

Elimination of Generalized Ping-Pong Effects Using Triple-Layers of Location Areas in Cellular Networks

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Abstract. Location-areas is a popular location management scheme in cellular networks. In the location areas scheme, a service area is partitioned into location areas, each consisting of contiguous cells. 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: cellular networks; location management, location areas, ping-pong effects, triple-layers.

1. Introduction

Location management is one of the fundamental issues in wireless communication networks [15] no matter it is a traditional PCS system, or a mobile broadband system like 3G and WiMAX. It deals with how to track mobile users within the communication system. In a cellular network, a service area is divided into smaller areas, called cells. Each cell is served by a base station (BS). Each base station is connected to the mobile switching

center (MSC) that is, in turn, connected to the public switched telephone network (PSTN) [12]. A mobile terminal (MT) communicates with another terminal, either mobile or fixed, via a base station. Fig. 1 illustrates a typical cellular network in a PCS network.

Location management consists of two basic operations: location update and paging. A location update is performed by a mobile terminal. Through this operation the mobile terminal sends its current location to the cellular system. The paging operation is performed by the cellular system when an incoming call for a mobile terminal arrives. In this operation, the cellular network pages the mobile terminal in all possible cells to find out the cell in which the mobile terminal is currently located so the incoming call can be routed to the corresponding base station. Each operation has a cost. The total cost of location management is the sum of location update cost and paging cost. The goal of a location management scheme is to reduce the total cost.

Location areas is a popular location management scheme in cellular networks [1, 9, 11]. In the location areas scheme, the service coverage area is partitioned into location areas. Each location area consists of several contiguous cells. The base station of each cell broadcasts the identification of the location area to which the cell belongs. Therefore, a mobile terminal knows which location area it is in. 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 the cells within the location area reported by the mobile terminal at its last update.

A lot of research has been performed on the location management and location area schemes [2, 3, 4-9, 10, 14]. 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 location 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 Fig. 3 in Section 2).

Several strategies have been studied to reduce the ping-pong effect. Examples include the two location area scheme [10] and the virtual layer scheme [2]. 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 that, as in Fig. 3 of Section 2, 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 [10] and the virtual layer scheme [2] while keeping the same paging cost. The study also shows the overlapping scheme [7] is able to eliminate both the traditional and

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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.

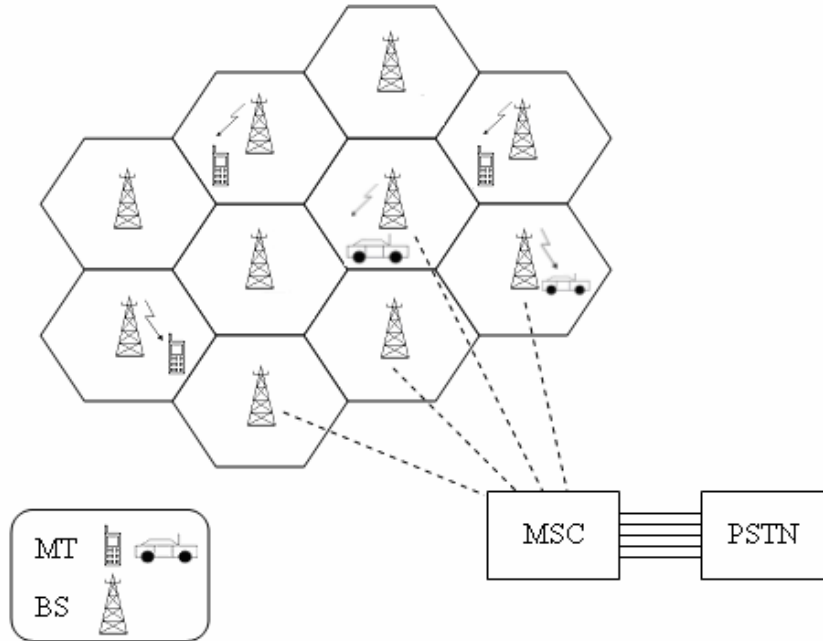


Fig. 1. A typical cellular network

The rest of the paper is organized as follows. Section 2 defines traditional and generalized ping-pong effects and their weights in the total location update cost. Section 3 reviews existing related schemes. Section 4 proposes the triple-layer scheme. Section 5 compares the performance of the triple-layer scheme with existing related schemes including the traditional location area scheme, two location area scheme, virtual layer scheme, and overlapping scheme. Finally, Section 6 summarizes the results.

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 location update effect. Several schemes have been proposed to address the issue. In addition to the traditional ping-pong effect, there is another form of movement that involves more than two location

areas in a short time period, which also causes excessive location updates. In this paper, we refer to this effect as the generalized ping-pong location update effect.

A *traditional ping-pong* location update effect occurs when a mobile user immediately comes back to a previously visited location area, which causes consecutive location updates within a short time period. For example, given the location areas shown in Fig. 2(a), if a mobile user moves from cell *a* to *b*, it will perform a location update to register with location area *LA2*. However, if the mobile user immediately comes back to the cell *a* or another cell *c* in location area *LA1*, it will again perform a location update to register with *LA1*. This is referred to as the traditional ping-pong location update effect or simply the traditional ping-pong effect.

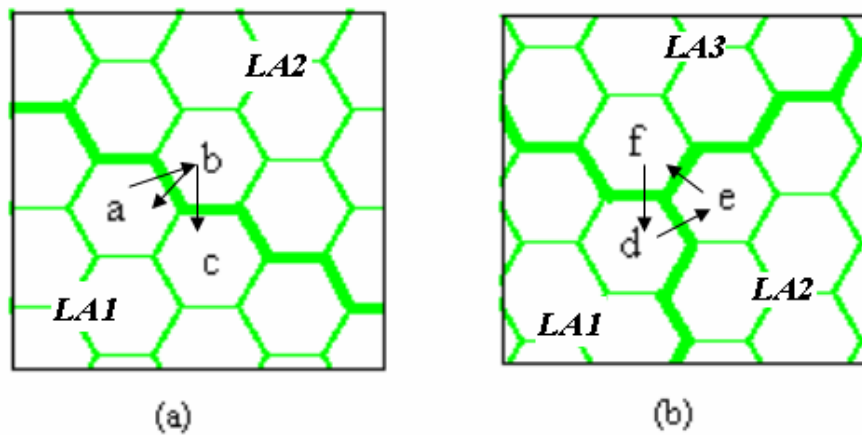


Fig. 2. The traditional and generalized ping-pong effects

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 Fig. 2(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. This behavior is not considered as traditional ping-pong effect. In this paper, it is named as the generalized ping-pong effect, and we propose a triple-layer location area scheme to eliminate it.

Fig. 3 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 $(1-p)/6$ [5, 8]. In this simulation, the range of p is from 0 to 1.0. ($p=0$ means the

subscriber always moves, and $p=1.0$ means the subscriber does not move at all.) The simulation runs for 10000 time slots. In each time slot the subscriber either moves to one of the six neighbors or does not move based on the stationary rate p . 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.

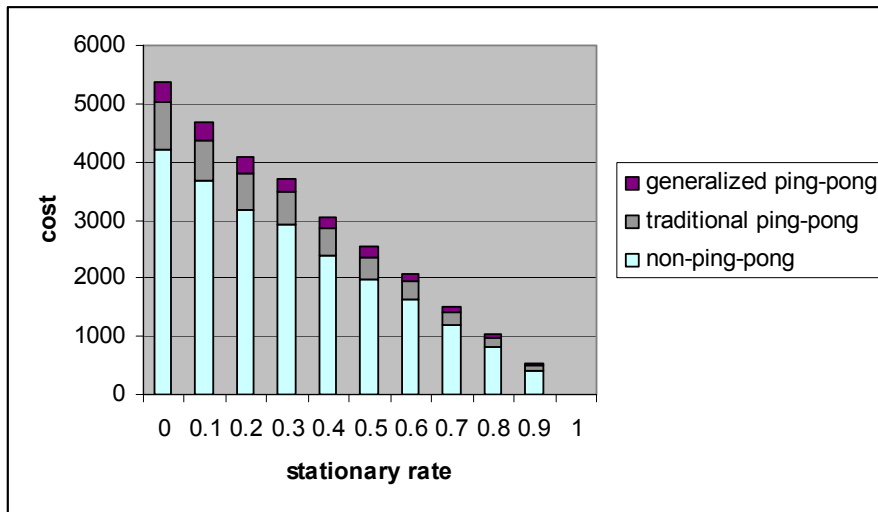


Fig. 3. The traditional and generalized ping-pong location updates cost

3. Related Work

The ping-pong location update effect along the location area 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. Those schemes include the traditional location area (LA) scheme, two location area (TLA) scheme, virtual layer scheme (VLA), and overlapping scheme.

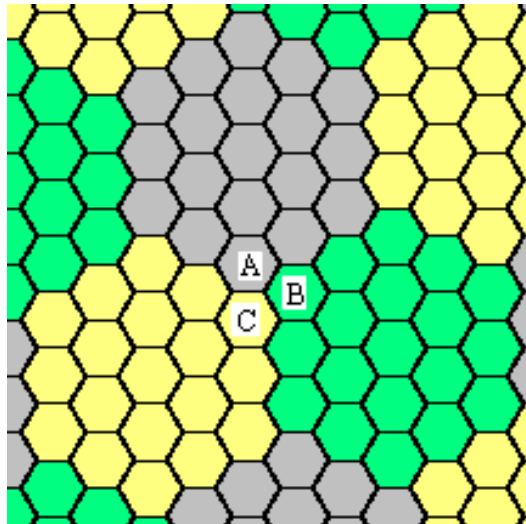
3.1. Traditional Location Area (LA) Scheme

In the traditional LA scheme [11], location areas are non-overlapping. A mobile terminal remembers the most recently visited location area. The

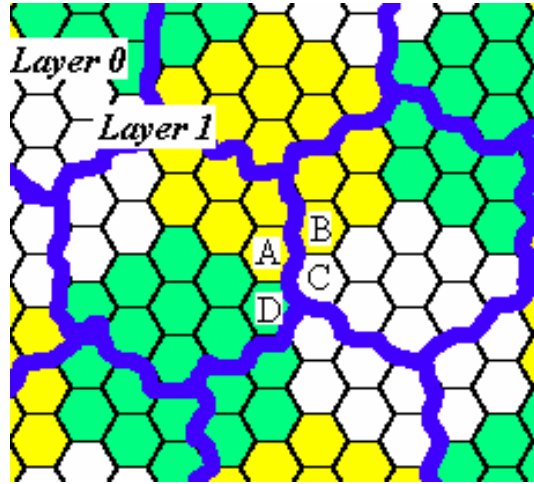
mobile terminal updates its location whenever it moves into a cell that belongs to a new location area. The traditional location area scheme can incur both traditional and generalized ping-pong effects.

3.2. Two Location Area (TLA) Scheme

In the TLA scheme [10], a mobile terminal remembers two most recently visited location areas. When the mobile terminal moves into a new location area, it checks if the new location is in the memory. If the new location is already in the memory, no location update is performed. Otherwise the most recently visited location is kept and the other location is replaced by the new location. In this case, a location update is required to notify the cellular system of the change. In this scheme, a mobile terminal does not need to update its location when it comes back to the previously visited location area. Therefore the traditional ping-pong effect has been eliminated. However, the TLA scheme cannot eliminate the generalized ping-pong effect. For example, in Fig. 4(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)

Fig. 4. TLA and VLA schemes

3.3. Virtual Layer (VLA) Scheme

In [2], 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. In this scheme, each cell belongs to a location area in the original layer as well as a location area in the virtual layer. 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 Fig. 4(b), it will perform a location update that indicates the entry to the location area in the virtual layer (Layer 1). 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 Fig. 4(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 virtual layer. For example, as illustrated in Fig. 4(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. We will show in Section 5 that the generalized ping-pong location update will increase after the virtual layer is applied.

3.4. Overlapping Location Area Scheme

In the overlapping location area scheme [7], 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 (MT for short) 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, the mobile terminal 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 three 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 another location update in a shorter time period, the MT will choose the layer whose boundary is farther away from the MT. corresponding location area center is closer to the boundary in the new location area.

Fig. 5 illustrates 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 location 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 covered by both *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. Table 1 shows how the MT performs the location updates when it moves along the path a-b-a-b-c-d-c-d-e-f-e-f-g-h-i.

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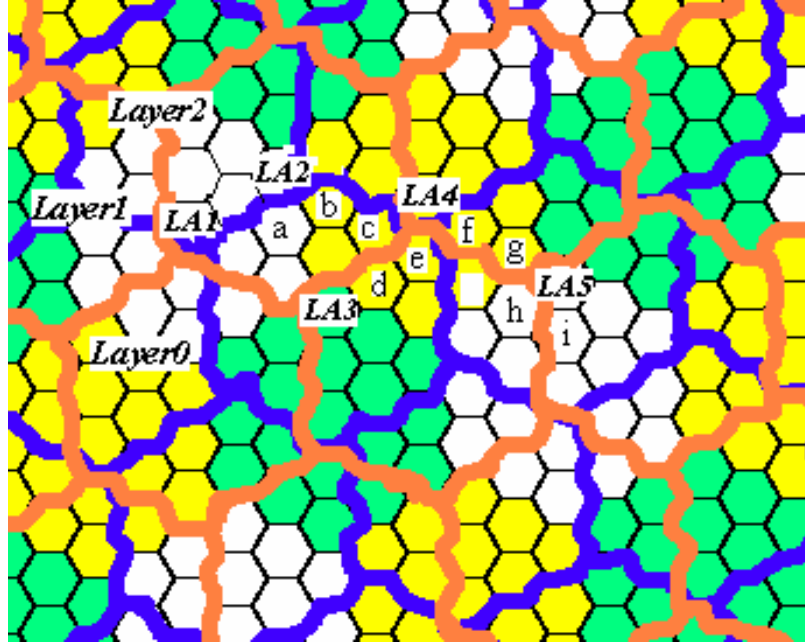


Fig. 5. A triple-layer scheme

Table 1. Example of location updates in the triple-layer scheme

Path	Layer Number	Location Area	Location Update
A	0	LA1	N/A
→b	2	LA2	Yes
→a	2	LA2	No
→b	2	LA2	No
→c	2	LA2	No
→d	1	LA3	Yes
→c	1	LA3	No
→d	1	LA3	No
→e	1	LA3	No
→f	0	LA4	Yes
→e	0	LA4	No
→f	0	LA4	No

→g	0	LA4	No
→h	1	LA5	Yes
→i	1	LA5	No

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 by simulation. In the simulation, we assume the location area(LA) has a ring structure in accord with the work by other researchers [3, 5]. In addition, when the cell size become smaller and smaller to accommodate more subscribers, it is feasible and efficient for location areas to a ring structure. We will use the number of rings to describe the size of a location area. It is assumed that the cost of a location update is the same as the cost to page one cell.

The incoming call arrival rate and the mobility model play a very important role when the performance of location management schemes is evaluated. We assume the incoming call arrivals to a subscriber follow a Poisson process. We use the discrete random walk as the mobility model for performance comparison. In the random walk model, it is assumed that time is slotted. If the probability that a mobile subscriber remains in the same cell is p (referred to as the stationary rate), the probability that the subscriber moves to a neighboring cell is equal to $(1-p)/6$. In accord with most researchers, it is assumed that the cost of one location update is one while the paging cost is the number of cells to be paged.

In this section, we will first 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, which leads to the same paging cost regardless of incoming call arrival rates. 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. Fig. 6 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 similar percentage-wise. 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. The expanded location areas in Overlap1 have the same size as the other schemes while Overlap2 has the same location area size as the other schemes before the expansion. 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. It is worthwhile to mention that Overlap2 will incur more paging cost due to its expanded location area size. The details will be given in Section 5.3.

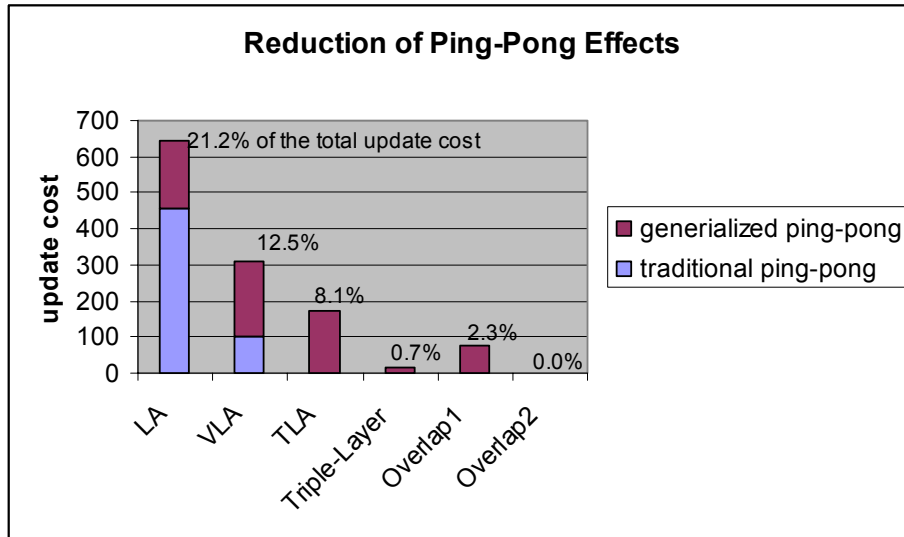


Fig. 6. Reduction of the tradition and generalized ping-pong effects

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.

Fig. 7 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 Tripple-Layer form the third group. Fig. 7 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.

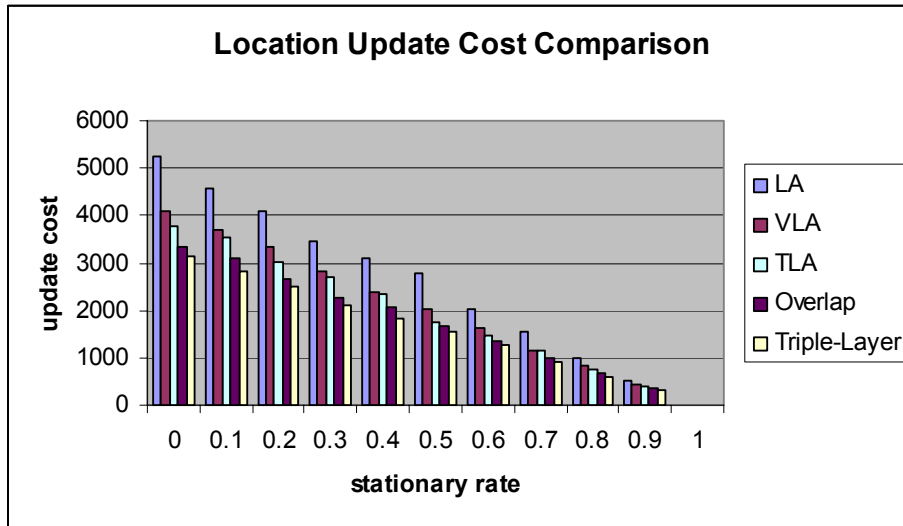


Fig. 7. Location update cost comparison of LA, VLA, TLA, overlapping, and triple-layer schemes

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 in terms of total costs 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 relatively 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. Fig. 8 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.

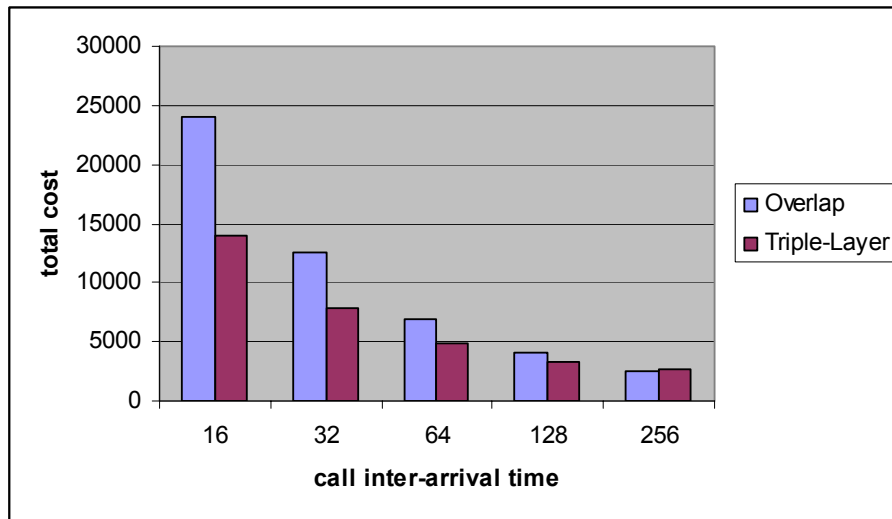


Fig. 8. Total cost comparison of the overlapping and triple-layer schemes under the random walk model with stationary rate being 0.4

6. Summary

In the location areas scheme, the ping-pong location update effect exists when a mobile terminal moves back and forth between two location areas. In addition to the traditional ping-pong effect, we defined a new kind of ping-pong effect, referred to as the generalized ping-pong effect, and showed 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 proposed a triple-layer location management strategy to eliminate the generalized ping-pong effect, therefore greatly reducing the total location update cost. Simulation results have shown that the triple-layer strategy outperforms the existing schemes designed to reduce the ping-pong effect including the traditional location area (LA) scheme, two location area (TLA) scheme, virtual layer (VLA) scheme, and overlapping scheme.

It has also shown Triple-Layer and Overlapping performs better than TLA and VLA that, in turn, outperforms the traditional LA scheme. This is mainly because the traditional LA scheme eliminates no ping-pong effect, TLA and

VLA eliminate or reduce the traditional ping-pong effect, and Triple-Layer and Overlapping eliminate or reduce both traditional and generalized ping-pong effects.

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Jingyuan Zhang received his Ph.D. degree in computer science from Old Dominion University in 1992. He is currently an associate professor with the Department of Computer Science at the University of Alabama. Prior to joining the University of Alabama he was a principal computer scientist with ECI Systems and Engineering, an assistant professor with Elizabeth City State University, and an instructor at Ningbo University. His current research interests include wireless networks, mobile computing, and collaborative software.

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