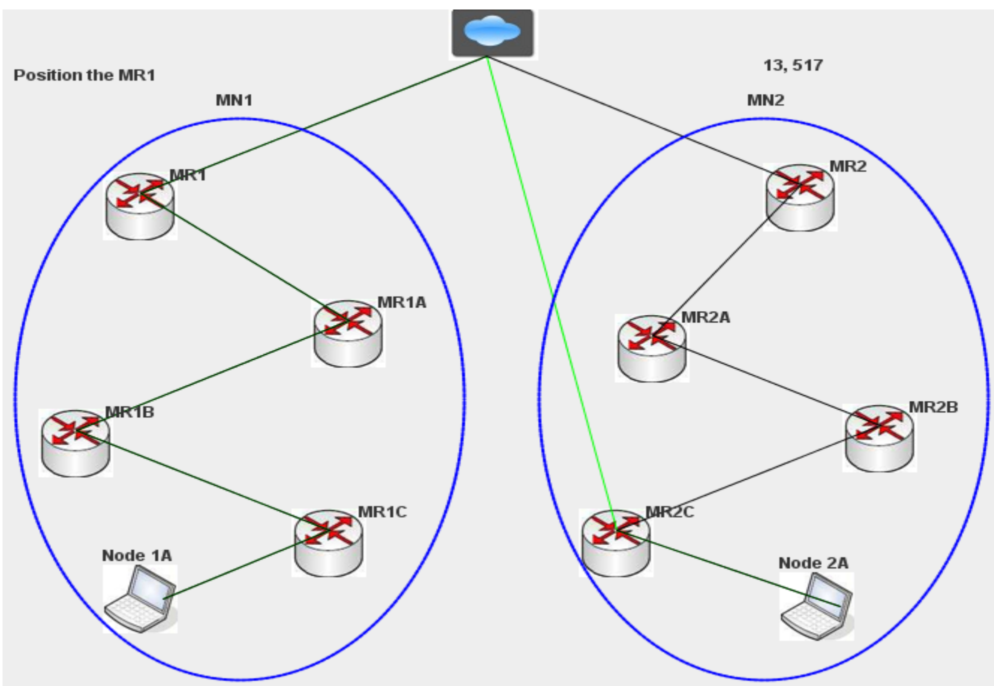


Figure 6. Mobile Network (Scenario 2)

Figure 7 shows the time taken to establish RO between MN1 and MN2. As the nesting level for scenario 2 is 3, the total time taken to establish RO is greater than the scenario 1. The total number of links (i.e. MR1C→ MR1B, MR1B→MR1A, etc.) in NEMO is greater than the total number of links in the DSRNEMO which in turn reduces the time taken to establish RO.

Existing algorithm RO supported	Proposed algorithm RO supported
MR1C→MR1B=t1=3 secs MR1B→MR1A=t2=4 secs MR1A→MR1=t3=3 secs MR1→MR1-HA=t4=4 secs MR1-HA→MR1A-HA=t5=1 sec MR1A-HA→MR1B-HA=t6=1 sec MR1B-HA→MR1C-HA=t7=5 secs MR1C-HA→MR2C-HA=t8=6 secs MR2C-HA→MR2B-HA=t9=5 secs MR2B-HA→MR2A-HA=t10=3 secs MR2A-HA→MR2-HA=t11=3 secs MR2-HA→MR2=t12=1 sec MR2→MR2A=t13=3 secs MR2A→MR2B=t14=3 secs MR2B→MR2C=t15=3 secs α = 2(t1+t2+t3+t4+t5+t6+t7+t8+t9+t10+t11 +t12+t13+t14+t15)	MR1C→MR1B=t1=3 secs MR1B→MR1A=t2=4 secs MR1A→MR1=t3=3 secs MR1→MR1-HA=t4=4 secs MR1-HA→MR1A-HA=t5=1 sec MR1A-HA→MR1B-HA=t6=1 sec MR1B-HA→MR1C-HA=t7=5 secs MR1C-HA→MR2-HA=t8=6 secs MR2-HA→MR2=t9=5 secs β = 2(t1+t2+t3+t4+t5+t6+t7+t8+t9)

α = 2(t1+t2+t3+t4+t5+t6+t7+t8+t9+t10+t11+t12+t13+t14+t15)
β = 2(t1+t2+t3+t4+t5+t6+t7+t8+t9)
α = 2(3+4+3+4+1+1+5+6+5+3+3+1+3+3+3) = 96 secs
β = 2(3+4+3+4+1+1+5+6+5) = 64 secs
£ = α - β = 32 secs

In proposed algorithm 32 secs are saved to establish RO

route(actual): Node1A→MR1C→MR1B→MR1A→MR1→MR1-HA→MR1A-HA→MR1B-HA →MR1C-HA→MR2C-HA→MR2B-HA→MR2A-HA→MR2-HA→MR2→MR2A→MR2B →MR2C→Node2A

route(optimized): Node1A→MR1C→MR1B→MR1A→MR1→MR1-HA→MR1A-HA →MR1B-HA→MR1C-HA→MR2C-HA→MR2C→Node2A

Figure 7. NEMO vs. DSRNEMO (RO supported)

Figure 8 clearly shows that the DSRNEMO gives better result in reducing the time taken to establish RO. The X axis shows the algorithms used and Y axis shows the time. For the scenario shown in Figure 6, the DSRNEMO saves 32 secs to establish RO which in turn enhances the QoS.

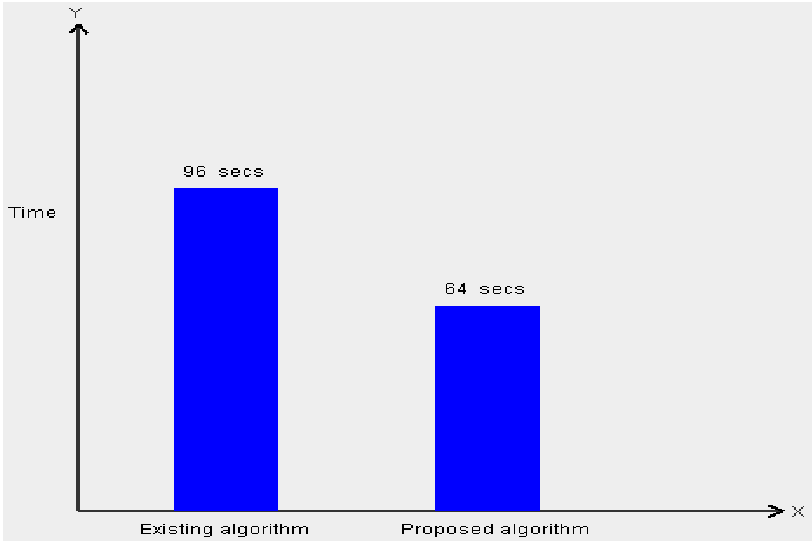


Figure 8. Graph Showing the Total Time Taken by NEMO vs. DSRNEMO (RO supported)

Even if RO is not supported, the DSRNEMO shows that the time taken to identify the MRs that do not support RO is less than the time taken by NEMO and significant amount of time is saved. For the scenario shown in Figure 6, the DSRNEMO saves 32 secs to identify that MRs do not support RO. All the figures in this section that represents mobile network scenario, computation results, and graphs are the product of this simulator.

5. Findings and Interpretations

The simulation results show that the DSRNEMO gives better results and enhances the QoS significantly. Figure 9 shows the time taken for NEMO and DSRNEMO to establish RO for the different levels of nesting and the time saved by the DSRNEMO. It shows that about 1/3 of the time is saved irrespective of the level of nesting.

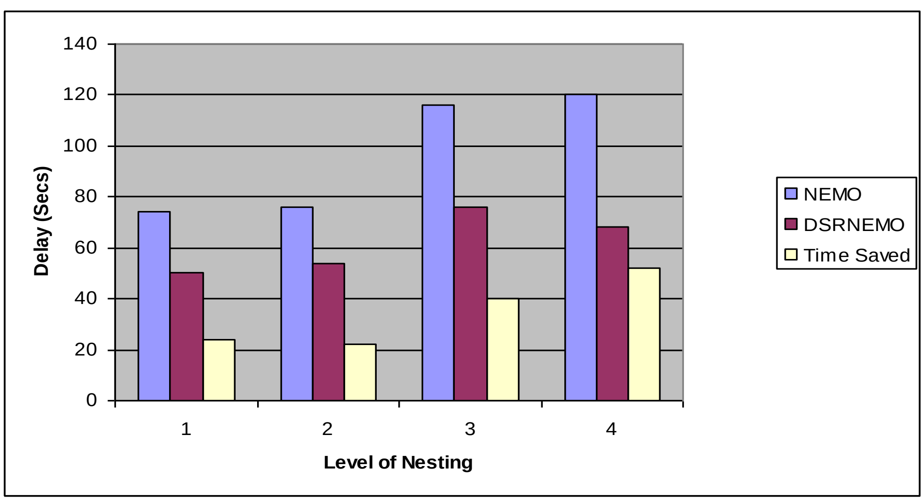


Figure 9. Level of Nesting vs. Delay

The results show that the DSRNEMO greatly enhances the QoS by reducing the delay in establishing RO and fall back procedure. Even if RO is not supported by a mobile router, the DSRNEMO helps to identify the nodes that do not support RO with minimum time than the time taken by NEMO.

6. Conclusion

This paper is intended to detect and integrate the nodes in existing internet infrastructure with better RO solution. It has derived a mathematical model and simulated the results for DSRNEMO. The mathematical model clearly shows that the cost for DSRNEMO to identify the RO support is less than the cost for NEMO to identify the RO support. The simulation results show that the DSRNEMO gives better RO solution. In other words, the time taken to establish RO is comparatively reduced than the NEMO. In particular, the outcome of the DSRNEMO reduces the time needed for fall back procedure that in turn reduces excessive delay in establishing RO.

In general, DSRNEMO helps to increase the Quality of Service (QoS) with respect to delay. The service providers can implement our idea to provide better QoSs to the customers for delay-sensitive applications like video conferencing, telephony, etc. Although this paper has better RO solution, it also has few weaknesses. That is, considerable amount of time is needed to search the table for RO support. The mechanism that identifies the new functionalities like RO is out of the scope of this research work and can be taken into account in future.

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