A Triple Layer Location Management Strategy for Wireless Cellular Networks

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***Abstract*—Location areas is a popular location management scheme in cellular networks. In the location areas scheme, a mobile terminal updates its location whenever it moves into a cell that belongs to a new location area. However, no matter how the location areas are designed, the ping-pong location update effect exists when a mobile terminal moves back and forth between two location areas. The paper defines a new kind of ping-pong effect, referred to as the generalized ping-pong effect, and shows that it accounts for a non-negligible portion of the total location update cost. Although several strategies have been proposed to reduce the ping-pong effect in the literature, they either eliminate no generalized ping-pong effect or introduce a larger paging cost. This paper proposes a triple-layer location management strategy to eliminate the generalized ping-pong effect, therefore greatly reducing the total location update cost. Simulation results show that the triple-layer strategy outperforms the existing schemes designed to reduce the ping-pong effect.**

Keywords-location management; ping-pong effects; triple layer scheme; cellular networks

1. Introduction

Location management is one of the fundamental issues in cellular networks. It consists of two basic operations: location update and paging. The total cost of location management is the sum of location update cost and paging cost. Location areas is a popular location management scheme in cellular networks [4]. In the location areas scheme, the service coverage area is partitioned into location areas. Each location area consists of several contiguous cells. A mobile terminal will update its location whenever it moves into a cell that belongs to a new location area. On a call arrival for a particular mobile terminal, the cellular system will page all cells within the location area reported by the mobile terminal at its last update.

A lot of research has been performed on the location area scheme [5]. However, no matter how well the location areas are designed, there exist two problems. One is that the boundary cells between two location areas are always burdened with all location update signaling while the cells inside a location area do not have any location update signaling at all. The other problem is that the excessive ping-pong update effect occurs when a mobile terminal is moving back and forth between the two neighboring location areas. This ping-pong effect could account for 14% of the total location update cost (See Section 2).

Several strategies have been studied to reduce the ping-pong effect. Examples include the two location area (TLA) scheme [3] and the virtual layer scheme [1]. However, these strategies can only reduce the ping-pong update effect over a boundary. They cannot eliminate the ping-pong update effect around a corner. A corner is the intersection of three different cells that belong to three different location areas. We refer to such kind of ping-pong effect as the generalized ping-pong effect. It is shown in Section 2 that the generalized ping-pong effect could account for 7% of the total location update cost.

In this paper, a triple layer scheme is proposed to eliminate the generalized ping-pong effect. Simulation results show that the triple layer scheme incurs less location updates than the two location area scheme and the virtual layer scheme while keeping the same paging cost. The simulation also shows the overlapping scheme [2] is able to eliminate both the traditional and generalized ping-pong effects, but it performs worse than the triple-layer scheme in term of the total cost because of its expanded location areas.

2. Traditional and Generalized Ping-Pong Effects

In the location areas scheme, a mobile terminal updates its location whenever it moves into a cell that belongs to a new location area. When a mobile terminal is moving back and forth between the two neighboring location areas, it causes excessive location updates. This phenomenon is referred to as the *traditional ping-pong* effect. For example, ping-pong effects occur when a mobile terminal moves along *a-b-a-b* in Figure 2-1(a). The *generalized ping-pong* location update effect happens if a mobile user is moving around a corner that involves three or more location areas, which also causes consecutive location updates. For example, assume a mobile user is currently in cell *d* as shown in Figure 2-1(b), if the user moves to cell *e*, then immediately to cell *f*, it will perform location updates within two successive steps because *e* and *f* belong to two different location areas. More severe cases will happen when the user is moving in a loop such as *d-e-f*, where each move will cause a location update.

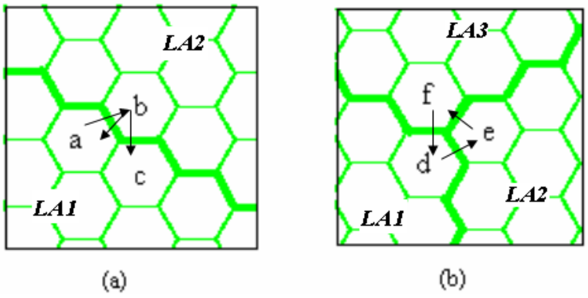


Figure 2-1. The traditional and generalized ping-pong effects.

Figure 2-2 illustrates location update costs due to the traditional and generalized ping-pong effects under the random walk mobility model. In the random walk mobility model, if the probability that the mobile subscriber remains in the same cell is p (referred to as the stationary rate), and the probability that the subscriber moves to a neighboring cell is equal to $(1-p)/6$. The figure shows the total ping-pong location update cost accounts for about 20-22% of the total location update cost, and the generalized ping-pong cost accounts for about one-third of the total ping-pong cost.

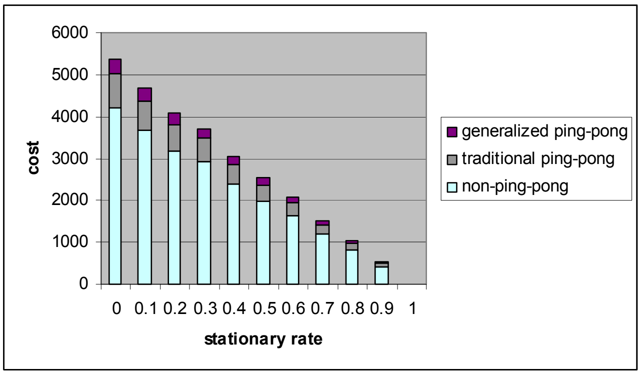


Figure 2-2. Traditional and generalized ping-pong location update costs.

3. Related Work

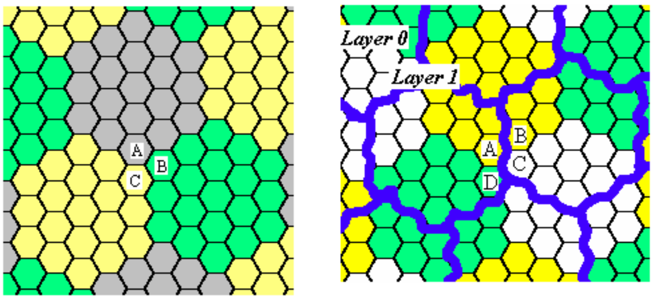
The ping-pong location update effect along the LA boundaries greatly affects the location management performance and therefore receives a lot of attention. Several schemes have been proposed to reduce the effect. In this section, we will review several existing related schemes and analyze each of them to see if it can eliminate the traditional and generalized ping-pong effects.

Traditional Location Area (LA) Scheme

In the traditional LA scheme [4], location areas are non-overlapping. A mobile terminal remembers the most recently visited location area. The mobile terminal updates its location whenever it moves into a cell that belongs to a new location area. The traditional location area scheme can incur both traditional and generalized ping-pong effects.

Two Location Area (TLA) Scheme

In the TLA scheme [3], a mobile terminal remembers two most recently visited location areas. When the mobile terminal moves into a new location area that is already in the memory, no location update is performed. Otherwise the less recently visited location is kept replaced by the new location, and a location update is required. In this scheme, the traditional ping-pong effect has been eliminated. However, the TLA scheme cannot eliminate the generalized ping-pong effect. For example, in Figure 3-1(a), if a mobile terminal moves in a loop *A-B-C*, it needs to perform a location update every time it enters a new cell because it can remember only two location areas. Another disadvantage of the TLA scheme is the increased paging cost. When an incoming call arrives, the cellular system needs to page two location areas in the worst case. If a mobile terminal can remember more than two location areas, it is possible to eliminate the generalized ping-pong effect. However, the paging cost will be more than two location areas in the worst case when an incoming call arrives.



(a) (b)

Figure 3-1. TLA and VLA schemes

Virtual Layer (VLA) Scheme

In [1], the authors have proposed a location update scheme using a virtual layer, referred to as VLA here. The VLA scheme adds a virtual layer on the original location area scheme to reduce the traffic for location updates near the location area boundaries. Each original location area will be covered by two virtual location areas, and vice versa. When a mobile terminal moves out of an original location area, it will enter the location area of the virtual layer covering the new cell. The authors show that the VLA scheme significantly reduces the traditional ping-pong effect. For example, when a mobile terminal moves from cell B to C in Figure 3-1(b), it will perform a location update that indicates the entry to the location area in the virtual layer. When it moves back to the cell B, it is still in the same location area of the virtual layer. Therefore no location update is necessary. However, the VLA scheme has two drawbacks. First, the VLA cannot eliminate the traditional ping-pong location updates completely. For example, the traditional ping-pong location updates occur when a mobile terminal moves back and forth between two cells C and D in Figure 3-1(b). Second, although the VLA may reduce some of the ping-pong location updates in the original layer, it can also introduce some more ping-pong location updates due to the added layer. For example, as illustrated in Figure 3-1(b), if a mobile terminal is currently in cell A and registered with the LA of layer 1 (the virtual layer), the mobile terminal performs a location update after every step when it moves along A-B-C-D-A.

Overlapping Location Area Scheme

In the overlapping location area scheme [2], each location area (LA) is partially overlapped by its neighboring LAs. Thus the boundary cells of a given LA may belong to more than one LA. A mobile terminal moving out of the current location area will not be in the boundary cell of the new location area. Therefore even if it moves back to the previously visited cell, an immediate location update is not possible due to the overlapping of two neighboring location areas. Therefore the traditional ping-pong effect is eliminated. However, if the degree of overlapping is small, a MT that moves out of the current location area will probably be close to the boundary of the new registered location area and is likely to perform the location update soon. The generalized ping-pong effect can be eliminated if the area of overlapping is large. In this case, the paging cost will increase because the location area in this scheme is usually larger than the location area in the traditional location area scheme to make two neighboring location areas overlap.

4. Triple-Layer Scheme

To eliminate the generalized ping-pong effect, we propose a triple-layer location management scheme. In this scheme, any cell belongs to three location areas in different layers. Three layers are placed in such a way that any boundary or corner in one layer could be covered by a location area of another layer. If a mobile terminal moves out of the location area of the current layer, it could register with any of two location areas of the other two layers. To keep the MT away from the boundary in the new location area, the MT will choose the layer whose corresponding location area center is closer to the MT.

Figure 4-1 shows a layer structure of the triple-layer scheme, where the service area is covered by three layers, *Layer0* (with colored LAs), *Layer1* (with blue LA boundaries) and *Layer2* (with red LA boundaries). We will use this figure to illustrate how a subscriber performs location updates in the triple-layer scheme. Assume a MT is initially in cell *a* and registered with area *LA1* in *Layer0*. (Every location area is labeled at its center in the figure.) If the MT moves from cell *a* to cell *b*, it moves out of the current location area *LA1*. Cell *b* is both covered by *LA2* of *Layer2* and *LA3* of *Layer1*. The MT will register with *LA2* of *Layer2* because the distance to the center of *LA2* is smaller.

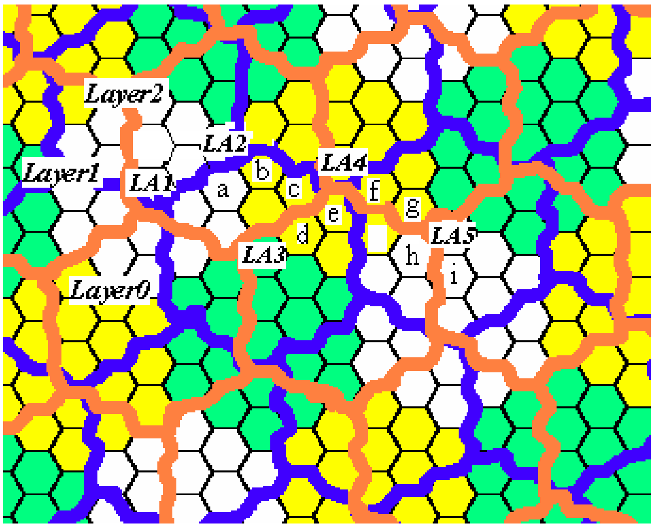


Figure 4-1. A triple-layer scheme

5. Performance Comparison

In this section, we will compare the performance of the triple layer scheme with the traditional location area (LA) scheme, two location area (TLA) scheme, virtual layer scheme (VLA), and overlapping scheme. We assume location areas have a ring structure as in [2]. The number of rings is used to describe the size of a location area. The incoming call arrivals to a subscriber follow a Poisson process. We use the discrete random walk as the mobility model. It is assumed that the cost of a location update is the same as the cost to page one cell.

First, we will show what percentage of the traditional and generalized ping-pong effects can be reduced by each of the location management schemes including traditional LA, TLA, VLA, Overlapping and triple layer schemes. Then we will compare the triple-layer scheme with the traditional LA, TLA, and VLA in terms of the location update cost. We do not compare the paging cost because we use the same size of location areas. Finally we will compare the performance of the triple-layer scheme with the overlapping scheme in terms of the total cost.

5.1 Ping-Pong Effect Reduction

In Section 3, we reviewed the schemes that have been proposed to reduce the ping-pong effect. Next we will use the simulation to evaluate how well they perform in terms of the reduction of the traditional and generalized ping-pong effects. Figure 5-1 shows the location update costs related to the traditional and generalized ping-pong effects under the LA, VLA, TLA, overlapping and triple-layer location update schemes. The simulation is done using the random walk model. We will show the case of stationary rate p = 0.4, with the other cases being relatively similar. Each LA used in all the schemes except Overlapping has three rings with a total of 19 cells. We will test two configurations of the overlapping scheme: Overlap1 and Overlap2. In Overlap1, the LAs have 3 rings, i.e. 19 cells, and each LA will overlap a neighboring LA with one ring. In Overlap2, the LAs have 4 rings, i.e. 37 cells, and each LA will overlap a neighboring LA with 2 rings.

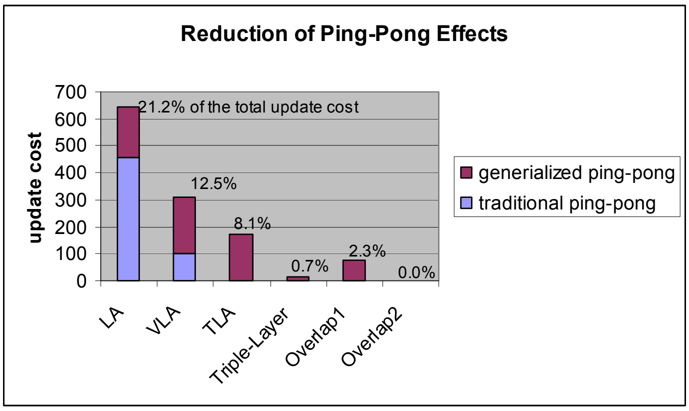


Figure 5-1. Reduction of the tradition and generalized ping-pong effects.

The figure shows that the total ping-pong effect is about 21% of the total location update cost in the LA scheme. It is greatly reduced in the VLA scheme, but it still accounts for 12.5% of the total location update cost. This is mainly due to the reduction of the traditional ping-pong effect. In fact, the generalized ping-pong location update cost increases a little bit. That is because that when a virtual layer is added over the original layer, more generalized ping-pong location updates might happen when a mobile user is moving around an intersection made by the boundaries from two different layers. The TLA scheme is able to eliminate the traditional ping-pong effect, but it cannot eliminate any of the generalized ping-pong effect. Finally, the triple-layer scheme is also able to eliminate the traditional ping-pong effect, and it reduces the generalized ping-pong location update cost to below 1%. For the Overlap1 case, that is, the expanded location area has the same size as the other schemes, the traditional ping-pong effect is completely eliminated, and the generalized ping-pong effect is reduced to 2.3%. For the Overlap2 case, that is, the location area before the expansion has the same size as the other schemes, both traditional and generalized ping-pong effects are completely eliminated. Our simulation results also show that the triple-layer scheme completely eliminates the generalized ping-pong effect if the size of LAs is equal or greater than 4 rings. This is because, in this case, all the boundaries and corners can be totally covered by a location area in one of the three layers.

5.2 Location Update Cost Comparison

Next we will compare the location update costs of LA, VLA, TLA, overlapping, and triple-layer schemes. We will assume the random walk model. Each LA used in all the schemes has three rings with a total of 19 cells, including the expanded LA in Overlapping (corresponding to the Overlap1 case in Section 5.1). Because the location area size is the same for all the schemes, the paging cost will be the same regardless of the incoming call arrival rate. (The only exception is, in the TLA scheme, the cellular system may need to page two location areas.) Therefore we only need to compare the location update costs of those schemes.

Figure 5-2 shows the location update cost comparison of LA, VLA, TLA and overlapping and triple-layer schemes under various stationary rates ranging from 0 to 1. It can be seen that the relative performance of those scheme does not change when the stationary rate changes. We can divide those five schemes into three groups. The first group contains the LA scheme only. TLA and VLA are in the second group, and Overlapping and Triple-Layer form the third group. Figure 5-2 shows the third group performs better than the second group that, in turn, outperforms the first group. This is mainly because the first group, i.e. the LA scheme, eliminates no ping-pong effect, the second group eliminates or reduces the traditional ping-pong effect, and the third group eliminates or reduces both traditional and generalized ping-pong effects. The triple layer scheme performs the best among those five schemes in terms of location update costs.

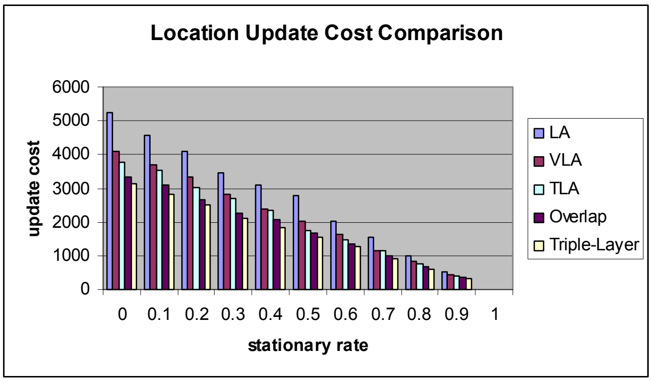


Figure 5-2. Location update cost comparison of LA, VLA, TLA, overlapping, and triple-layer schemes

5.3 Total Cost Comparison of Overlapping and Triple-Layer Schemes

As mentioned earlier, the overlapping and triple-layer schemes are able to eliminate or reduce both traditional and generalized ping-pong effects. Next we will compare the performance of the triple-layer scheme with the overlapping scheme under various incoming call arrival rates. Again we will illustrate using the random walk model with stationary rate $p = 0.4$. For the other stationary rates, the results are similar. In the triple layer scheme, each LA has three rings of 19 cells. We assume the size of the LAs in the overlapping scheme is also 3 rings before expansion. In order to make neighboring location areas overlapping, we expand each original location area by one ring. Therefore, each LA will overlap with a neighboring LA with 2 rings. This corresponds to the Overlap2 case in Section 5.1. Recall, in Section 5.1, the Overlap2 case eliminates more ping-pong location updates than the corresponding triple layer scheme. However, the size of the LAs in the Overlap2 case is one ring larger than the corresponding triple layer scheme. Therefore the overlapping scheme will incur more paging cost. Figure 5-3 shows the total cost comparison of the triple-layer and overlapping schemes under various call inter-arrival times ranging from 16 to 256. The simulation shows that the triple-layer scheme performs better than the overlap scheme, especially when the call arrival rate is high.

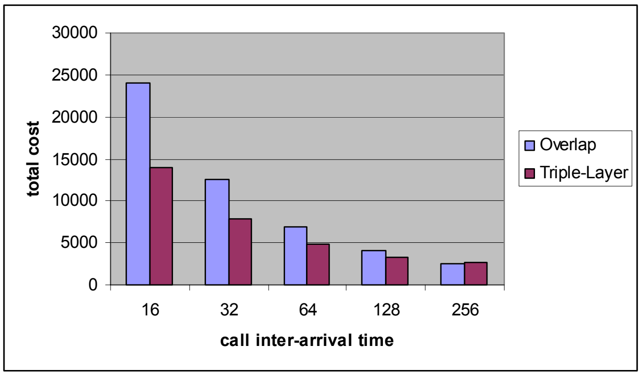


Figure 5-3. Total cost comparison of the overlapping and triple-layer schemes under the random walk model with stationary rate being 0.4.

References

[1] D. Chung, H. Choo and H. Y. Youn, Reduction of Location Update Traffic Using Virtual Layer in PCS, *Proceedings of the 30th Annual International Conference on Parallel Processing*, Valencia, Spain, September 2001, 331-338.

[2] D. Gu and S. S. Rappaport, Mobile user registration in cellular systems with overlapping location areas, *Proceedings of the 50th Vehicular Technology Conference*, May 1999, pp. 802-806.

[3] Y.-B. Lin, Reducing location update cost in a PCS network, *IEEE/ACM Transactions on Networking*, vol. 5, no. 1, February 1997, pp. 25-33.

[4] M. Rahnema, "Overview of the GSM Systems and Protocol Architecture," *IEEE Communications Magazine*, vol. 31, no. 4, April 1993, pp. 92-100.

[5] J. Zhang, Location Management in Cellular Networks, in *Handbook of Wireless Networks and Mobile Computing*, Ivan Stojmenovic (Editor), John Wiley & Sons, 2002, 27-49.