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Queuing theory based Delay Analysis for Dual-homed UMTS Networks

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Abstract. Dual-homed cellular networks are useful for handoff minimization when the mobility of users is diurnal in nature [6-8]. In this paper, we have proposed a location management technique (LM-DH) for a dual-homed network using conventional location update and paging operations. We have modeled the complete network with the help of queuing theory in order to quantify the signaling delays involved in the system.

Keywords: Location Management planning, Cellular network, UMTS, Dual-homing, HLR, DLR, VLR.

I Introduction

Conventional UMTS Network is single homed [2]-[5] which has many-to-one mapping from NodeBs to Radio Network Controllers (RNCs) in tier-1 and the same from RNCs to Mobile Switching Centres (MSCs)/Serving GPRS Support Nodes (SGSNs) in tier-2. Current business challenge with a service provider is to cope up with the falling Average Revenue per User (ARPU). This problem can be addressed partly by an efficient utilization of network infrastructure including scarce resource like spectrum. Traditionally this is mapped as a network planning problem. In literature, people have considered the planning problem as pre-deployment and post-deployment. Even pre-deployment planning to optimize total cost of operation (TCO) for a network is done properly, over years with the evolution of settlement (schools, colleges, malls, railway stations, residential complex etc.) in an area TCO increases. This calls for post-deployment network planning. In case a certain percentage of MT users exhibits a diurnal pattern dual homing may be a solution for TCO optimization.

Planning of dual-homed cellular network is studied by [6-8] with respect to minimization of TCO in post deployment phase of the network where two dominant costs like handoff cost

and amortize cable cost was considered. The paper [7] shows that some inter MSC handoff cost can be reduced to intra MSC handoff cost due to dual homing of RNCs. With the change in proposed network structure with respect to connectivity there is a need to modify the location management processes for single-homed network namely, location update and paging, to realize the benefit of the new dual-homed structure.

No study has been made with respect to location planning and management in dual-homed cellular network. The frequency of update depends on the mobility pattern of the MT whereas the frequency of paging depends on call arrival rate to the MT. Inter/Intra MSC handoff needs LA update operations of the MT. The paging operation is needed when there is a call for the MT and the network must locate the MT to deliver the call [14]. An important research issue for location management is minimizing the network signaling cost. In a single-homed cellular network, when a MT crosses the current LA boundary, the most expensive LA update request from MT reaches to HLR via serving VLR whereas the most inexpensive update request from MT ends at serving VLR. Some algorithms avoid the expensive update to HLR, use forwarding chain of pointers to current serving VLR till some threshold on the forwarding chain length is reached when the update to HLR is made and chain length is reset to zero. For call delivery, the VLR of the calling MT sends a location request message to the HLR of the called MT which forwards the route information (obtained from VLR of the called MT) to the VLR of the calling MT. In this paper, we have assumed that only RNCs can be dual-homed, i.e. one RNC can be connected to two MSCs via one primary link and one secondary link. One LA is the geographical area under the set of NodeBs connected via primary links of one MSC. When an MT sends a location update message to RNC, the message is sent to the primary MSC for necessary updates at the location registers. By this configuration an MSC can have multiple number of primary links and multiple number of secondary links. Figure 1 shows a dual-homed cellular network (where RNC is dual-homed) and its associated HLR/VLR.

The outline of this paper is as follows. Following introduction (Section I), problem description and related works are presented in Section II. LM-DH is described in Section III. Section IV presents the signaling delay analysis. Section V contains the experimental results with discussion. Section VI concludes the paper.

II Problem Description & Related Works

A dual-homed RNC will have two links connecting to two different MSCs. The link belonging to a single-homed network configuration (derived from pre-deployment network planning) is called primary link. The other link connecting to second MSC (derived from post-deployment network planning) is called secondary link. A MSC is said to be a primary (secondary) MSC with respect to a RNC, if the RNC is connected to the MSC via primary (secondary) link. Since at any point of time, a MT is under one RNC, so the RNC's primary (secondary) MSC is also said to be the MT's primary (secondary) MSC. LA is defined as a set of cells under primary links of a MSC. When a MT changes its LA, there will be correspondingly a change in its primary MSC. In Fig 2, there are three LAs, namely, LA-1, LA-2 and LA-3 which consist of the cells {cell-1,cell-2,cell-3,cell-4}, {cell-5, cell-6} and {cell-7, cell-8} respectively. The primary

and secondary MSC of RNC-2 is MSC-1 and MSC-2 respectively. MSC-2 has two primary RNCs (RNC-3 and RNC-4) and one secondary RNC (RNC-2). The primary and secondary MSC of MT when residing in the cell-3 is MSC-1 and MSC-2. The primary MSC of MT when residing in the cell-2 is MSC-1 and has no secondary MSC.

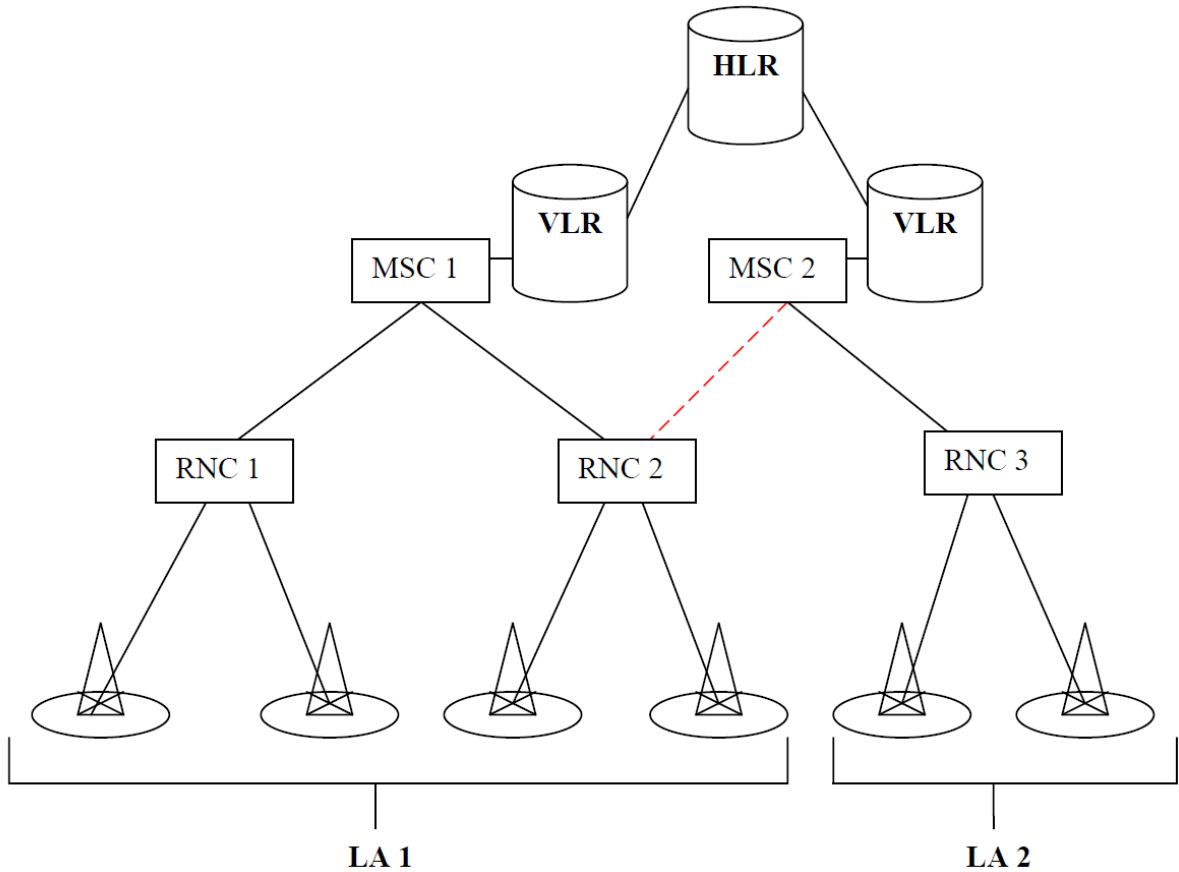


Fig 1: A dual-homed cellular network and its associated VLR/HLR

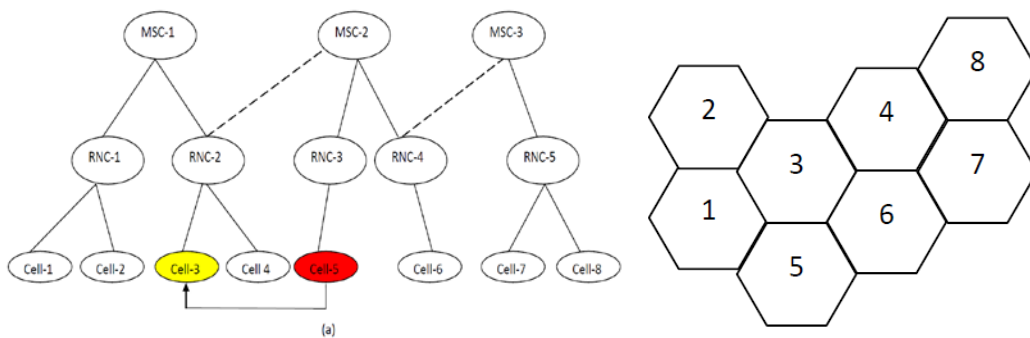


Fig 2: Movements of an MT in the network and geographical adjacency of the cells

Recent research efforts [1]-[4] provides schemes for location management in cellular networks. In [1], the authors have proposed a selective location update strategy. Their proposal is based on the location areas approach. The idea behind their proposal is that it is a waste of scarce wireless bandwidth to do location update at the location area where a mobile station stays for a very short interval of time and has an extremely low probability of receiving a call. In their proposal, each subscriber updates only in certain pre-selected location areas, called *update areas*, based on his/her own mobility pattern. The authors in [2] have discussed the location area planning based on the mobility characteristics of each individual mobile subscriber or a group of mobile subscribers. In [3], the authors have introduced a location management mechanism that incorporates the distance based location update scheme with the selective paging mechanism that satisfies predefined delay requirements. Simulated annealing algorithm is used in [4] to get optimal result for LA planning in cellular network. Simulated annealing give optimal results in acceptable run-time.

There also has been extensive work in the analysis of delay probability [10][12][13] in CDMA systems. A hybrid of TDMA and CDMA or the so-called time slotted CDMA is a popular mainstream multiple-access technique in coordinating resource to accommodate a number of traffic connections/sources. In [10][13], delay analysis for S-ALOHA based random access method for CDMA system is shown. In [13], closed-form equations are developed for collision process of arriving random access packets in slotted-offset and slotted-ALOHA random access channels. Performance analysis of signaling delay of GSM wireless network is presented in [9] using queuing network [11].

II Description of LM-DH

Like single-homed network, two registers, namely, HLR, and VLR are used to keep location management information in dual-homed network. In a dual-homed network, it is possible the MT is connected to two MSCs (at the most) through a RNC. In such case, the MT will have one primary MSC and one secondary MSC. In this setting, if MT moves to another LA, its primary MSC will always change and a LU is made at HLR.

The HLR stores the location management information of the MT, for which the location area is home location. The VLR of the primary MSC of the MT stores the location management information of the MTs who are visiting the location area. When MT changes its LA, it sends the LA update message to primary MSC via the RNC. An HLR update is made when MT enters a location area with new primary MSC in its new LA. The flowchart for location update LM-DH for dual-homed network is given in the Fig 3.

Location search is made when an MT (calling MT) wants to make a call to another MT (called MT). The calling MT sends a call request message to its RNC, which in turn forwards it to its primary MSC. The primary MSC then, find the called MT's HLR address and send a route request to the HLR. The HLR queries the VLR of the called MT and after getting response of route information from the VLR, send the route information to the calling MSC. The flowchart for location search LM-LS for dual-homed network is given in the Fig 4.

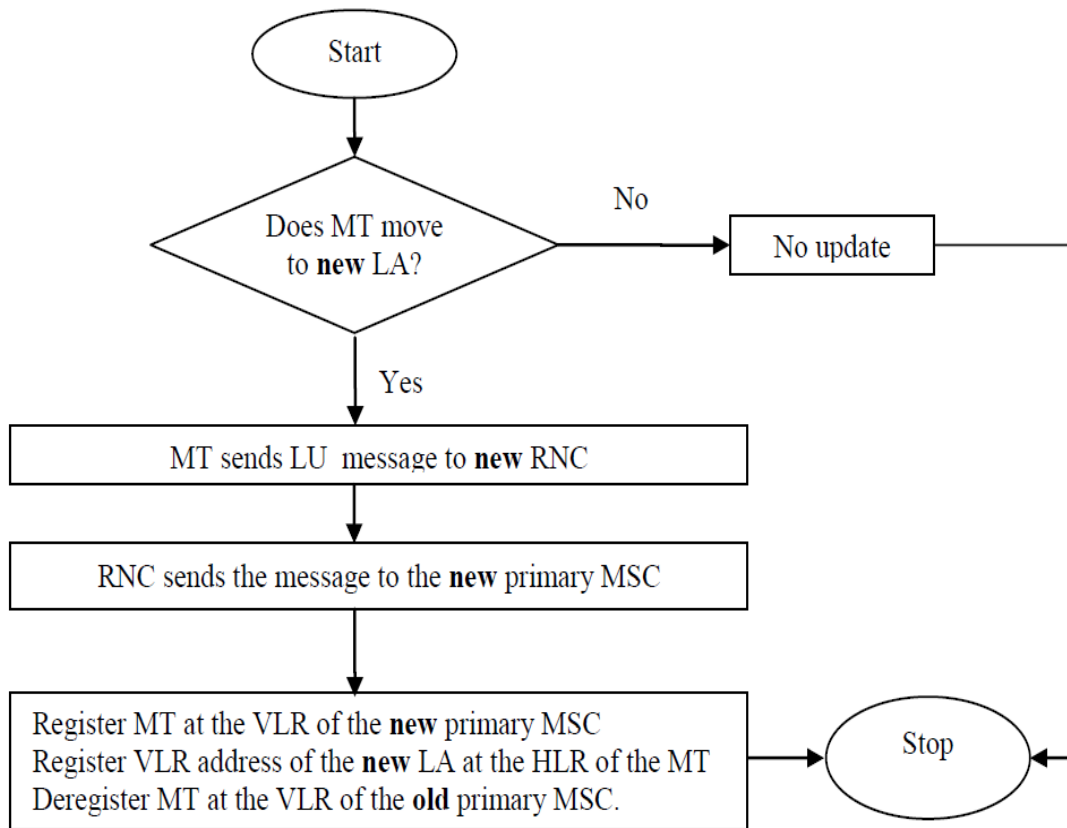


Fig 3: Flowchart of LM-DS for location update in dual-homed cellular network

Example - 1:

Let us consider a scenario (Fig 2) where a MT moves from cell-5 to cell-3. There is a change in LA. MT moves from a single-homed RNC to dual-homed RNC. The MT is presently in cell-3. Now the MT sends location update message to RNC-2 which is forwarded to primary MSC-1. According to the flowchart, MT is registered at VLR of MSC-1 and LU update is made at HLR.

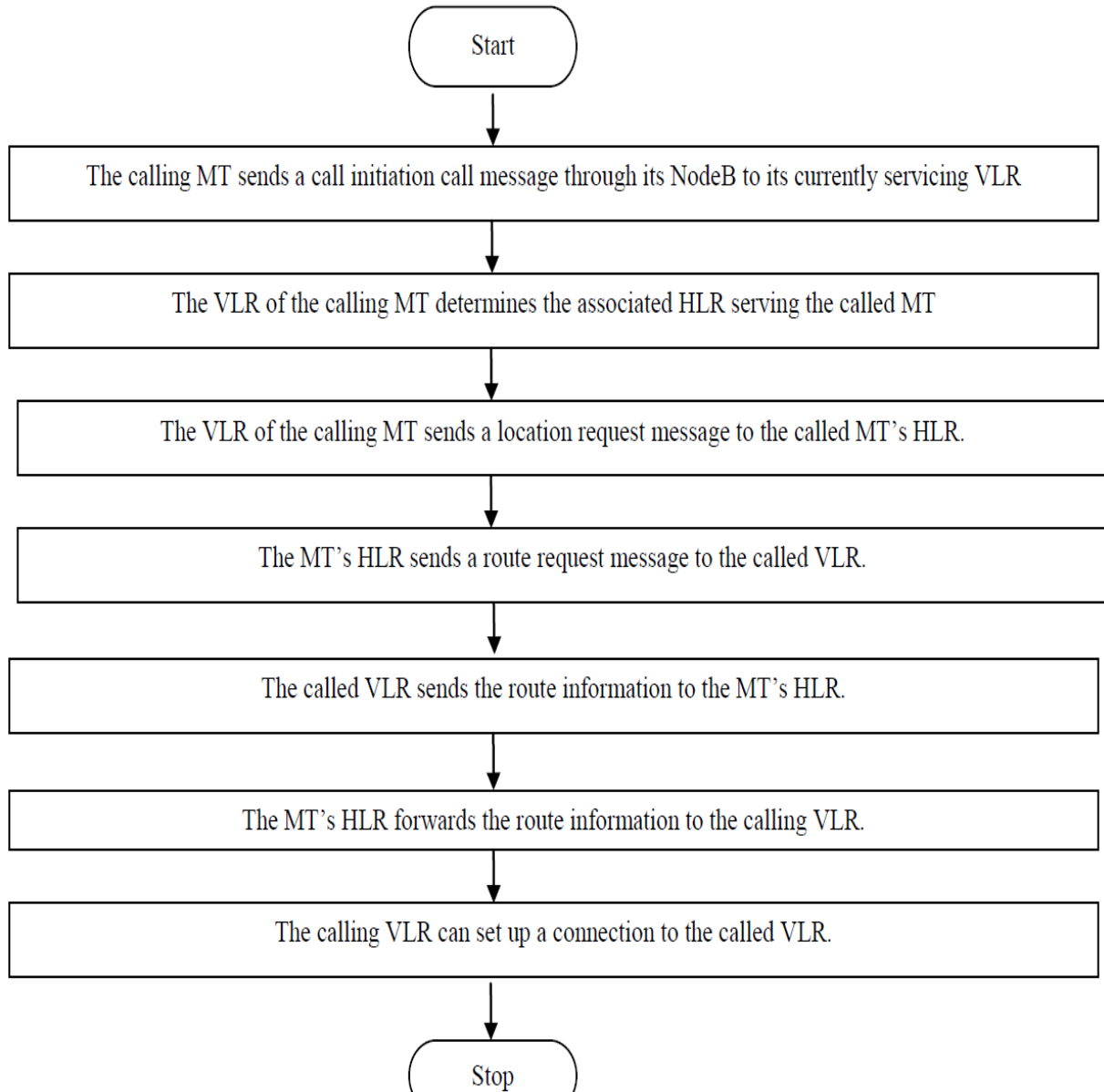


Fig 4: Flowchart of for location update in dual-homed cellular network

Example-2: Let us consider that a MT is currently within LA 1, which in turns is under RNC 1 (Fig 5). The HLR of the MT will contain the VLR (VLR-1) address of the LA in which it is currently residing and the VLR (VLR-1) of the primary MSC 1 stores MT's registration. When it moves to LA 2, the location update will be as follows: MT will register itself in the VLR (VLR-2) of the MSC 2 and enter address of VLR-2 in the HLR (Red entries). It will deregister at VLR (VLR-1) of the MSC 1.

The current location of the MT will be search as follows: Let MT' be the calling MT and MT be the called MT. The VLR of MT' determines the called MT's HLR and sends a location request message to the MT's HLR. The MT's HLR determines the called VLR (VLR-2) and sends a route request message to VLR-2. The called VLR (VLR-2) sends the route information to MT's HLR. MT's HLR forwards the route information to the VLR of MT' . Now, the VLR of MT' can setup connection to the called VLR (VLR-2).

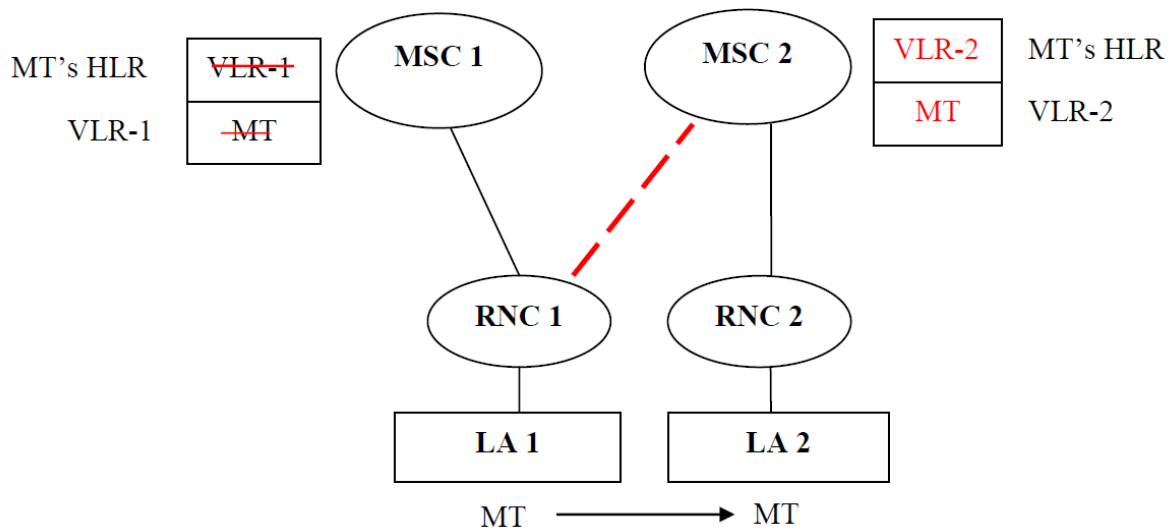


Fig 5: HLR/VLR entry during LU in dual-homed cellular network

IV Signaling delay analysis

We assume that a dual-homed UMTS network has all the usual components, namely MT, NodeB, RNC and MSC. The network has one logical HLR, and each MSC has one VLR. One RNC can be connected to at most two MSCs. We represent $MSC(P)$ and $MSC(S)$ to denote the primary MSC and secondary MSC respectively of an RNC. Each LA has its dedicated $MSC(P)$. In this paper, we evaluate the signaling packet delays involving location update (LU) and paging (PG) operations.

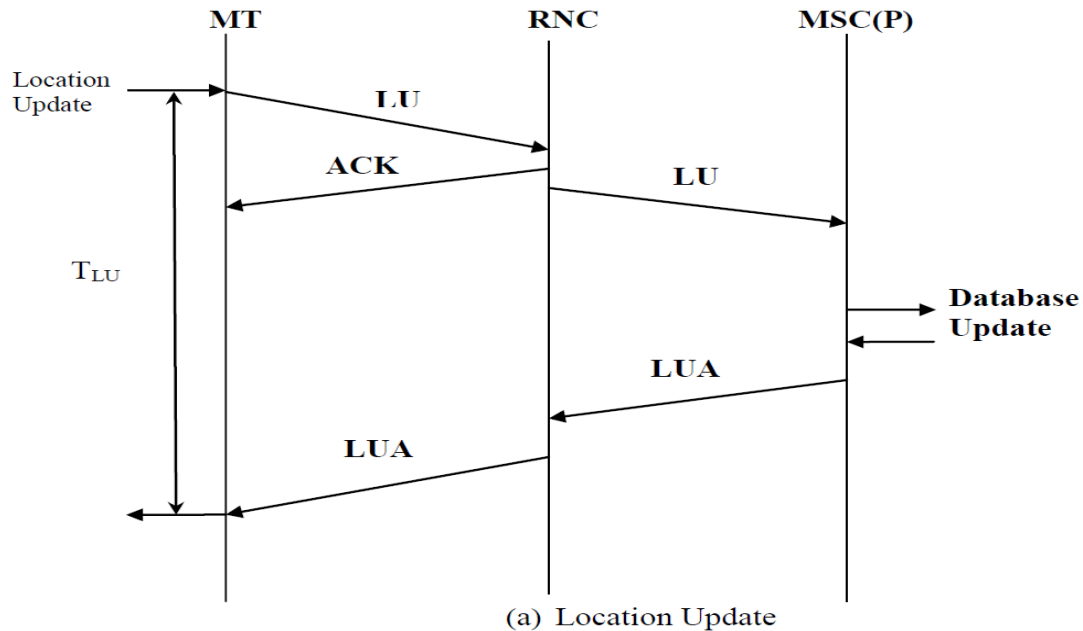
When an MT crosses LA boundary, it generates an LU packet, by which the involved RNCs are informed of the location change of the MT. We divide the MTs into two types: busy and idle. If an MT is making/receiving call, it is said to be busy; else idle. For an idle MT, two types of call arrivals are possible: (i) outgoing call initiated by MT by sending a CR (call request) packet to RNC. We denote this call as MT-originating call. (ii) incoming call initiated by another MT (say MT') and the call is targeted for the MT under consideration. Here the MT will receive a PG packet (issued by MSC) and issue a CR packet in response to it. We denote this call as MT-terminating call. When an MSC receives an MT-terminating call request for the

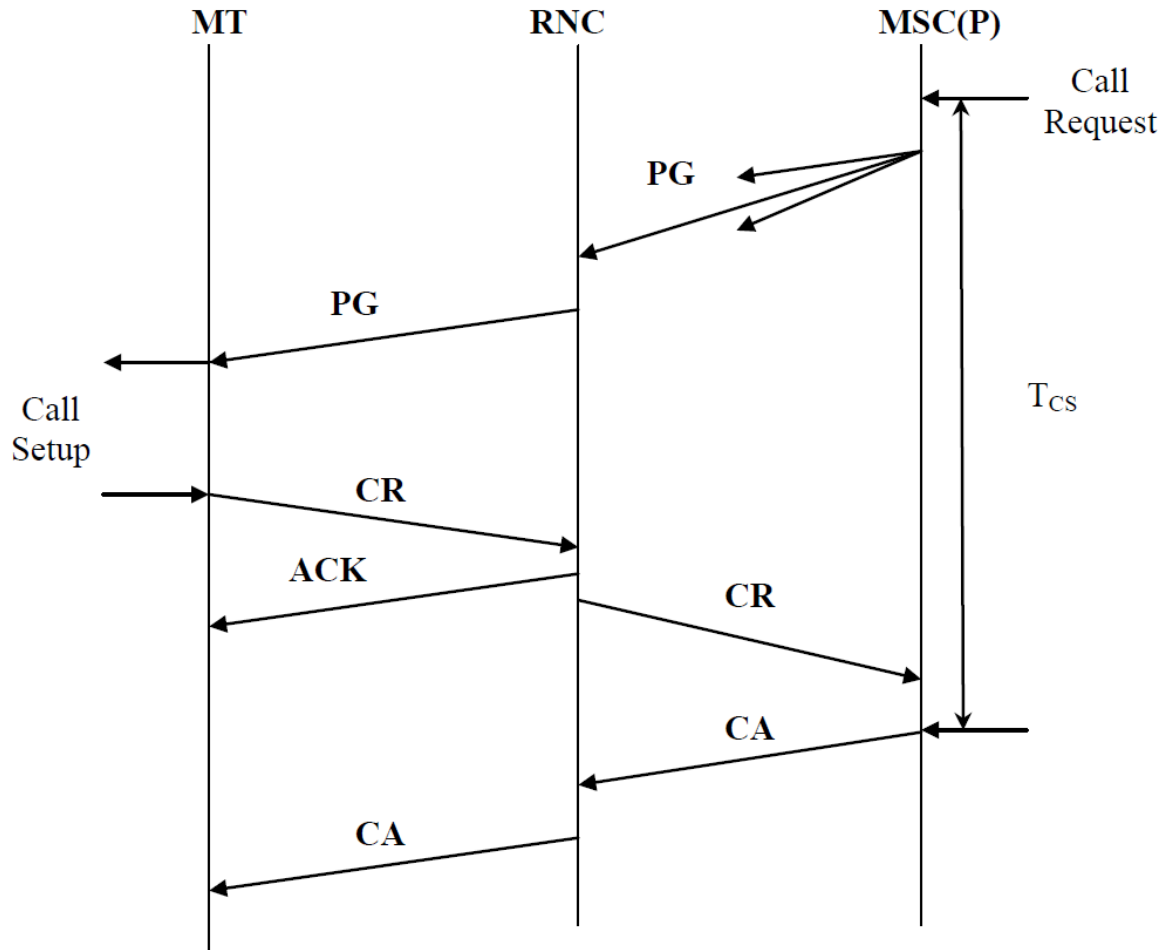
MT within its LA, PG packets are broadcast by MSC to RNCs in the LA and subsequently by RNCs to NodeBs to alert the MT of the incoming call. Upon receipt of the response from the destined MT, the call setup becomes possible.

W-CDMA random access (RA) channel is used by MT to originate calls, response to a RNC 'page' and perform MT location registration updates [13]. In CDMA/TDD mode, code, frequency and timeslot define a physical channel. The wireless channel uses multiple access method, in which the RA channel assumes that any two simultaneously arriving RA packets who arrive on the same timeslot and signature code will collide and their RA attempts will be unsuccessful, which results in re-transmission of the RA packets after a random waiting period [10].

A signaling packet experiences transmission delay on wireless channel (both uplink and downlink), processing delays at different switches, such as NodeB, RNC and MSC, and processing delay at the wired network. Fig 6a and Fig 6b show the flow of signaling packets for LU and the flow of signaling packets for MT-terminating call setup respectively.

LU processing delay (T_{LU}): The flow of LU request is MT → RNC → MSC(P) and the corresponding LUA (location update acknowledgement) is returned as MSC(P) → RNC → MT





(b) Location Search & MT terminating call setup

Fig 6: Sequence diagram of flow of signaling packets for location update & MT-terminating call setup

Location search & Call setup processing delay (T_{CS}): The flow of LS (location search) request for MT-terminating call is $MSC(P) \rightarrow RNC \rightarrow MT$. T_{CS} is the time from the arrival of call request at $MSC(P)$ to the time when its response is sent to the wired network. For calls destined to some other MT, PG packet is broadcast from $MSC(P)$ to RNC in its LA, and sent to MTs via NodeB. Then the corresponding MT generates CR packet which is returned to the wired network.

To analytically derive processing delays, we build a queuing network model as depicted in Fig. 7, Fig 8 and Fig 9 for dual-homed UMTS network. We define the following queues.

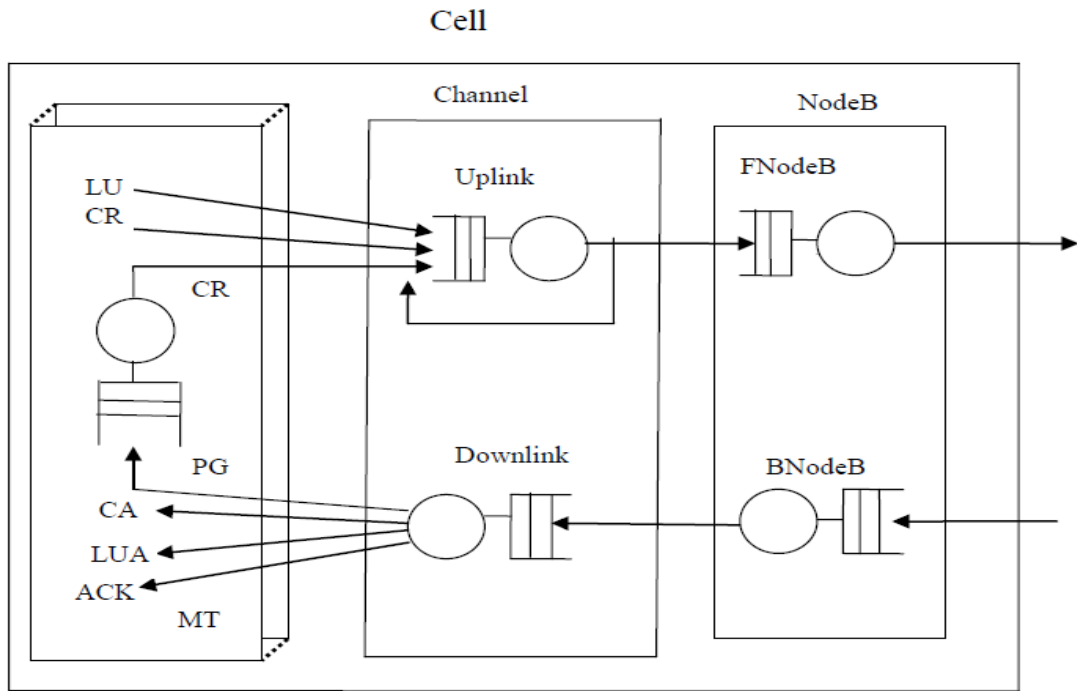


Fig 7: Queuing Network of a cell

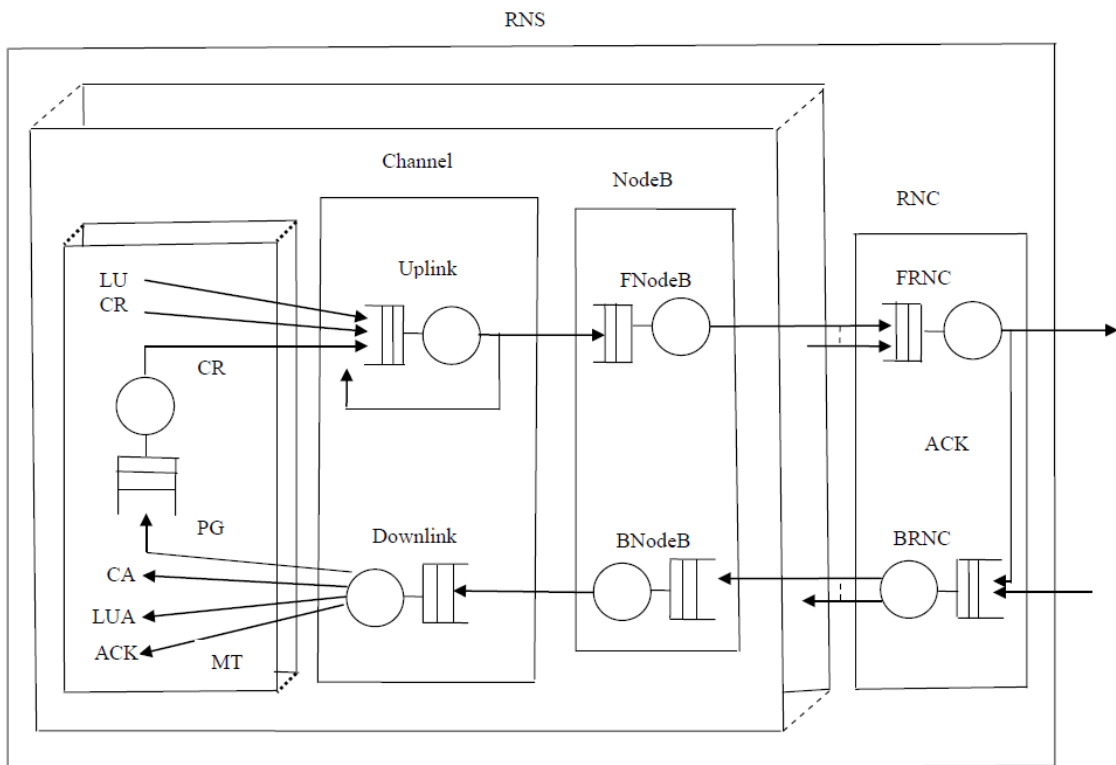


Fig 8: Queuing Network of Radio Network Subsystem (RNS)

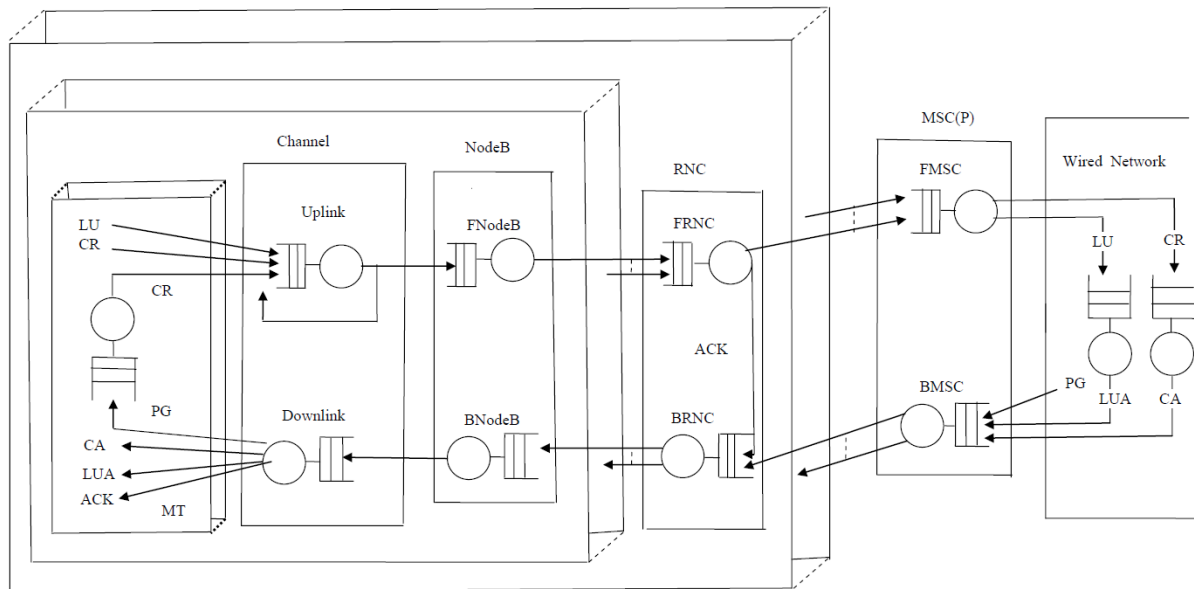


Fig 9: Queuing Network of dual-homed cellular network

1. WCU (wireless channel uplink) queue: The uplink is contended by CR and LU packets and CR packets (in response to PG packets). The delays of those packets are determined by the approximate analysis which takes into account collision of the packets due to the multiple access protocol on RA channel of the W-CDMA in UMTS.
2. WCD (wireless channel downlink) queue: The packet delay at the downlink queue can be modeled by (M/D/1) queue processed in FIFO manner since the RNC can actively schedule the CA, LUA, PG and ACK packets transmission on the wireless channel.
3. FRNC (forward RNC) queue: When RNC processes the LU and CR packets, it returns acknowledgement (ACK) to the sending MT via the corresponding NodeB. At the same time RNC forwards the LU packet to MSC(P) and MSC(S) and CR packet to primary MSC. The packets are processed in an FIFO manner and we have modeled FRNC queue as an M/M/1 queue.
4. BRNC (backward RNC) queue: Signaling packets coming from MSC(P) and MSC(S) are processed in an FIFO manner at the RNC, modeled as M/M/1 queue.
5. FMSC(P) (forward MSC - primary) queue: MSC(P) handles incoming packets from RNCs within its LA. Those packets are processed in an FIFO manner (M/M/1 queue) and forwarded to the wired network.

6. BMSC(P) (backward MSC - primary) queue: CA and LUA packets are returned to RNC by MSC(P). PG packets coming from the wired network are also forwarded (broadcast) to the RNCs under this MSC. Those packets are processed in an FIFO manner and the queue is modeled as M/M/1 queue.

7. CR and LU queues: We assume two queues, one for CR packets and other for LU packets, are used for calculating the processing delays at the wired networks. We use infinite server queues for the scheduling discipline.

Let us consider that there are a nodeBs, b RNCs and c MSCs in the dual-homed cellular network. Let $I = \{1, 2, \dots, a\}$ denote the set of NodeBs, $J = \{1, 2, \dots, b\}$ denote the set of RNCs, and $K = \{1, 2, \dots, c\}$ denote the set of MSCs. There can be at most one connection (one link) from NodeB to RNC and at most two connections (one primary link and one secondary link) from RNC to MSC. Throughout this formulation we will use a small letter to denote a member of the set represented by the corresponding capital letter; for example, $i \in I$, $j \in J$, $k \in K$. A cell is a wireless coverage area under a NodeB. Let NodeB- i denote the i^{th} NodeB. Similarly for cell- i , RNC- j and MSC- k . Let us consider the following binary variables:

$e_{ij} = 1$, if NodeB- i is connected to RNC- j via a link, 0, otherwise

$e'_{jk} = 1$, if RNC- j is connected to MSC- k via a primary link, 0, otherwise

Table I: List of Symbols used

Symbol	Description
N_{MT}^i	Number of MT in cell- i
λ_T	MT-terminating call rate
λ_0	MT-originating call rate
$1/\mu$	Average call duration of a MT
$1/h$	Average MT sojourn time in a cell
$1/\mu_{MT}$	Average processing time in MT
$1/\mu_{RNC-j}$	Average processing time in RNC- j
$1/\mu_{MSC-k}$	Average processing time in MSC- k
$1/\mu_{CR}$	Average call setup time
$1/\mu_{GLU}$	Average global location update time
s	Total no. of signatures
T	Slot time
$(0, R)$	Random number range
δ	Re-transmission time in number of slots
$D_{TU}^i(*)$	Transmission delay on device uplink.
$D_{TD}^i(*)$	Transmission delay on device downlink
$D_{RU}^j(*)$	Processing delay on forward RNC- j
$D_{RD}^j(*)$	Processing delay on backward RNC- j

$D_{MU}^k(*)$	Processing delay on forward primary MSC-k
$D_{MD}^k(*)$	Processing delay on backward primary MSC-k
$D_{MP}^k(*)$	Processing delay for database update at the wired network for primary MSC-k
$D_{MT}^k(*)$	Transmission delay of call setup at MT.

The symbol ‘*’ used in the above table represents the type of signaling packets e.g. CR, PG etc. We assume the following:

1. Random variables which are exponentially distributed: (i) call duration in an MT (ii) MT’s sojourn time in a cell (iii) processing time at MT (iv) processing time at RNC (v) processing time at MSC (vi) call setup processing time in the wired network (vii) LU processing time in the wired network.
2. Random variables which are Poisson distributed: (i) MT-originating call arrival (ii) MT-terminating call arrival.
3. The transmission delay at wired network is zero because it is negligibly small compare to other delays.
4. No processing delay at any NodeB.
5. A busy MT cannot generate CR packets.
6. Each random variable is independently and identically distributed (iid).

We have distinguished the delays in each cell, in each RNC and in each MSC. Since the number of MTs in each cell is different, the average processing time in each RNC and each MSC are different. Moreover, the arrival rates of LA packets are different at each cell, according to the position of the cell in the location area [9].

The different delay components in LU is shown in Fig. 10. The total delay for location update T_{LU} can be obtained as follows:

$$T_{LU} = D_{TU}^i(LU) + D_{TD}^i(LUA) + D_{RU}^j(LU) + D_{RD}^j(LUA) + D_{MU}^k(LU) + D_{MP}^k(LU) + D_{MD}^k(LUA)$$

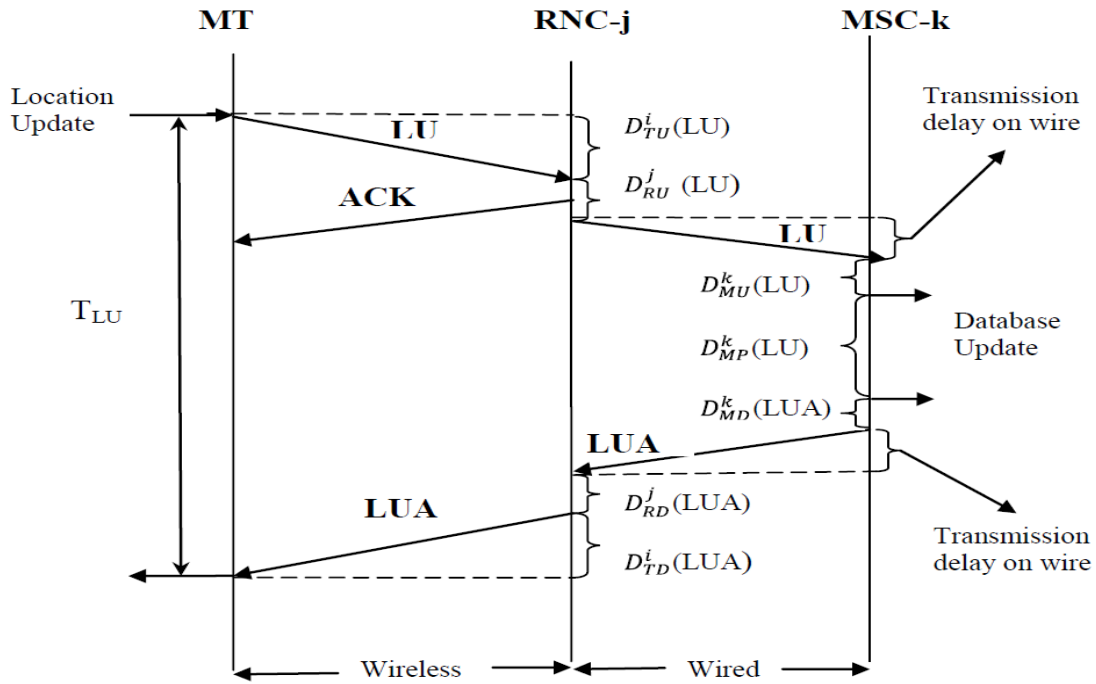


Fig 10: Location update messages flow and queuing delay

The different delay components in MT-terminating call setup are shown in the Fig.11. The total delay can be obtained as follows:

$$T_{CS} = D_{MD}^k(PG) + D_{MU}^k(CR) + D_{RD}^j(PG) + D_{TU}^i(CR) + D_{RU}^j(CR) + D_{TD}^i(PG) + D_{MT}(PG)$$

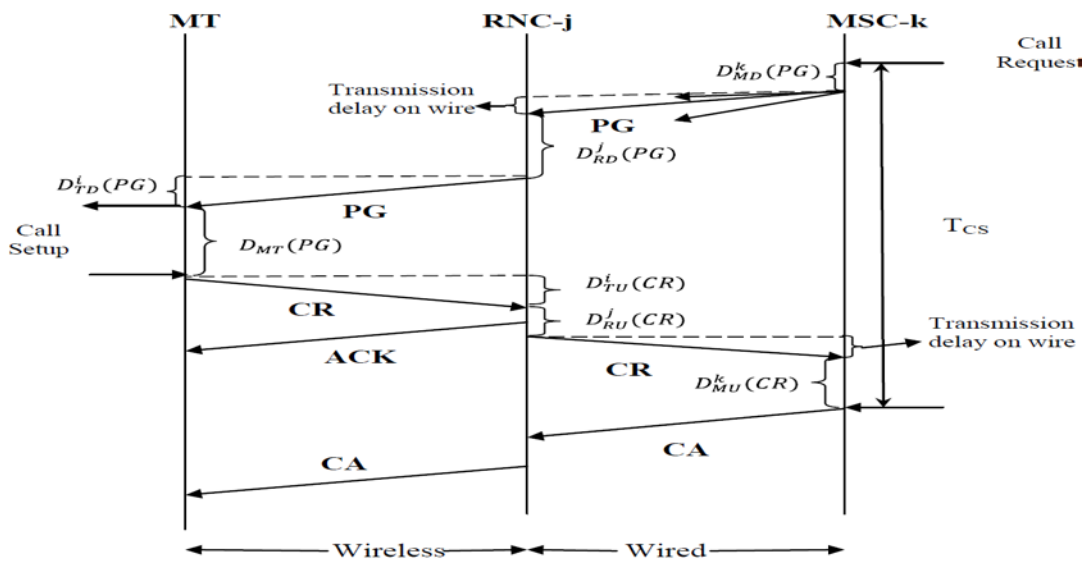


Fig 11: MT-terminating call messages flow and queuing delay

Let us assume that the NodeB-i is under the RNC-j which is under the primary MSC-k. Before we go into the analysis of the delay from the queues adopted here, we first calculate mean arrival rates of CR, LU, PG, CA, LUA and ACK packets at the uplink and downlink of cell-i which is under the location area k.

Let λ_{CR}^i be the CR packet arrival rate at uplink of the cell-i. CR packets are generated by the call request in both directions (MT-originating call and MT-terminating call). Moreover from our assumption, that a busy MT cannot generate CR packets, only idle MT can generate CR packets. Let p_{idle} be the probability that the MT has no active call. The average number of idle MTs of the cell-i is $p_{idle} * N_{MT}^i$. Then $\lambda_{CR}^i = (\lambda_o + \lambda_T) p_{idle} * N_{MT}^i$. To calculate p_{idle} , we assume each MT as M/M/1/1 queue system. Then $p_{idle} = \mu / (\mu + \lambda_o + \lambda_T)$

Let λ_{LU}^i be the arrival rate of the LU packets at the cell-i. We have

$$\lambda_{LU}^i = (p_{idle} * N_{MT}^i) * C^i * h$$

where C^i is the probability that the cell boundary falls in the boundary of the LA k [9].

So the total packet arrival rate is $(\lambda_{CR}^i + \lambda_{LU}^i)$ at the uplink of cell-i.

When the MT-terminating call arrives at MSC, it broadcasts PG packets to all its primary RNCs which in turn broadcast to all its NodeBs. Since the PG packets are broadcast by MSC and replicated by all its primary RNCs and respective NodeBs, each cell in the location area will experience the same PG packet arrival rate as experienced by the corresponding MSC. Let λ_{PG} be the PG packet arrival rate at the primary MSC-k. Then

$$\lambda_{PG} = \lambda_T * p_{idle} * \sum_{j \in J} \sum_{i \in I} e'_{jk} e_{ij} N_{MT}^i$$

By our assumption, the NodeB-i is under the RNC-j which is under the primary MSC-k. Therefore, the arrival rate of PG packets at the RNC-j and at the cell-i is also λ_{PG} each.

Since the MSC receiving CR and LU packets generates corresponding CA and LUA packets, those arrival rates are obtained as

$$\begin{aligned} \lambda_{CA}^i &= \lambda_{CR}^i \\ \lambda_{LUA}^i &= \lambda_{LU}^i \end{aligned}$$

Furthermore, RNC returns the ACK packet when it receives CR and LU packets correctly. The arrival rate of ACK packets is then given as

$$\lambda_{ACK}^i = \lambda_{CR}^i + \lambda_{LU}^i$$

We have the arrival rate of downlink at cell-i as follows:

$$\lambda_{DOWN}^{ki} = (\lambda_{PG} + \lambda_{CA}^i + \lambda_{LUA}^i + \lambda_{ACK}^i)$$

Analysis of uplink transmission delay: We assume that in the RA channel, any two simultaneously arriving RA packets on the same timeslot and signature code will collide and their attempt will be unsuccessful, which results in re-transmission of RA packet after a random waiting period [10]. To calculate the probability of delay, we first calculate the probability of multiple arrivals and collisions.

A. Probability of Multiple Arrivals: The probability that m MTs in a cell may try to access the system in the same slot depends on the amount of RA traffic. We assume a Poisson distributed arrival process with $\lambda = \lambda_{CR}^i + \lambda_{LU}^i$ in cell-i and use the following expression for the probability of m arrivals within [0,1) or one slot.

$$P_{m,\lambda}[0,1) = \frac{\lambda^m e^{-\lambda}}{m!}$$

where λ is the average number of RA arrivals per slot.

B. Probability of unique signature selection: Let there are s signatures S_1, S_2, \dots, S_s and m MTs. An MT can choose any one signature independent of other MTs. The total number of ways the m MTs can choose the signatures is s^m . Let n_r be the number of MTs that select the signature S_r . Then $n_1 + n_2 + \dots + n_s = m$. Let n be the number of MTs out of m MTs, that choose a signature not selected by any one else and rest select those used at least by one other MT. Then $\{|n_r : n_r = 1, r=1..s\} = n$

The probability of n signature uniquely chosen out of s signatures by n MTs out of m MTs is

$$P_s(m, n) = s^{-m} \sum_{\substack{n_1 + n_2 + \dots + n_s = m \\ |\{n_r : n_r = 1, r=1..s\}| = n}} \binom{m}{n_1 \dots n_s}$$

C. Probability of collision: The probability of signaling packet lost due to collisions can be written as [10]

$$P_{coll} = \frac{1}{\lambda} \sum_{m=2}^s \left[m P_{m,\lambda} \left\{ 1 - \sum_{\substack{n=1 \\ n \neq m-1}}^m \frac{n}{m} P_s(m, n) \right\} \right]$$

D. Total Delay:

The delay is calculated with the help of a generating function signal flow graph as shown in Fig. 12 and its associated generating function [15].

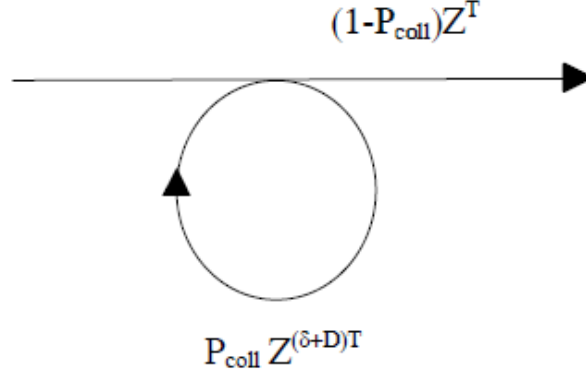


Fig 12: Signal Flow graph

All arriving packets are successful with a probability of $1-P_{\text{coll}}$. When a MT fails to receive an acknowledgement within δ slots after the transmission of the RA packet, it considers the transmission as unsuccessful and re-transmits the RA packet, using a newly randomly selected signature after a delay of D slots, where D is a random number uniformly distributed in $[0,R]$ [10]. The generating function can be written as

$$H(z) = \frac{(1-P_{\text{coll}})Z^T}{1-P_{\text{coll}}Z^{(\delta+D)T}}$$

The average delay of the system conditioned on D is obtained from:

$$E[\text{delay}|D] = \frac{d}{dz} \ln H(z) \Big|_{z=1} = T \left\{ 1 - \frac{P_{\text{coll}}(\delta+D)}{1-P_{\text{coll}}} \right\}$$

The average delay can be obtained after integrating over D

$$E(\text{delay}) = \frac{1}{R} \int_0^R T \left\{ 1 - \frac{P_{\text{coll}}(\delta+D)}{1-P_{\text{coll}}} \right\} dD$$

Thus the delay in terms of P , R , δ and T is

$$E(\text{delay}) = T \left[1 + \frac{P_{\text{coll}}}{2(1-P_{\text{coll}})} (R + 2\delta) \right]$$

Therefore, $D_{TU}^i(*) = T \left[1 + \frac{P_{\text{coll}}}{2(1-P_{\text{coll}})} (R + 2\delta) \right]$

Analysis of downlink transmission delay:

We approximately model the downlink queue as an M/D/1 queue where transmission time of signaling packets is T . then we obtain the downlink delay at cell- i as follows

$$D_{TD}^i(*) = T^2 \lambda_{DOWN}^i / (2(1 - T \lambda_{DOWN}^i))$$

Analysis of FRNC Queue: To calculate, $D_{RU}^j(LU)$, we need to analyze FRNC queue at RNC-j. The arrival rates of CR and LU packets at FRNC queue at RNC-j is given by $\sum_{i \in I} e_{ij} \lambda_{CR}^i$ and $\sum_{i \in I} e_{ij} \lambda_{LU}^i$ respectively. We can derive the processing delay at FRNC at RNC-j by modeling it as M/M/1 queuing system.

By assuming exponential distribution for processing time with means $1/\mu_{RNC-j}$ for all signaling packets, we can derive delays for CR and LU packets as identical:

$$D_{RU}^j(CR) = D_{RU}^j(LU) = 1 / \{ \mu_{RNC-j} - \sum_{i \in I} e_{ij} (\lambda_{CR}^i + \lambda_{LU}^i) \}$$

Analysis of BRNC Queue: To calculate, $D_{RD}^j(LUA)$, we need to analyze BRNC queue at RNC-j. ACK packets should be considered in addition to CA, LUA, and PG packets. The arrival rates of CA, LUA, PG and ACK packets at BRNC queue at RNC-j is given by $\sum_{i \in I} e_{ij} \lambda_{CA}^i$, $\sum_{i \in I} e_{ij} \lambda_{LUA}^i$, λ_{PG} , $\sum_{i \in I} e_{ij} \lambda_{ACK}^i$ respectively. We can derive the processing delay at BRNC queue at RNC-j by modeling it as an M/M/1 queuing system as follows:

$$D_{RD}^j(*) = 1 / \{ \mu_{RNC-j} - \lambda_{PG} - \sum_{i \in I} e_{ij} (\lambda_{CA}^i + \lambda_{LUA}^i + \lambda_{ACK}^i) \}$$

Analysis of FMSC Queue: When a RNC is connected to a MSC, it is said to be primary (secondary) RNC if the RNC is connected to the MSC via a primary (secondary) link. Thus a MSC can have both primary RNCs and secondary RNCs. The FMSC processes CR and LU packets from its primary RNCs. To calculate $D_{MU}^k(LU)$, $D_{MU}^k(CR)$ we need to find the arrival rate of aggregate signaling packets from all primary RNCs under MSC-k. The total arrival rate of LU and CR packets at the FMSC queue at MSC-k is $\sum_{j \in J} \sum_{i \in I} (\lambda_{LU}^i + \lambda_{CR}^i) e_{ij} e'_{jk}$

We can derive the processing delay at FMSC at MKC-k by modeling it as M/M/1 queuing system. Thus, for a given k, we have:

$$D_{MU}^k(LU) = D_{MU}^k(CR) = 1 / (\mu_{MSC-k} - \sum_{j \in J} \sum_{i \in I} (\lambda_{LU}^i + \lambda_{CR}^i) e_{ij} e'_{jk})$$

Analysis of BMSC Queue: Note that at BMSC queue, the CA, LUA and PG packets to primary RNCs are processed. To calculate $D_{MD}^k(LUA)$, $D_{MD}^k(CA)$ and $D_{MD}^k(PG)$, we need to find arrival rate of aggregate signaling packets at BMSC queue at MSC-k. Thus the total arrival rate is $\lambda_{PG} + \sum_{j \in J} \sum_{i \in I} (\lambda_{LUA}^i + \lambda_{CA}^i) e_{ij} e'_{jk}$. We can derive the processing delay at BMSC at MSC-k by modeling it as M/M/1 queuing system. Thus for a given k we have,

$$D_{MD}^k(LUA) = D_{MD}^k(CA) = D_{MD}^k(PG) = 1 / \{ \mu_{MSC-k} - \lambda_{PG} - \sum_{j \in J} \sum_{i \in I} (\lambda_{LUA}^i + \lambda_{CA}^i) e_{ij} e'_{jk} \}$$

Analysis of the processing delay at the wired network: To calculate the processing delays $D_{MP}^k(LU)$ and $D_{MP}^k(CR)$ for location update and call request at the wired network we need to consider the LU packets from primary MSC and CR packets from primary MSC. According to our assumption, the average processing delay for each type of signaling packets at wired network is derived by using analytical result of M/M/1 queue. Thus, the processing delays at the wired network for a given k are

$$D_{MP}^k(LU) = 1 / \{ \mu_{GLU} - \sum_{j \in J} \sum_{i \in I} \lambda_{LU}^i e_{ij} e'_{jk} \}$$

$$D_{MP}^k(CR) = 1 / (\mu_{CR} - \sum_{j \in J} \sum_{i \in I} \lambda_{CR}^i e_{ij} e'_{jk})$$

Analysis of processing delay at MT:

$$D_{MT}(PG) = 1 / (\mu_{MT} - \lambda_T)$$

Thus the total delay of location update and MT-terminating call setup can be calculated analytically.

V Experimental results

Here we present some numerical examples based on the above formulation on the toy dual-homed UMTS network shown in Fig 2. The values of the different parameters used for the numerical examples are summarized in Table II:

Table II: List of Parameter values

Parameter	Value
MT terminating call rate (λ_T)	0.0013 calls/sec
MT originating call rate (λ_0)	0.002 calls/sec
Average call duration ($1/\mu$)	180 secs
Average MT sojourn time in a cell ($1/h$)	20 secs
Average processing time in MT ($1/\mu_{MT}$)	10 msec
Average processing time in RNC ($1/\mu_{RNC}$)	0.5 msec
Average processing time in MSC ($1/\mu_{MSC}$)	1 msec
Average call setup time ($1/\mu_{CR}$)	1 msec
Average global location update time ($1/\mu_{GLU}$)	2 msec
Total no. of signatures (s)	8
Slot time (T)	4 msec
Random number range (0,R)	(0,10)
Re-transmission time in number of slots (δ)	1

As per our analytical result and based on the values of the parameters, we calculate the LU delay and MT-terminating delay of an MT in cell-3. We have $C^3=1/2$. We assume each cell has equal number of MTs.

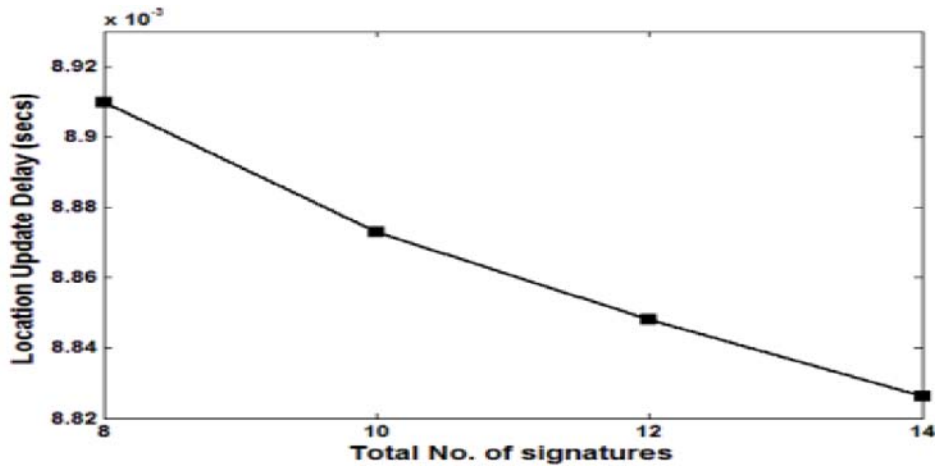


Fig. 13. Average LU delay with varying number of signatures in a cell

Fig. 13 shows the average LU delay of a boundary cell having 1000 MTs for different number of signatures. When the number of signatures used by the cell is set to 8 the LU delay is approximately 8.91×10^{-3} seconds. If the signature increases to 14 the delay reduces to 8.827×10^{-3} approximately. This is due to less collision in the access network.

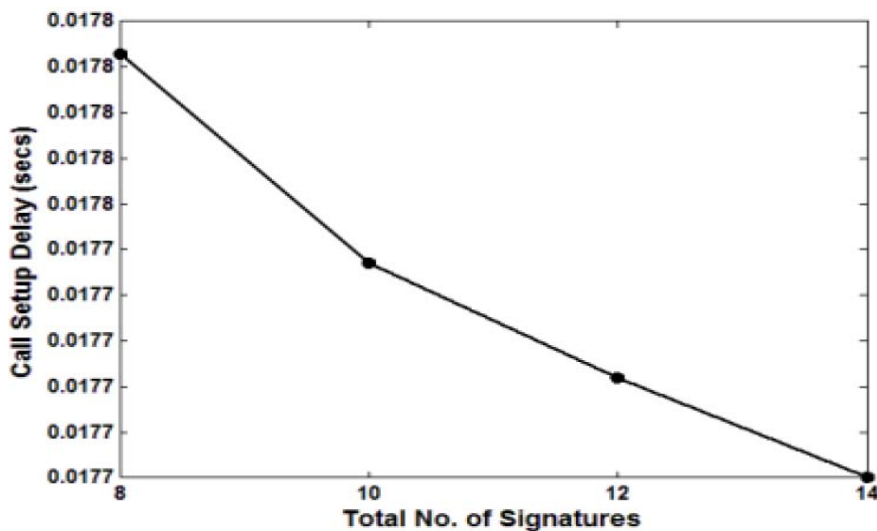


Fig. 14. Average call setup delay with varying number of signatures in a cell

Fig. 14 shows the average MT-terminating call setup time of a cell having 1000 MTs for varying number of signatures. When the number of signatures used by the cell is set to 8 the call

setup time 0.0178 secs which decreases to 0.0177 secs approximately when the signature increases to 14. It may be noted that average LU time is less than the MT-terminating call setup time. A majority of the time goes on paging and MTs processing capability.

VI. Conclusion

In this paper, we have proposed a location management techniques LM-DH for dual-homed UMTS cellular network using conventional LU method. The signaling delays for LU and MT-terminating call setup are analytically derived using a queuing network model of the dual-homed cellular network. We have assumed that each cell in the network has different number of MTs and each LA has varying number of cells under it. The position of the cell in an LA is considered for calculating the delay of LU. A slotted aloha based random access method for CDMA system is used in wireless access. We have presented some numerical examples based on our analytical formulation of signaling delay. In our future research, we will consider signaling packet flows for handoff process and priority processing of packets in addition to our current consideration.

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