

# Performance Evaluation of an Efficient Routing Protocol Designed for a Simple Access Network

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**Abstract:** This paper presents simulation results on the performance of the network layer routing protocol CL in the Access network of UMTS. The network is modeled by a rooted-tree queuing system.

**Keywords:** Wireless PCS, Wireless protocols, Fast routing, Wireless network simulation.

## 1. INTRODUCTION

With the introduction of connectionless message transfer in Universal Mobile Telecommunications System (UMTS) [1], the need for a supporting routing protocol that provides simple but reliable connectionless routing procedure became apparent. The key challenge is to design a simple protocol that will take advantage of UMTS-specific architecture with minimal overhead and have a superior performance. The UMTS architecture is by nature hierarchical: it separates the UMTS backbone and UMTS Access network. While the former has a general topology, the latter is tree-like by definition. Therefore, advantage can be taken of the simplified topology, separating backbone routing from UMTS access network routing, while reconciling both of them at the root of UMTS access tree node, which is at the same time a backbone node. While backbone routing may be based on the well-known algorithms (see [2] for an example), tree routing with handoff is not well studied. One approach was offered in [3] where the CL-protocol was introduced. It integrates routing and connectionless transfer.

In this paper we are interested in the performance evaluation of CL-protocol. We use the random access network simulation to evaluate average protocol performance. In particular, we concentrate on estimating the roundtrip time and buffer sizes as functions of tree structure and number of mobile units handled by access network. We compare simulation results with estimates announced in [3] for a simplified version of the networking environment. The rest of the paper is arranged as follows: section 2 reviews the architecture of UMTS Access Network, introduces the design of CL-protocol, and reviews the operations of the protocol. In section 3 we describe the assumptions that have been made to set up the simulation. Section 4 introduces the simulation algorithm and explains the choice of the related data

structures and their implementation. Section 5 presents simulation results and in section 6 we discuss our conclusions.

## 2. CL PROTOCOL FOR UMTS ACCESS NETWORK

The architecture of UMTS access network for which CL-protocol is designed is a routed tree (see Fig. 1). Base transceiver stations (BTS) are the network entities that include the functionality to adapt the network signaling and user traffic to the radio interface. The UMTS core network is connected to the public switched telephone network (PSTN) via twisted pair or optical fiber

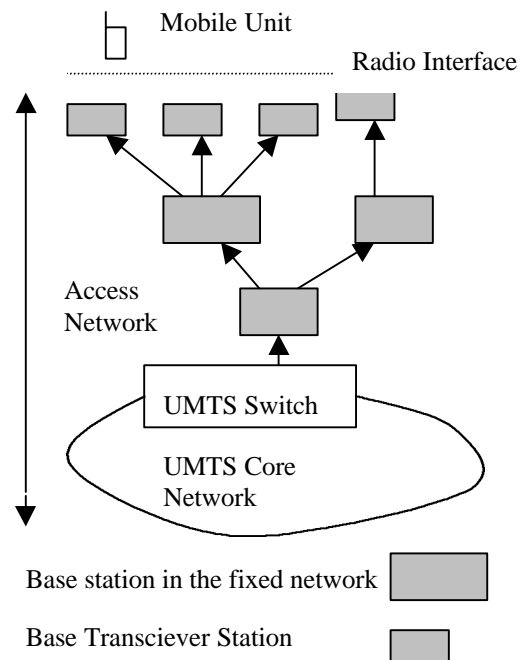


Figure 1. Structure of UMTS Network

networks. The access network connects the mobile units to the UMTS core network. Since different access systems may emerge from specific provider requirements, throughout the paper we assume that the access tree is of arbitrary structure and has an arbitrary number of nodes. The CL protocol for the UMTS network utilizes the rooted

tree topology of the UMTS. Signaling messages are transferred using connectionless transfer mode. Connectionless transfer provides location transparency and handoffs with uninterrupted signaling transport, and has a positive influence on the distribution of the processing load due to handoffs. The connectionless transfer service for signaling has been defined in a separate Network layer. The network layer provides transfer of upper layer signaling messages between mobile units and signaling functions residing in the fixed parts of the UMTS network. In this protocol it has been assumed that a mobile unit is allowed to communicate only with entities directly above it in the tree topology. The other principles that are applied in this protocol are as follows:

- A single route is maintained for each mobile unit.
- The base stations are responsible for initiating routing changes during handoffs.
- When a mobile unit loses its radio link with a base station, its old route becomes inactive but not deleted.
- After the handoff, the new route is set up towards the root of the tree but only until the new and old routes meet; nodes that are closer to the root of the tree are not affected.
- The rest of the old route is deleted as required.

The key features of the protocol that make it useful in the mobile environment (Fig. 2) are:

- limiting routing updates to part of the network where the mobile can communicate,
- providing base stations detected and controlled routing updates makes the mobile unit very simple,
- translation tables include buffering of messages temporarily to avoid message loss during handoffs when no routing information is available.

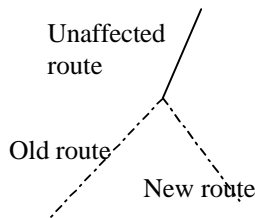


Fig. 2. Partial Rerouting Strategy

The protocol uses four messages in message transferring. They are:

- Unitdata (UDT): This message carries the user data.
- Routing Update (RTU): RTU ADD message is used to set up a new route and RTU DEL is used to remove an old route.
- Find (FND): This message is used to inform a mobile that there is a message waiting for it in a base station.
- Identity (IDN): When a mobile establishes a data link with a new base station, the mobile must inform the base station about its network layer address so that routing information can be correctly set up.

The CL protocol is used to transfer messages and routing information for mobile units in a pico- or micro- cellular environment. These cells have the diameter of the order of only tens of meters. The small cell size makes the handoff between cells frequent even at pedestrian speeds. Note that although CL protocol was originally designed for UMTS, its interface independence guarantees that with little modification it can be employed in hybrid wireless systems designed using vertical handoff [4]. This is the primary motivation for this work. However, if employed in hybrid wireless systems that are designed using vertical handoff, one cannot expect the access tree to have any predefined structure and a handoff may be performed between any two arbitrary nodes.

### 3. ASSUMPTIONS AND THE MODEL

Henceforth we assume that each mobile unit arrives in the network at a random time and immediately generates a data unit for transmission. The propagation time between a mobile unit and a base station is a random variable. With a probability  $p$  it will stay in the coverage area of its currently serving base station. With a probability  $1-p$  after a random time  $T_h$ , it will be handed off to a neighboring base station. The number of handoffs allowed in the system is predefined to be equal to HANDMAX. The mobile unit stays within a coverage area of the access network either until it receives a protocol data unit (PDU) confirming the receipt of original message or until it is handed off to another access network, i.e. until it exhausts the number of handoffs allowed. When the access network confirms the reception of a data unit by an addressee the mobile unit leaves the system.

An access network is represented by a queuing system that has a tree structure. Each node  $v_i$  in the tree represents a base station/routing node, each edge  $(v_j, v_k)$  in the tree represents a connection between node  $v_j$  and node  $v_k$ . With each edge  $(v_j, v_k)$  in the tree is associated random time  $t(v_j, v_k)$  that represents the propagation time of a PDU between nodes. We assume that processing time in the node is negligibly small compared with the propagation time and therefore the processing time is considered to be instantaneous. The root  $v_0$  of the tree is associated with a random time  $T(v_0)$  that represents a roundtrip travel time of a PDU in the backbone, which may be a PSTN. For performance evaluation purposes a tree structure with  $N$  leaves is chosen at random assuming that all trees with  $N$  nodes are equally probable. A Single source generates the appearances of mobile units in the system (calls) at a random intensity that is distributed between base stations. In particular, under the above assumptions a single call transition evolution can be described by the state transition diagram in Fig. 3. A simulation is based on the assumption that a number of mobile units that are expected to arrive in the access network during a time of simulation do not exceed some predefined value MAXUNIT. This number  $N_a$  (MU) is considered to be a random variable equally distributed between 1 and MAXUNIT. The next arrival of a mobile in an access

network is modeled by a random single source generating a next arrival time. With a probability  $1/N_a$  it is considered to be a call from a unit  $U_i$ . Each unit is initially randomly assigned to a base station with the assumption of uniformity. The handoff simulation procedure

*CURRENT* becomes equal to  $B_S$  or when the height of the tree reaches  $N$ . It is assumed that only the base stations (BS) at the bottom of the tree handle the mobile units. All other BSs are considered to be switches/routers that route messages to their destinations.

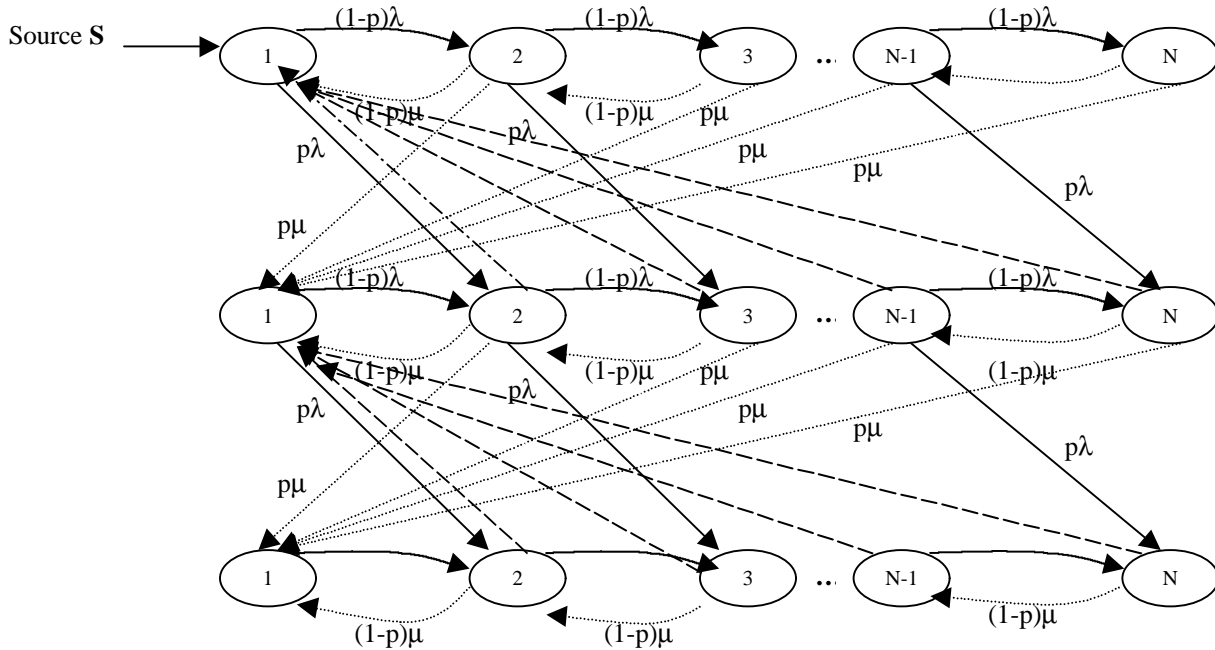


Figure 3: Call Evolution

simulates handoff process by randomly deciding if a handoff is going to take place or not, if there is a handoff, it generates a random time associated with this handoff. The latter results in updating the assignment of a new leaf base station to the mobile unit and updating the translation tables of routing nodes.

#### 4. PROTOCOL BEHAVIOR AND ITS SIMULATION BY THE ALGORITHM

The Access Network Structure Generation: The simulation begins with the generation of an access network structure. The algorithm generates a random tree by using the following randomly generated data:

1. random height  $N$  of a tree between 2 and MAXHEIGHT,
2. random number of nodes (routers/base stations)  $B_S$ , in the tree between 2 and MAXBS.

Then the maximal branching degree  $D$  of the tree is computed. We assume that the above variables are uniformly distributed over corresponding intervals. To begin with, node 1 is taken as a root of the tree and it is considered as *WORKING* node and *CURRENT* node. For each *WORKING* node a random number between 1 and  $D$  is generated and the nodes with the numbers  $CURRENT + 1$  to  $CURRENT + D$  are made children of a *WORKING* node with values of *WORKING* and *CURRENT* adjusted correspondingly. The tree generation stops when

Note: When creating a 'left-child/right-sibling' representation of the tree a field must be left for a number of this node in lexicographic ordering. This trick helps to determine the least common predecessor of two nodes efficiently. The latter is very useful when processing of events simulates handoff. Each node in the tree is also represented by its translation table, i.e., by a buffer that contains all received but unconfirmed messages. Therefore, a node in the access tree must also contain a pointer to the translation table buffer.

Discrete Event Simulation Procedure: The recurrent discrete event simulation procedure is based on the analysis of calendar queues [6]. It chooses a next-to-happen event, processes it, and then generates a chain of 'look-ahead' events in the future that cannot be affected by any intermediate event that may happen between current simulation time and the time when look-ahead event happens. This strategy is known as flow-event processing [5]. The look-ahead events can be processed simultaneously with the causing event and do not require a return to the expensive recurrent procedure of calendar queue analysis. Upon completion of processing of an event the algorithm returns to a calendar queue analysis. The initialization step of the algorithm involves generating an exponentially distributed random variable with a given parameter  $\lambda_s$ . This event models the arrival of a mobile unit in the access network. Each mobile unit is randomly assigned to the base stations at the bottom

level of the tree with a probability  $1/N_l$  where  $N_l$  is the number of leaves in an access tree. This event is added to a calendar queue and the recurrent procedure of calendar queue analysis is called. Processing of the next-in-queue event depends on the type of event. The latter could be mobile-unit arrival with no handoff in future and mobile-unit arrival with handoff in future. To determine which type of event is in order, the algorithm generates a random number  $0 \leq h \leq 1$ . If  $h < P$  then handoff is expected; otherwise no handoff is expected.

Message transfer without handoff: When a mobile terminal initiates a call, it first registers with the nearest base station and establishes a radio link with that base station. In the simulation, this event corresponds to generating a value of an exponentially distributed random variable with a given  $\lambda_s$ . The simulation assumes a negligible processing delay at each node, taken as zero units. The propagation time from a mobile unit to the nearest base station, the propagation time from a base stations to an immediate switches/routers, the propagation time between switches, and the travel time through the PSTN are generated according to exponential distribution with corresponding rates. After initial call generation the simulation procedure as pertained to this call is iterated repetition of the following event sequence simulation:

- Arrival of the message at upper level node after a time  $t_u$ ,
- Buffering of the address of the data unit and of the data link connection,

This procedure is repeated depth-of-the-tree number of times until a root of the tree is reached. At this point the roundtrip delay through the PSTN is computed and the event of corresponding to response arrival is generated. This event triggers a procedure of down propagation that consist of message retrieval from the buffer and arrival of the message in the lower level node after the time  $t_d$ . This procedure is iterated depth-of-the-tree number of times until a leaf of the tree (MU) is reached.

Denote the propagation time between a MU and the base station by  $t_{init}$ , the propagation time between switches  $t_p$ , the one way propagation time through backbone network  $t_{PF}$ , the propagation time down the tree between switches  $t_{DP}$ . The propagation time from base station to MU is denoted  $t_{ini}$ . Then the total time taken by an uplink message to reach the destination and the downlink message to reach the mobile unit  $t_{Tot}$ , is computed as

$$t_{UP} = t_{init} + N * t_p + t_{PF}$$

$$t_{DP} = t_{PF} + N * t_p + t_{ini}$$

$$t_{Tot} = t_{UP} + t_{DP}$$

In the case of no handoff we compute  $t_{Tot}$  for a call as above using the simulation results.

Obviously all the events of the scenario of message with no handoff are independent of other events that could possibly occur in the network and constitute a flow. Therefore, the message-transfer-without -handoff algorithm would be to:

- set initial flow-time to the time of causing event;

- generate random time corresponding to the next event;
- add/remove a representation of a data unit to a data structure that represents a node where the event must occur;
- compute necessary data;
- designate next event;
- go to the beginning of the loop.

When the flow is processed, a new random variable is generated that represents the arrival of a new mobile unit/handoff and adjoined to the calendar queue.

Message transfer with handoff: Mobile units are always handed off to the immediate neighboring base stations. The parameter  $\lambda$  for the propagation time at each node is defined as in message transfer without handoff. With a probability  $p$ , a MU may be handed off to another BS node. If this simulated event happens, two streams of events are triggered:

Stream 1. After a randomly generated time the address of MU is deleted from the buffer representing the node. A new event is generated representing the arrival of delete

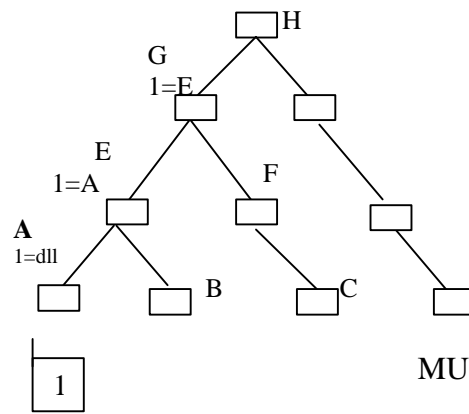


Figure 4: MU 1 establishes a route with BS A

message to the upper level switch. This event triggers the iterated procedure below that is called with parameter representing the new base station: if the passed parameter (new base station number) is outside the scope of this switch delete the message representation from the buffer and generate a new event of arrival of message in the upper level switch. Otherwise stop.

Stream 2: after a random generated time of handoff the event of message arrival at a base station is generated. Form here go to the modification of upper propagation procedure that was used in message without handoff transfer. The modification consists of checking if the message representation already exist in the node buffer. If it is found return to original stream of events.

Consider the network in Fig. 4. It reflects the state before the handoff. The network after the handoff is given on Fig. 5.

The time taken by the message to propagate through the old route is considered as the handoff delay  $t_{HD}$  and is added to the  $t_{Tot}$  time of that message. Therefore,  $t_{Tot}' =$



## 6. SIMULATION RESULTS

Simulation is performed using statistical sampling of random tree models. With each tree model, simulation is executed on different number of mobile units ranging from 10 (MINUNIT) to 200 (MAXUNIT). For each set of mobile units, the simulation is done over hundred times and the mean of  $t_{Tot}$  is calculated. The probability density function for a set of mobile units is also plotted to verify the exponential distribution that has been used to calculate propagation time at each node. Below we present in graphical form the results of the performance analysis of the protocol obtained by collecting simulation statistics.  $\lambda_i$  is the rate of message arrivals. The following values derived from [3] are used in a simulation:

- $\lambda_s = 0.735$  is a rate of propagation on the radio interface;  $\lambda_m = 0.00735$  is a rate of propagation time at the PSTN network,
- $\lambda_{bs} = 0.60$  is a rate of propagation time from BSs to the switches,
- $\lambda_{ss} = 0.35$  is a rate propagation time between switches.

The different randomized parameters used in the simulation are given in table 1. The number of levels,  $N$ , is a random number between 2 and MAXHEIGHT. The number of base stations in the network, the  $B_s$ , is a random number between 2 and MAXBS. The number of mobile units,  $M_U$ , is a random number between 1 and MAXUNIT.

$N$	Number of levels in the tree topology
$T(\lambda)$	Time generated using exponential distribution
$M_U$	Number of mobile units in the network
$B_s$	Number of base stations in the network

Experiment 1: For a particular tree structure the total

Table 1: Randomized Parameters

Experiment 1: For particular tree structure mean roundtrip time is evaluated for different number of mobile units with different  $T(\lambda)_s$  (see Fig. 6). As expected the mean roundtrip time stays constant for different number of mobile units because the processing time at each base/router station is assumed to be instantaneous.

Experiment 2: For a fixed number of mobile and a fixed tree model, the probability density function of the roundtrip propagation time is evaluated (see Fig. 7).

Experiment 3: Experiment 1 is repeated for a randomly generated access-tree and a mean roundtrip time is evaluated as a function of tree depth (see Fig. 8). It has been observed that as the number of levels in the tree

structure increases, the roundtrip propagation delay gets saturated. This seemingly surprising result may be attributed to the 'thinning' number of base station given a total number of nodes stay the same. The latter affects the number of handoffs for each MU. As the number of handoffs decreases the handoff delay  $t_{HD}$ , which is a part of the total roundtrip propagation delay, also decreases.

Experiment 4: The number of messages that require buffering due to handoff per base station is evaluated as a function of tree depth (see Fig. 9). The size of the buffer decreases at each node with increasing depth.

Experiment 5 is an extension of experiment 1. Roundtrip time is evaluated as a function of number of mobile units and tree depth. The results presented on Fig. 10.

## 7. CONCLUSIONS

This simulation shows that the protocol performs efficiently under realistic assumptions and indeed achieves considerable speed-up relative to architecture-independent protocols. However, the protocol is less efficient than it was announced in [3]. Its relative efficiency decreases with the number of nodes in the network

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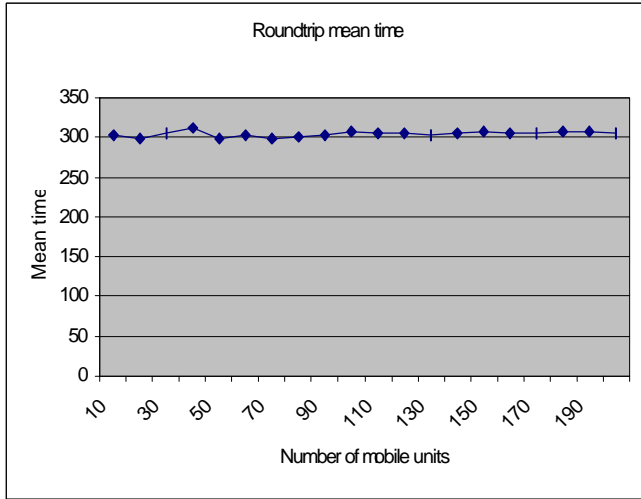


Fig. 6: Mean Round Trip Propagation Time

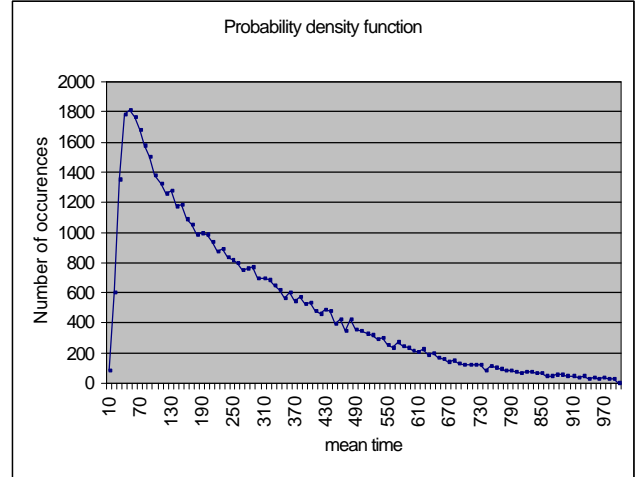


Fig. 7: Histogram for the Mean Roundtrip Propagation

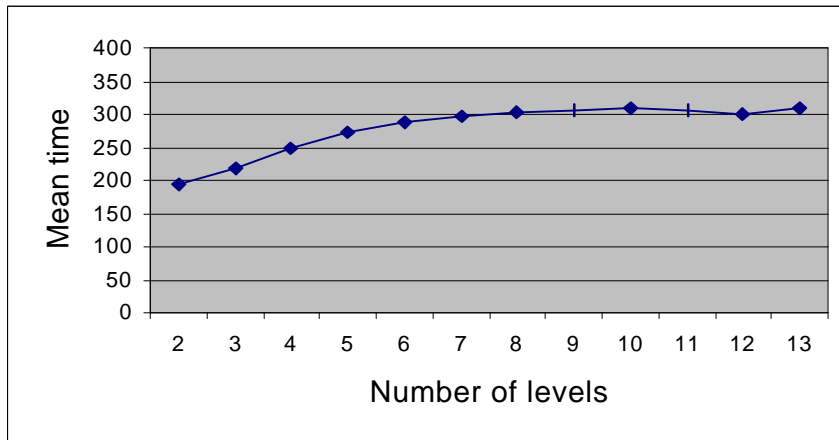


Fig. 8: Mean Roundtrip Propagation Time for Different Tree Structures

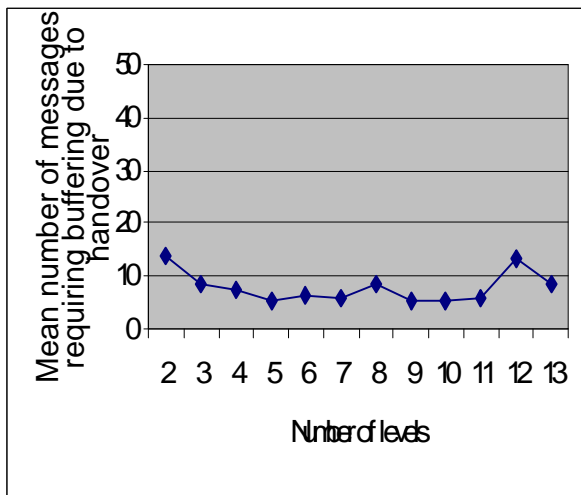


Fig. 9: Average Payload due to Handovers

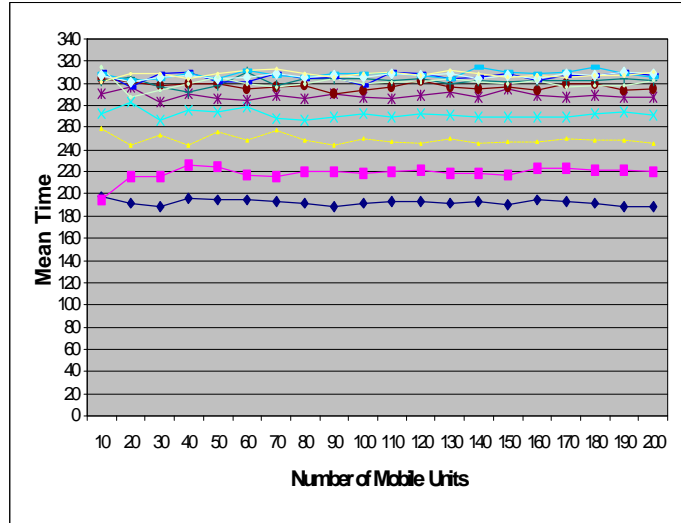


Fig. 10: Mean Roundtrip Propagation Time