Performance of Mobile Telecommunications Network With Overlapping Location Area Configuration

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***Abstract*—In a mobile telecommunications network, the location area (LA) of a mobile station (MS) is tracked by an LA update (LAU) mechanism. To reduce the LAU traffic caused by the ping-pong effect, the overlapping LA concept is introduced. In the overlapping LA configuration, an LA selection policy is required to select the new LA at an LAU when the MS enters a new cell covered by multiple LAs. This paper describes four LA selection policies and proposes an analytic model to study the performance of these LA selection policies. Our study provides guidelines to determine an appropriate degree of overlapping among the LAs.**

***Index Terms*—Location area (LA), location update, mobility management, overlapping LA, ping-pong effect.**

I. Introduction

In a mobile telecommunications network, the cells (the coverage areas of base stations) are partitioned into groups. These groups are referred to as the location areas (LAs; in GSM [7] and in the CS domain in GPRS/UMTS [8]), the routing areas (in the PS domain in GPRS/UMTS), the paging groups (in WiMax [6]), and so on. Without loss of generality, we use the term LA throughout this paper. The LA of a mobile station (MS) is tracked by the network. Whenever the MS moves from one LA to another LA, the MS issues an LA update (LAU) request to inform the network that it has entered the new LA. This way, the network keeps track of the LA in which the MS resides.

A typical LA layout is shown in Fig. 1(a), where every cell is covered by exactly one LA. Recently, the overlapping LA concept [where a cell is covered by multiple LAs; see the gray areas in Fig. 1(b)] has been proposed to avoid the ping-pong effect [1]–[5], [9]. Suppose that an MS resides in cell a of LA 1, as shown in Fig. 1. In the nonoverlapping LA configuration [Fig. 1(a)], when the MS moves to cell b in LA 2, the MS performs an LAU to register to LA 2. If the MS moves to cell c or back to cell a in LA 1 again, the MS performs another LAU to register to LA 1. If the MS repeatedly moves back and forth between LA 1 and LA 2, many LAUs are performed. This phenomenon is called the ping-pong effect. In the overlapping LA configuration, when the MS moves from cell a (in LA 1) to cell b (in LA 2), an LAU is executed as in the nonoverlapping LA configuration. If the MS moves to cell c or back to cell a, it still resides in LA 2, and no LAU is performed. Therefore, the ping-pong effect is mitigated.

Several studies [1], [2], [5] proposed analytic models to study the performance of the mobile telecommunications network with overlapping LAs. These studies assumed that at each movement, the MS moves to any of its neighboring cells with the same probability. In [5], the LA consists of odd numbers of cells. In [1] and [2], an example is provided, and no close-form solution was derived to evaluate the performance. Moreover, each of the previous studies investigated one LA selection algorithm. In this paper, we propose an analytic model with a 1-D overlapping LA configuration to investigate the performance for four LA selection policies where the MS can move to each of its neighboring cells with different probabilities.

This paper is organized as follows. Section II introduces the system model and four overlapping LA policies. Section III proposes the analytic models for these policies. Section IV quantitatively compares the four studied policies. Then, Section V provides guidelines to determine the appropriate degree of overlapping among the LAs.

II. System Model and LA Selection Policies

This section describes the system model and four LA selection policies in details. For the purpose of demonstration, the 1-D overlapping LA configuration is considered. Based on this configuration, in Section III, we describe a random-walk model for MS movement and construct state-transition diagrams to derive the LAU costs.

Figs. 2 and 3 show the 1-D overlapping LA configuration, where each LA covers N cells and is overlapped with each of its adjacent LAs by K cells $(0 \le K < N)$. We say that the overlapping degree for this LA configuration is K. In

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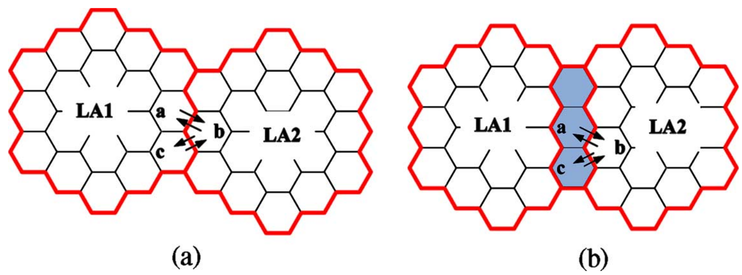

Fig. 1. Ping-pong effect reduction with overlapping LA configuration. (a) Cellular network with nonoverlapping LAs. (b) Cellular network with overlaping LAs.

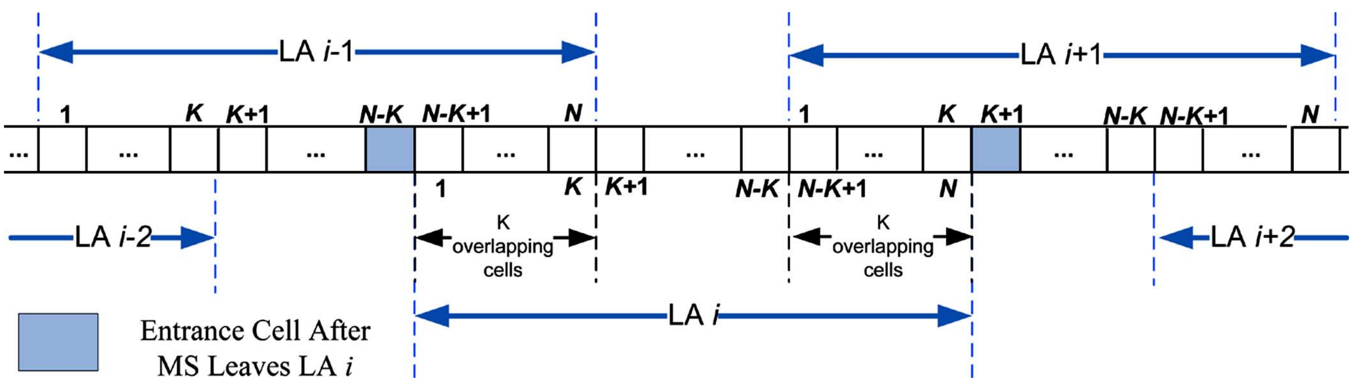

Fig. 2. One-dimensional overlapping LA registration scheme for $0 \leq K < (N/2)$.

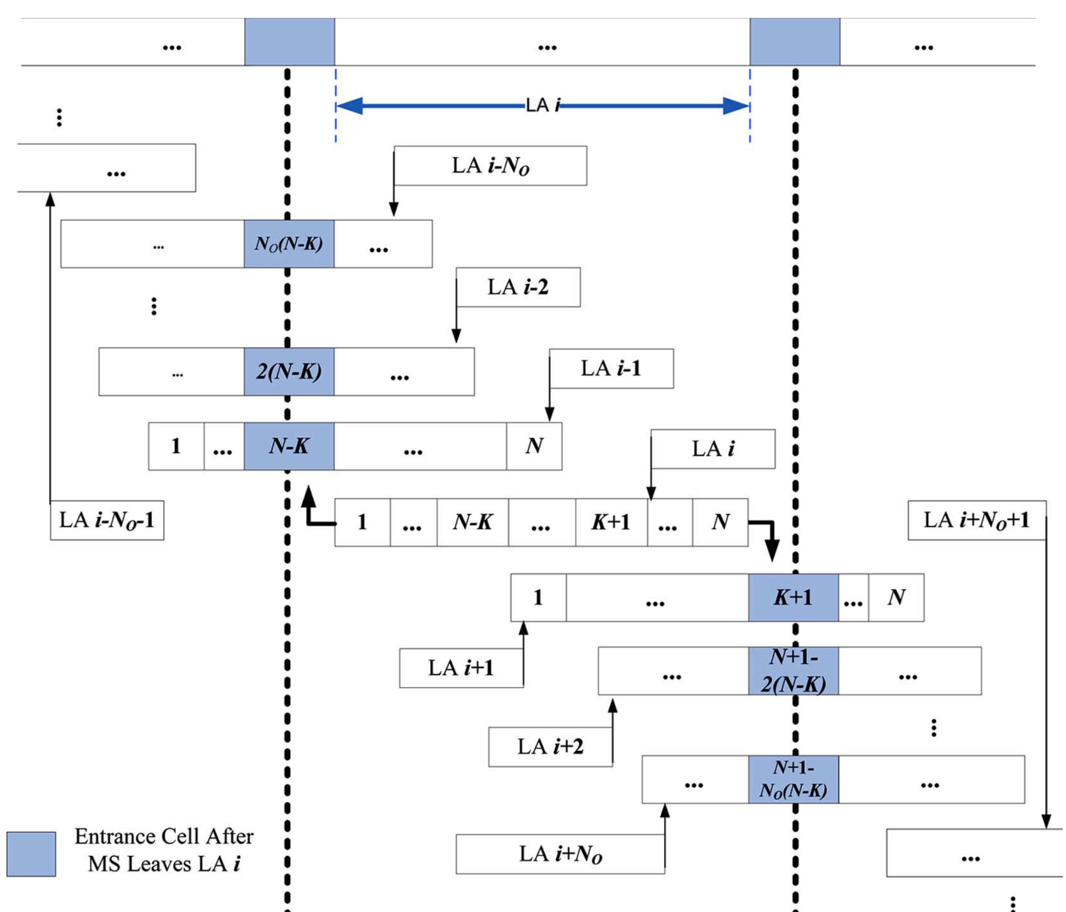

Fig. 3. One-dimensional overlapping LA registration scheme for $(N/2) \leq K < N$.

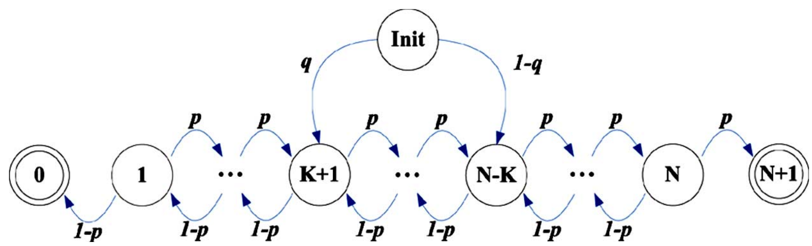

Fig. 4. State-transition diagram for K-degree overlapping LA configuration [the LA size is N, and $0 \le K < (N/2)$].

each LA, cells are sequentially labeled from 1 to N. An MS moves to the right-hand side neighboring cell with the routing probability p and moves to the left-hand side neighboring cell with probability $1-p$. If the MS moves into a new cell that does not belong to the currently registered LA (i.e., the MS moves out of the current LA), it performs an LAU. This new cell is called the entrance cell to the new LA. If $0 \le K < (N/2)$, the entrance cell is covered by only one LA. When the MS moves out of LA i from the right-hand side (the left-hand side), it enters LA $i+1$ (LA $i-1$). The entrance cell is cell $K+1$ of LA $i+1$ (cell $N-K$ of LA $i-1$); see the shadow boxes in Fig. 2. On the other hand, if $(N/2) \le K < N$, when an MS leaves the old LA and enters the new cell, this new cell is covered by several LAs adjacent to (or overlapping with) the old LA. As shown in Fig. 3, when the MS leaves LA i, the new cell can be the entrance cell for each of N_O LAs, where

$$N_O = \left\lceil \frac{K+1}{N-K} \right\rceil. \tag{1}$$

That is, if the MS moves out of LA i and enters a right-hand side LA, the entrance cell can be cell $K+1$ of LA $i+1$, cell $N+1-2(N-K)$ of LA $i+2$, $N+1-3(N-K)$ of LA $i+3, \ldots$, or cell $N+1-N_O(N-K)$ of LA $i+N_O$ (see the shadow boxes in Fig. 3). Similarly, if the MS moves out of LA i and enters a left-hand side LA, the entrance cell can be cell $N-K$ of LA $i-1$, cell $2(N-K)$ of LA $i-2, \ldots$, or cell $N_O(N-K)$ of LA $i-N_O$. Since the new cell is covered by more than one LAs for $(N/2) \le K < N$, a policy is required to select the new LA at an LAU. In this paper, we investigate four LA selection policies described as follows.

1) In the maximum overlapping (MaxOL) policy [1], [2], [5], after moving out of the current LA i from the right-hand side (the left-hand side), the MS will register to the adjacent LA $i+1$ (LA $i-1$). In this case, the number of cells overlapped between the old and the new LAs is maximal.
2) In the central policy [5], after moving out of the current LA, the MS always registers to the LA whose central cell is closest to the entrance cell.
3) In the random policy, the MS randomly registers to one LA covering the entrance cell.
4) In the minimum overlapping (MinOL) policy, after moving out of LA i, the MS chooses the farthest LA of the entrance cell from LA i (i.e., LA $i+N_O$ in the right-hand side and LA $i-N_O$ in the left-hand side in Fig. 3). In this case, the number of cells overlapped between the old and the new LAs is minimal.

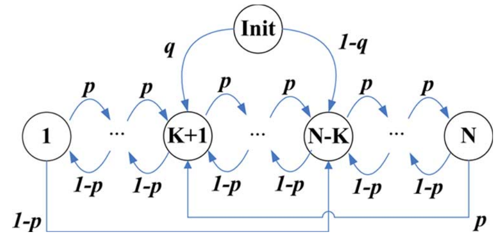

Fig. 5. Modified state-transition diagram for K-degree overlapping LA configuration [the LA size is N, and $0 \le K < (N/2)$].

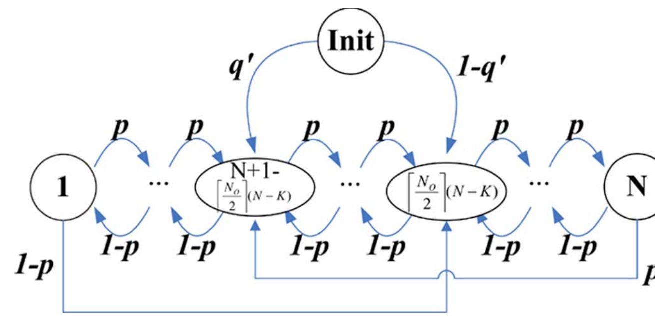

Fig. 6. State-transition diagram for the Central policy $[(N/2) \le K < N]$.

Note that for $0 \le K < (N/2)$, the aforementioned four policies are the same, i.e., the only LA covering the entrance cell is selected.

III. Analytic Model

This section proposes an analytic model to study the LAU costs for mobile telecommunications networks with overlapping LAs. Suppose that an MS makes M cell movement before it leaves an LA. For each of the four policies described in Section II, we derive the expected number $E[M]$. It is clear that the larger the $E[M]$ value, the better the performance.

A. *Case 1:* $0 \le K < (N/2)$

Fig. 4 shows the state-transition diagram for MS cell movement in an LA, where $0 \le K < (N/2)$. In this diagram, state Init represents that the MS moves into the LA in the steady state. State j represents that the MS resides in cell j of the LA, where $1 \le j \le N$. Two virtual states, 0 and $N+1$, are the absorbing states representing that the MS moves out of the LA from cell 1 and from cell N, respectively. For $1 \le j \le N$, the MS moves from state j to state $j+1$ with probability p, and the MS moves from state j to state $j-1$ with probability $1-p$. As mentioned before, the entrance cell can be cell $K+1$ (cell $N-K$) of the new LA when the MS leaves the old LA from

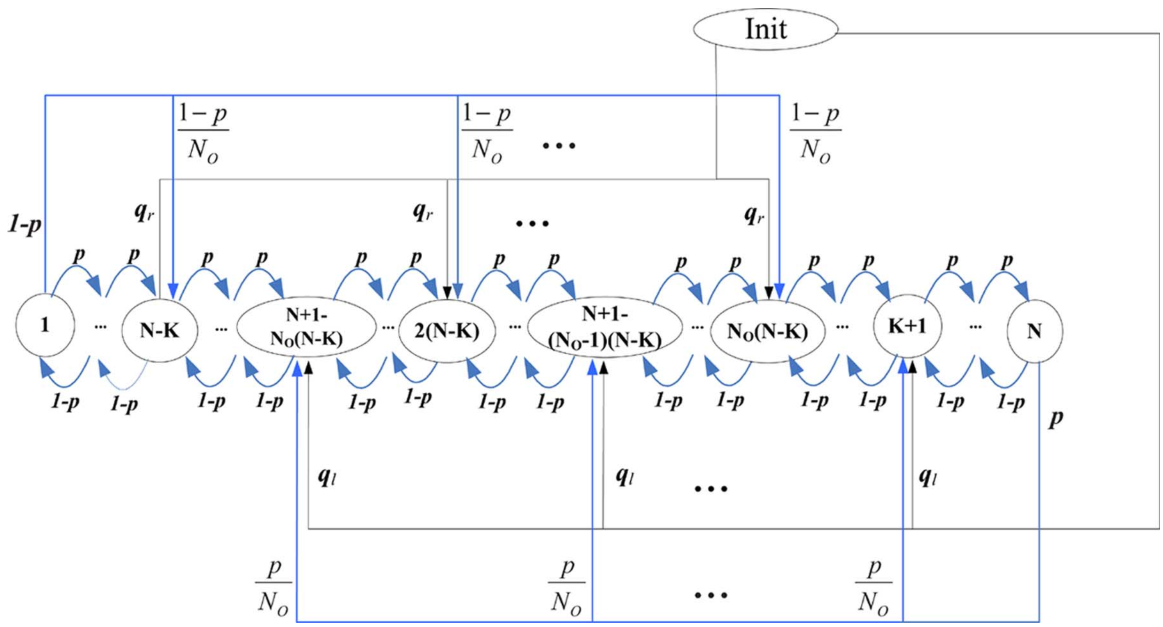

Fig. 7. State-transition diagram for the Random policy $[(N/2) \leq K < N]$.

the right-hand side (the left-hand side). Let q be the probability that the MS moves from the old LA to the new LA through the entrance cell $K+1$. Then, the MS moves from state Init to state $K+1$ with probability q and to state $N-K$ with probability $1-q$. Note that q is affected by the routing probability p, the overlapping degree K, and the LA size N. We will derive q later.

Starting from the entrance cell j, let N_j be the number of cell movement before the MS leaves the LA. The expected number $E[M]$ is

$$E[M] = qE[N_{K+1}] + (1-q)E[N_{N-K}]. \tag{2}$$

We model the MS cell movement as the Gambler's Ruin Problem [10] to solve $E[N_j]$.

Let α_j be the probability that starting from cell j, the MS will reach state $N+1$ before reaching state 0 (i.e., the MS moves out from the right-hand side). In Fig. 4, we obtain the following recurrence relation for α_j:

$$\alpha_j = p\alpha_{j+1} + (1-p)\alpha_{j-1}, \qquad \text{for } j = 1, 2, \ldots, N. \tag{3}$$

Since $\alpha_0 = 0$ and $\alpha_{N+1} = 1$, (3) is solved to yield

$$\alpha_j = \begin{cases} \frac{1-\left(\frac{1-p}{p}\right)^j}{1-\left(\frac{1-p}{p}\right)^{N+1},} & \text{for } p \neq \frac{1}{2} \\ \frac{j}{N+1,} & \text{for } p = \frac{1}{2}. \end{cases} \tag{4}$$

Define a random variable X_y as follows:

$$X_y = \begin{cases} -1, & \text{if the MS moves left at the } y\text{th cell movement} \\ 1, & \text{if the MS moves right at the } y\text{th cell movement.} \end{cases}$$

Then

$$N_j = \min\left\{n : \sum_{y=1}^{n} X_y = -j \quad \text{or} \quad \sum_{y=1}^{n} X_y = N+1-j\right\}.$$

Note that $E[X_y] = 1 \times p + (-1)(1-p) = 2p-1$ and that N_j is a stopping time for X_y's. The $E[X_y]$ value can be a positive or a negative number, and the sign of $E[X_y]$ indicates the direction of the MS movement. By using the Wald's equation [10], we have

$$E\left[\sum_{y=1}^{N_j} X_y\right] = (2p-1)E[N_j]. \tag{5}$$

Consider the left-hand side of (5). We have

$$\sum_{y=1}^{N_j} X_y = \begin{cases} N+1-j, & \text{with probability } \alpha_j \\ -j, & \text{with probability } 1-\alpha_j \end{cases}$$

or

$$\begin{aligned} E\left[\sum_{y=1}^{N_j} X_y\right] &= (N+1-j)\alpha_j + (-j)(1-\alpha_j) \\ &= (N+1)\alpha_j - j. \end{aligned} \tag{6}$$

Substituting (6) into (5) yields

$$E[N_j] = \frac{(N+1)\alpha_j - j}{2p-1}. \tag{7}$$

If p approaches (1/2), $E[N_j]$ can be derived by applying the L'Hospital's Rule [11] to (7), which yields

$$\lim_{p \to \frac{1}{2}} E[N_j] = (N+1)j - j^2. \tag{8}$$

To derive q, Fig. 5 modifies the state diagram in Fig. 4 by removing the absorbing states 0 and $N+1$ and by adding the transitions from state N to state $K+1$ (with probability p) and from state 1 to state $N-K$ (with probability $1-p$). When the MS moves out of the current LA from the right-hand side (the left-hand side), the process moves from state N to state $K+1$

(from state 1 to state $N-K$). In other words, the MS moves from cell N (cell 1) of the old LA to cell $K+1$ (cell $N-K$) of the new LA. In this case, the MS would leave the current LA from the right-hand side boundary and move to cell $K+1$ of new LA with probability $q\alpha_{K+1}$ (i.e., the probability that the MS moves into the entrance cell $K+1$ and then moves out the LA from the right-hand side) plus $(1-q)\alpha_{N-K}$ (i.e., the probability that the MS moves into entrance cell $N-K$ and then moves out the LA from the right-hand side). Since the MS moves from state Init to state $K+1$ with probability q, we have the following equation:

$$q = q\alpha_{K+1} + (1-q)\alpha_{N-K}$$

or equivalently

$$q = \frac{\alpha_{N-K}}{1-\alpha_{K+1}+\alpha_{N-K}}. \tag{9}$$

Substituting (4) and (7)–(9) into (2), $E[M]$ is expressed as

$$E[M] = \begin{cases} \left(\frac{\alpha_{N-K}}{1-\alpha_{K+1}+\alpha_{N-K}}\right) \\ \times\left[\frac{(N+1)\alpha_{K+1}-K-1}{2p-1}\right] \\ +\left(\frac{1-\alpha_{K+1}}{1-\alpha_{K+1}+\alpha_{N-K}}\right) \\ \times\left[\frac{(N+1)\alpha_{N-K}-N+K}{2p-1}\right], & \text{for } p\neq\frac{1}{2} \\ (N-K)\times(K+1), & \text{for } p=\frac{1}{2}. \end{cases} \tag{10}$$

B. Case 2: $(N/2) \le K < N$

In this case, an entrance cell is covered by two or more LAs. Therefore, after the MS leaves the old LA, an LA selection policy is required to select the new LA. The $E[M]$ values for the four policies are derived as follows.

1) MaxOL: The MS always chooses a new LA with maximum overlapping with the old LA. When the MS moves out of LA i from the right-hand side (the left-hand side), it registers to LA $i+1$ (LA $i-1$). Clearly, the LA selected in this policy is the same as that selected in case $0 \le K < (N/2)$ described in Section III-A. Therefore, the expected number of MS cell movement in an LA is expressed in (10).
2) Central: After moving out of LA i, the MS always registers to the LA whose central cell is closest to the entrance cell. The selected LA is the $\lceil N_O/2\rceil$th LA away from LA i. That is, the entrance cell is cell $N+1-\lceil N_O/2\rceil(N-K)$ of LA $i+\lceil N_O/2\rceil$ on the right-hand side or cell $\lceil N_O/2\rceil(N-K)$ of LA $i-\lceil N_O/2\rceil$ on the left-hand side. The state-transition diagram for the Central policy is shown in Fig. 6, where the MS moves from state Init to state $N+1-\lceil N_O/2\rceil(N-K)$ with probability q' and to state $\lceil N_O/2\rceil(N-K)$ with probability $1-q'$. Following the derivation in Section III-A, we have

$$q' = \frac{\alpha_{\lceil \frac{N_O}{2}\rceil(N-K)}}{1-\alpha_{N+1-\lceil \frac{N_O}{2}\rceil(N-K)}+\alpha_{\lceil \frac{N_O}{2}\rceil(N-K)}}$$

TABLE I
ANALYTIC AND SIMULATION RESULTS ($N = 15$)

K	0	4	8	12
$p=0.5$				
E[M] (Analytic)	15	55	63	39
E[M] (Simulation)	15.022	54.979	62.913	38.845
Error	−0.152%	0.037%	0.136%	0.396%
$p=0.7$				
E[M] (Analytic)	15	26.716	17.482	7.499
E[M] (Simulation)	15.032	26.622	17.458	7.501
Error	−0.214%	0.351%	0.141%	−0.023%

(a) The MaxOL Policy

K	0	4	8	12
$p=0.5$				
E[M] (Analytic)	15	55	63	63
E[M] (Simulation)	14.987	55.060	62.925	62.927
Error	0.084%	−0.109%	0.118%	0.115%
$p=0.7$				
E[M] (Analytic)	15	26.716	17.482	22.380
E[M] (Simulation)	15.032	26.622	17.465	22.330
Error	−0.214%	0.351%	0.100%	0.223%

(b) The Central Policy

K	0	4	8	12
$p=0.5$				
E[M] (Analytic)	15	55	45.5	45
E[M] (Simulation)	15.003	54.899	45.129	44.833
Error	−0.020%	0.181%	0.814%	0.370%
$p=0.7$				
E[M] (Analytic)	15	26.716	21.818	18.608
E[M] (Simulation)	15.025	26.738	21.992	18.579
Error	−0.169%	−0.083%	−0.798%	0.157%

(c) The Random Policy

K	0	4	8	12
$p=0.5$				
E[M] (Analytic)	15	55	28	15
E[M] (Simulation)	15.003	54.899	27.969	14.995
Error	−0.020%	0.181%	0.107%	0.031%
$p=0.7$				
E[M] (Analytic)	15	26.716	24.137	15
E[M] (Simulation)	15.025	26.738	24.136	15.008
Error	−0.169%	−0.083%	0.007%	−0.056%

(d) The MinOL Policy

and the expected number is in (11), shown at the bottom of the next page.
3) Random: The MS randomly registers to one LA covering the entrance cell. Let $q_l(q_r)$ be the probability that the MS moves from a left-hand side LA (right-hand side LA) to the new LA through the entrance cell. The state-transition diagram for the Random policy is shown in Fig. 7, where the MS moves from state Init to state $N+1-m(N-K)$ with probability q_l and to state $m(N-K)$ with probability q_r, where $1 \le m \le N_O$. In Fig. 7, $E[M]$ is expressed as

$$E[M] = q_l\left\{\sum_{m=1}^{N_O} E\left[N_{N+1-m(N-K)}\right]\right\} + q_r\left\{\sum_{m=1}^{N_O} E\left[N_{m(N-K)}\right]\right\}. \tag{12}$$

Since the entrance cell is covered by N_O LAs, when the MS leaves the old LA, the process moves from

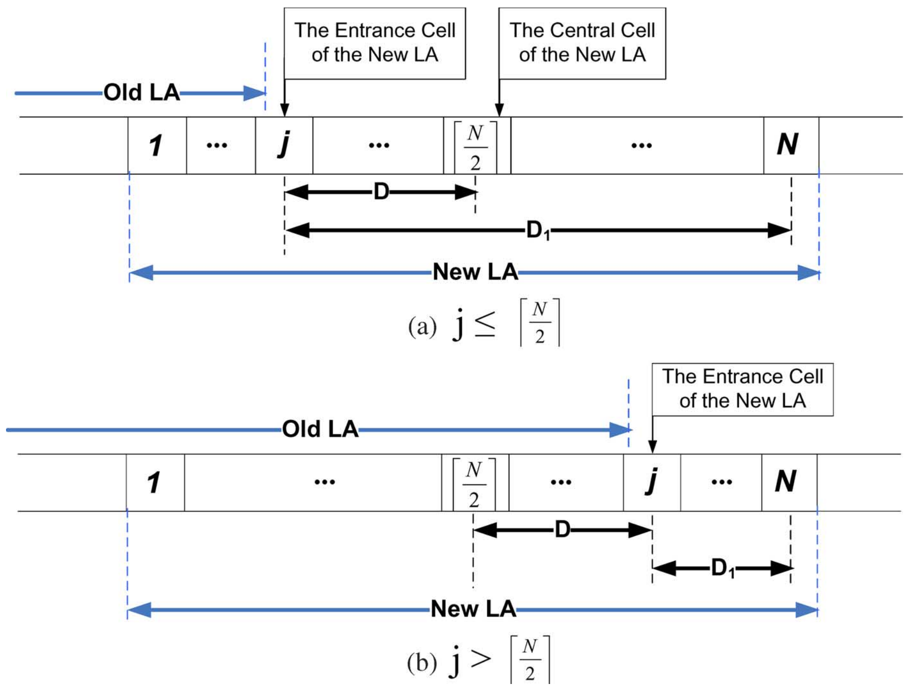

Fig. 8. Distances D and D_1 in the new LA.

state N (state 1) to state $N+1-m(N-K)$ (state $m(N-K)$) with probability (p/N_O) $((1-p)/N_O)$, where $1 \leq m \leq N_O$ (see Fig. 7). From the balance equations for the states previously described, probabilities q_r and q_l can be computed. Then, $E[M]$ for the Random policy can be derived by substituting these probabilities into (12). The details are omitted.

4) MinOL: After leaving LA i, the MS chooses the farthest LA of the entrance cell from LA i. The entrance cell is cell $N+1-N_O(N-K)$ of LA $i+N_O$ on the right-hand side or cell $N_O(N-K)$ of LA $i-N_O$ on the left-hand side. Derivation of $E[M]$ for this policy is similar to that for case $0 \leq K < (N/2)$, and the details are omitted.

Note that our analytic results have been validated against the simulation experiments (see Table I). The errors between the analytic and simulation models are under 1%.

IV. Performance Evaluation

This section studies the performance of the LA selection policies (i.e., MaxOL, Central, Random, and MinOL). Specifically, we investigate the expected number $E[M]$ of cell movement in an LA before an MS leaves the LA. It is clear that the larger the $E[M]$ value, the better the performance. In our numerical examples, we show the results for LA size $N = 15$. The results for other N values are similar and are omitted.

We first note that due to the symmetric cell structure in each LA, the effect for p is identical to that for $1-p$. Therefore, it suffices to consider $0.5 \leq p \leq 1$. Denote D as the distance (the number of cells) between the entrance cell (cell j in Fig. 8) and the central cell of the new LA (cell $\lceil N/2 \rceil$ in Fig. 8).

Denote D_1 as the distance between the entrance cell and the new LA's right-hand side (left-hand side) boundary cell if the MS enters the new LA from the left-hand side (right-hand side) of the LA (cell N in Fig. 8). Note that $E[M]$ is affected by the ping-pong effect and moving-to-one-direction effect. Besides

$$
\begin{aligned}
E[M] &= q' E\left[N_{N+1-\lceil \frac{N_O}{2} \rceil (N-K)}\right] + (1-q')E\left[N_{\lceil \frac{N_O}{2} \rceil (N-K)}\right] \\
&= \begin{cases}
\left[\dfrac{\alpha^{\lceil \frac{N_O}{2} \rceil (N-K)}}{1-\alpha^{N+1-\lceil \frac{N_O}{2} \rceil (N-K)}+\alpha^{\lceil \frac{N_O}{2} \rceil (N-K)}}\right] \times \left\{\dfrac{(N+1)\left(\alpha^{N+1-\lceil \frac{N_O}{2} \rceil (N-K)}-1\right)+\lceil \frac{N_O}{2} \rceil (N-K)}{2p-1}\right\} & \\
\quad + \left[\dfrac{1-\alpha^{N+1-\lceil \frac{N_O}{2} \rceil (N-K)}}{1-\alpha^{N+1-\lceil \frac{N_O}{2} \rceil (N-K)}+\alpha^{\lceil \frac{N_O}{2} \rceil (N-K)}}\right] \times \left[\dfrac{(N+1)\alpha^{\lceil \frac{N_O}{2} \rceil (N-K)}-\lceil \frac{N_O}{2} \rceil (N-K)}{2p-1}\right], & \text{for } p \neq \frac{1}{2} \\
\left[\lceil \frac{N_O}{2} \rceil (N-K)\right] \times \left[N+1-\lceil \frac{N_O}{2} \rceil (N-K)\right], & \text{for } p = \frac{1}{2}
\end{cases}
\end{aligned} \quad (11)
$$

TABLE II
DISTANCE D BETWEEN THE ENTRANCE CELL AND THE CENTRAL CELL OF THE NEW LA ($N = 15$)

K	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
MaxOL	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7
Cental	7	6	5	4	3	2	1	0	1	2	2	0	1	0	0
Random	7	6	5	4	3	2	1	0	3.5	3	4	2.7	3.8	3.4	3.7
MinOL	7	6	5	4	3	2	1	0	6	4	7	4	7	6	7

TABLE III
DISTANCE $D_1 (N = 15)$

K	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
MaxOL	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Cental	14	13	12	11	10	9	8	7	6	5	9	7	8	7	7
Random	14	13	12	11	10	9	8	7	9.5	8	9	7	8	7	7
MinOL	14	13	12	11	10	9	8	7	13	11	14	11	14	13	14

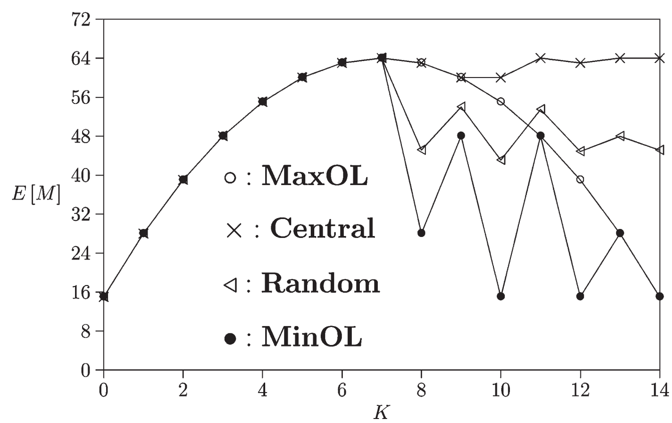

Fig. 9. Effects of K on $E[M]$ for $p = 0.5$ and $N = 15$.

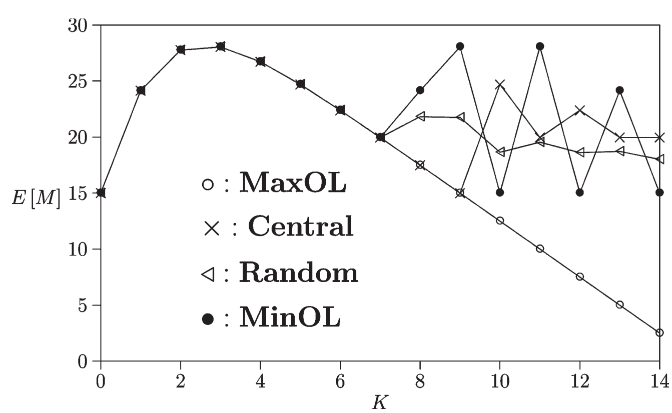

Fig. 10. Effects of K on $E[M]$ for $p = 0.7$ and $N = 15$.

p, these effects are determined by D and D_1. The smaller the D value, the less significant the ping-pong effect. The larger the D_1 value, the less significant the moving-to-one-direction effect. Tables II and III list D and D_1 as functions of K for $N = 15$. These D and D_1 values are computed from the analytic model and are validated by the simulation experiments.

Figs. 9–12 show $E[M]$ as a function of K and p, where $N = 15$. Consider $0.5 \leq p \leq 1$. When p is small, the ping-pong effect is significant, and $E[M]$ is likely to increase as D decreases. When $p = 0.5$, $E[M]$ is a decreasing function of D (see Fig. 9 and Table II). When $p = 1$, the MS always moves in one direction. Therefore, $E[M]$ increases as D_1 increases (see

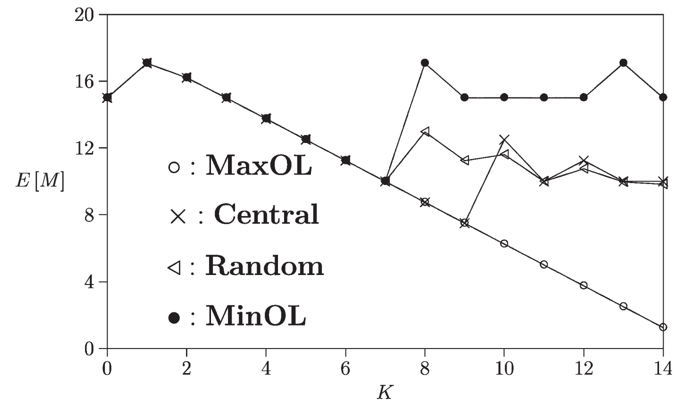

Fig. 11. Effects of K on $E[M]$ for $p = 0.9$ and $N = 15$.

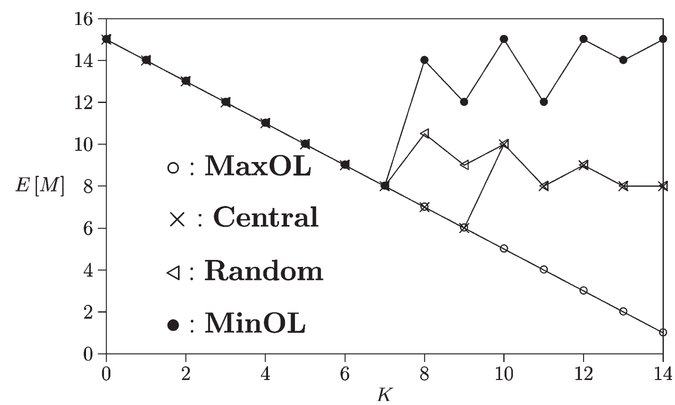

Fig. 12. Effects of K on $E[M]$ for $p = 1.0$ and $N = 15$.

Fig. 12 and Table III). When p increases, the ping-pong effect (impact of D) becomes insignificant, and the moving-to-one-direction effect (impact of D_1) becomes significant. Considering the MaxOL policy, $E[M]$ increases and then decreases as K increases. For $p = 0.5, 0.7, 0.9, 1$, the maximal $E[M]$ values occur when $K = 7, 3, 1, 0$, respectively. For a maximal $E[M]$ value, the corresponding K value is called the best overlapping degree. As p increases, the impact of D_1 becomes more significant, and the best overlapping degree decreases.

In Figs. 9–12, we observe that when $0 \leq K < (N/2)$, all four policies result in the same performance. When $(N/2) \leq K < N$, the Central policy makes sense for $p = 0.5$, while the MinOL policy is more appropriate for $p = 1.0$. For all policies, these figures show an apparent result that for the same K value, $E[M]$ decreases as p increases. By differentiating the analytic equations [e.g., (10) and (11)], we can formally prove that the best overlapping degree always occurs when $0 \leq K < (N/2)$. That is, in a 1-D overlapping LA configuration, it suffices to consider the configurations for $K < (N/2)$.

V. CONCLUSION

This paper studied four LA selection policies for overlapping LA configuration: MaxOL, Central, Random, and MinOL policies. We proposed an analytic model to investigate the $E[M]$ performance of these policies for the 1-D overlapping LA configuration. The analytic results were validated against the simulation experiments.

Our study for the 1-D overlapping LA configuration is more general than the previous studies [1], [2], [5]. For specific scenarios in the previous studies, their results are consistent with ours (which validates that our results are correct). The major difference between our model and those in the previous studies is the setup for the routing probability p. All previous studies assumed that at each movement, the MS moves to any of its neighboring cells with the same routing probability. In our study, we assume that the MS moves to each of its neighboring cells with different probabilities (i.e., $0 < p \leq 1.0$). Furthermore, the overlapping degree K in our study can be arbitrary (i.e., $0 \leq K < N$). Previous studies made a restrictive assumption, where $0 \leq K < (N/2)$. We note that there is a typo in [5, eq. (11)]. Specifically, the $(2d - w + 1)$ term in the right-hand side of the equation should be rewritten as $(2d - w - 1)$.

Our study indicates the following results.

1) It suffices to consider the configurations for $0 \leq K < (N/2)$, and all four policies result in the same performance in these configurations. When $(N/2) \leq K < N$, the Central policy makes sense for $p = 0.5$, while the MinOL policy is more appropriate for $p = 1.0$.
2) When the routing probability $p \in [0.5, 1]$, the $E[M]$ value decreases as p increases. When $p = 1$ (i.e., the mobile telecommunications network is deployed in the highway), the $E[M]$ performance for $K = 0$ is always better than that for $K > 0$.

From the numerical comparison of the four LA selection policies, our study indicates that in practical scenarios, the best overlapping degree occurs for $0 \leq K < (N/2)$, and it suffices to consider the MaxOL policy. This important result has not been reported in the literature. In the future, we will extend our 1-D model for a 2-D LA layout.

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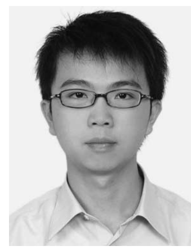

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