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A Hierarchical Mobility Management Technique for Wireless Cellular Networks

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Abstract

Mobility Management is one of the major functions of wireless networks to allow mobile terminals (MTs) to stay connected. The aim of mobility management is to track where MTs are, so that calls and other services can be delivered to them. In this paper, we suggest a complete framework for mobility management in hierarchical cellular networks (HCNs), where MTs receive signal from both micro and macro cell tiers. It takes into account the dynamic factors for location area update along with a cost effective paging strategy suitable for HCNs. Comparative performance analyses indicate that this new technique outperforms the basic techniques (originally proposed for HCNs) considerably in terms of both signaling cost and delay.

Keywords: *Mobility management, hierarchical cellular networks, macro/micro paging, dynamic location update.*

1. Introduction

2. Background

The usual strategies for LAU in single tier networks are normal LAU (NLAU) or periodic LAU (PLAU) (Figure 2). NLAU [3] is a static location update strategy, where the buffered location information of the MT is only updated if an LA boundary is crossed. If the MT faces a check point event such as abnormal detachment or battery failure, it is not registered. Thus, initial trunk setup cost maybe wasted. A check point is defined as an action to inform the network whether the MT is attached. An incoming or an outgoing call, or NLAU will trigger a checkpoint action. PLAU [4] is a location update strategy where irrespective of the change in the LA boundary, the location information is updated in the register, which may cause unnecessary overhead.

LAU

Single tier

Hierarchical

Dynamic
(PNLAU)

Static
(PLAU, NLAU, PNLAU)

Dynamic
(NLAU, PNLAU)

Figure 2. Classification of LAU Techniques

The combination of the above two schemes, PNLAU [2], needs the synchronization of the implicit detach timer, maintained by the network and the identification timer maintained by the MT. These two are set with the length T'. But the frequency of these actions can not be predicted. So, a dynamic method is needed. The dynamic PNLAU chooses a T' such that:

$$T' = v(t_1 + t_2 + t_3 + \ldots\ldots\ldots + t_k)/k, \quad (1)$$

where v is the weighting factor and t_i (i= 1, 2, 3, …., k) is the time interval between two check point events.

The two issues served by the optimal PNLAU [2] are minimization of (a) total cost of signaling and (b) failure rate of call set up. But optimal PLAU is only cost effective in single tier cellular networks. The signaling cost for maintaining an LAU strategy that is dynamic as well as optimal (where delay is concerned), is very high. Even with the prospect of low paging cost for LAU with the change of each micro LA, the total cost still remains very high. Thus, a dynamic location area update strategy, suited for a hierarchical cellular network is needed.

Many LAU/paging combinations have been proposed previously in literature. However, not only most of them are suitable only for single tier cellular networks, but either they overlook the

ary. In comparison to MMT_4, this method is found to be costly in HCNs (discussed in Section 5). So next we formulate MMT_4.

Let us explain MMT_4 with the help of a concrete example. Suppose there are 4 macro LAs, namely LA_1, LA_2, LA_3 and LA_4, and each macro LA_i contains 10 micro LAs, namely LA_{i1}, LA_{i2}, …, and LA_{i10}. If an MT moves from LA_{i1} to LA_{i2}, there will be no new registration. If a checkpoint event, such as an incoming call, occurs the location register would connect the call at the previously registered location. For paging purpose, the micro cells are grouped into micro partition areas (PAs) and the macro cells are grouped into macro PAs. Let each PA contain two cells. Since the paging strategy adopted is SMMP, the paging message will wait either in the micro paging queue or in the macro paging queue (randomly with a probability p or (1-p), respectively). The message will be paged in the entire partition area, i.e., in this case in the entire region LA_{i1} and $LA_{i2.}$ The paging message would be executed in FIFO manner.

Now, if before the checkpoint event the MT changes LA, (i.e., it moves from LA_{11} to $LA_{21,}$ an LAU will take place. If the MT is abnormally detached before the LAU, initial trunk set up cost would be wasted. If, however the LAU is done prior to the incoming call, the channel would be set up as per the new LAU and the paging message would be sent in the new PA.

4. Cost analysis

The cost of LAU/paging process is mainly the cost of bandwidth consumption in the wireless channels and the signaling exchange in the core network. Along with cost, another important factor for HCNs is the delay and the call dropping probability. We present the final results here in terms of them, and the initial analysis is given in Appendix II.

Let p_{ua} denote the probability that there is at least one LAU between two consecutive calls to an MT. Then,

p_{ua}

For MMT_2 the total cost is given by T_2,

$$T_2 = M_a w_{pa}(1 - p(Q)) + (M_a+1)/2) M_i W_{pi} p(Q) + A_{T1} W_{ua} \quad (4)$$

where M_i denotes the number of micro cells.

Now, for MMT_3, the cost denoted by T_3 is:

$$T_3 = M_a W_{pa}(1 - p(Q)) + (M_a+1)/2) M_i W_{pi} p(Q) + C_{op} \quad (5)$$

Here, p(Q) is the probability that an MT has to be paged in the micro LA, when all the Q queuing positions are filled in the overlaid macro LA. C_{op} is the total cost involved per check pointing event for the optimal PNLAU scheme [2]:

$$C_{op} = \mathbf{C}_{NLAU} + \mathbf{C}_{PLAU} + \mathbf{C}_{INIT} \quad (6)$$

where, $\mathbf{C}_{NLAU} = C_{nlau}\, n_{nlau} / r$,

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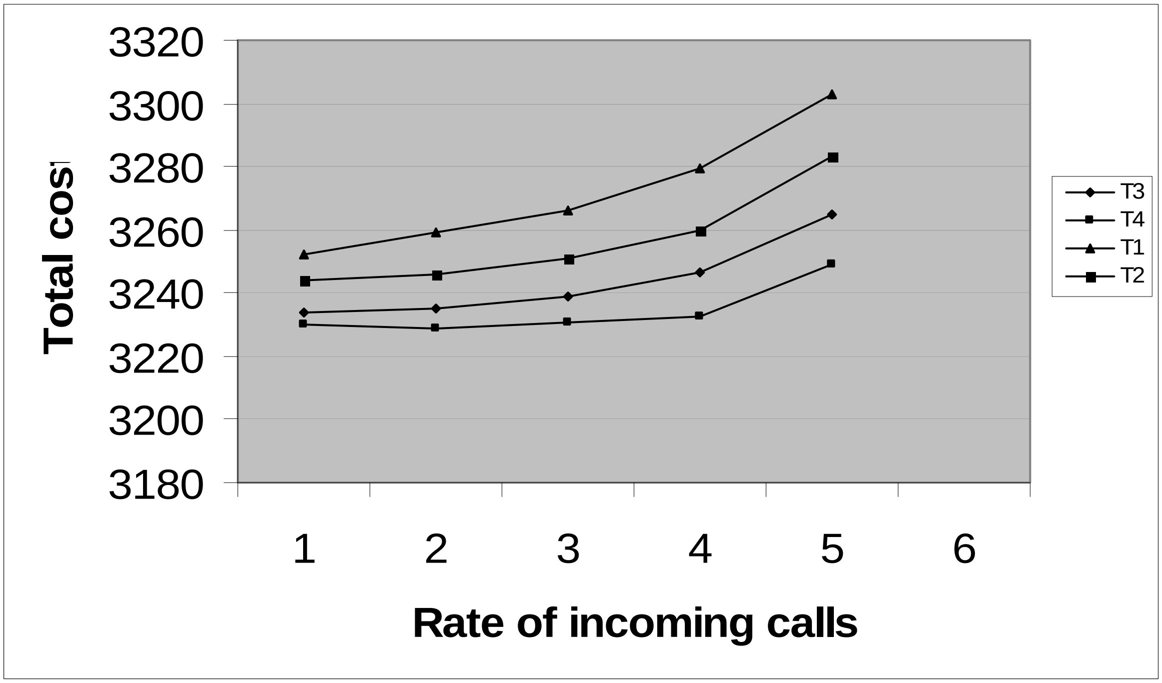

Figure 4. Signaling cost comparison for various MMTs.

5. Analysis of Delay

Using Little's law, the average delay D is given by:

$$D = q/\Lambda\,(1 - p(n))$$

where q is the average number of users in the system, p(n) is the probability of the queue being in such a state, where n paging messages are queued at that time, and Λ is the paging message arrival rate.

Delay for MMT_1 can be found from this equation as:

$$D_{T1} = q/\Lambda_{ma}(1 - p(n)) \qquad (8)$$

where Λ_{ma} is the paging message arrival rate at macro cell tier.

The probability that the paged MT can be found in each micro-LA is $1/M_a$, where M_a is the number of micro-LAs overlapped with the macro-LA.

Let us define N to be the average number of times that a paging message will be broadcast in the micro-LAs until the paged user is found.

$$N= (M_a+1)/2$$

For MMT_2, the delay is

$$D_{T2} = D_{ma}(1-p_{ov}) + ((M_a+1)/2)D_{mi}\ p_{ov} \quad (9)$$

D_{ma} and D_{mi} are the delays in the macro and the micro cell tiers, respectively.

Let us define D_{T3} to be the average processing delay for MMT_3. Then

$$D_{T3} = D'(1 - E(N_{pnlau})) + ND'E(N_{pnlau}) \quad (10)$$

$E(N_{pnlau})$ denotes the average number of PNLAU events per check point event. The paging delay is lesser in MMT_4 because, unlike MMT_3, it is adaptive to HCNs.

Thus, because the LAU is done dynamically for every micro LA, less area has to be paged, and also the paging load balance takes less time.

Let us define D_{T4} to be the average processing delay for MMT_4. Then

$$D_{T4} = N\,D\,(T_a + T_i) \quad (11)$$

$$T_a = m/u + p\Lambda m(m+1) / 2u(u-p\Lambda m)$$

$$T_i = m/u + (1-p)\Lambda m(m+1) / 2u(u-(1-p)\Lambda m)$$

1/u is the mean service time, and Λ is the call arrival rate such that $p\Lambda=\Lambda_{ma}$ and $(1-p)\Lambda=\Lambda_{mi}$.

6. Results and Discussion

The results are based upon some assumptions for important network parameters. For the purpose of simplification of analysis, LAs are taken to be circular with a radius of 600m. The vehicular MTs are supposed to have a homogeneous average velocity of 20m/sec. The time be-

Figure 4 shows that, in comparison with the other techniques, MMT_4 performs better as the rate of incoming calls increases. While f()4.1223 mT

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scenario, where an MT may change place rapidly, as long as a relatively large micro LA is assigned to one base station, MMT_4 performs well.

Acknowledgements

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References

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[2] Y. Xiao and Hui Chen, "Optimal Periodic Location Area update for Mobile Telecommunications Networks." IEEE trans on wireless communications, vol 5, no 4, April 2006.

[3]

Appendix I

Step1a: Set the clock timers (ID Timer and Implicit Detach Timer), synchronized at with time T'. The value of T' is not fixed. (No. of PLAU messages per T' is not fixed).

Step1b: Set the probability that the next paging message would wait in the micro paging queue to be p.

Step2: Set the mobile configuration such that it receives signal from both the tiers.

Step2a: If the MT crosses micro LA boundary, send a NLAU message.

Step2b: Else, if it crosses micro cell boundary, no NLAU message is sent.

Step3: If ID Timer expires without any PLAU message within a certain T', CC records the MT to be detached from the next T'.

Step 3a: If a checkpoint event occurs, such as an incoming call, no new voice trunk is set up. The incoming call is dropped.

Step4: Else, the buffered LA information is replaced by the new PLAU information.

Step5: While T' does not expire.

Step5a: If new NLAU message arrives replace the existing registration information with the new one.

Step5a1: If checkpoint event, such as incoming call, occurs before new NLAU, initial voice trunk wasted.

Step5a2: Else, call is set up and monitored for handover.

Step5a3: The incoming paging request will wait in either of the two queues with a probability of p.

Step5a4: The paging message will be broadcasted in the entire partition area.

Step5b: If abnormal detachment occurs between previous PLAU and next checkpoint event, it will not be registered.

Step5c: If abnormal detachment occurs between two PLAU events with no new checkpoint event, it will be registered by the CC for the following PLAU.

Step6: If the latency between previous abnormal detachment and current checkpoint event is less than the latency between (a) previous PLAU and next NLAU (b) two PLAU messages (c) previous PLAU and current checkpoint, then next T' commences.