Mobility Modeling and Analysis in Mobile Communication Networks

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***Abstract*— In the previous work by Wang et al. [9], they presented the analytical results for cell or location area (LA) border crossing rate and LA residence time of user equipment (UE) by adopting fluid-flow model. They showed that the LA residence time follows an exponential distribution if cell residence time is exponentially distributed. Note that the LA residence time summed up the cell residence time cannot follow an exponential distribution. In this paper, we obtain computer simulation results by using RAPTOR visual tool [6], and compare the crossing rate and LA residence time. Then, through the analysis of coefficient of variation, the distribution of simulated LA residence time is estimated.**

Keywords—Mobility management; location registration; paging; location area; location area residence time; RAPTOR

I. Introduction

In a mobile communication networks, continuous management of the user equipment (UE) location is required to connect an incoming call to the UE. Two basic operations are performed in the location management: location registration and paging [4,7]. Since the trade-off relation between location registration and paging schemes exists, many studies have been performed [2,3,5]. In those studies, to analyze the performance of management schemes, it is essential to adopt an adequate model for UE's mobility.

In the previous work by Wang et al. [9], under the fluid-flow model, they presented the analytical results for crossing rate of cell (or location area (LA)) and LA residence time. In particular, they observed that if cell residence time follows an exponential distribution, then the LA residence time also follows an exponential distribution. However, note that the LA residence time composed of the cell residence times exponentially distributed cannot follow an exponential distribution. Nevertheless, Wang analyzed the performance of movement-based registration by using Markov chain method which is adequate only for the exponentially distributed LA residence time. In this paper, adopting the same model, we investigate the border crossing rate and LA residence time by RAPTOR visual computer simulation [6]. By using the values of coefficient of variation, the exact distribution of the LA residence time is also presented.

II. Mobility Modeling

In this section, we summarize the Wang's analytical results [9], where (1) number of cell crossings of UE that entered a new LA until it enters another new LA, (2) number of LA crossings, and (3) LA residence time are investigated. To analyze the mobility of UE, it is assumed that cells are regular hexagons of identical size and that an LA is constructed by arranging cells in concentric cycles around a center cell as shown in Fig. 1 with 3 rings (radius=3). Note that the LA in Fig. 1 has a total of 19 cells, and an UE requires a registration when the UE enters a new LA by crossing the cell's boundary indicated as circled number.

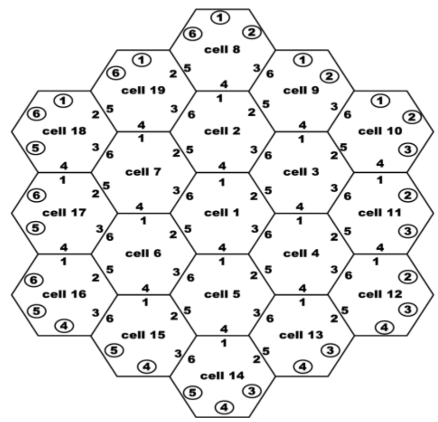

Figure 1. LA of radius 3.

The following are defined to obtain the parameter values.

n : radius of LA, n = 1, 2, 3, …,

$S_{n,n}$: expected number of cell crossings of UE required to move out of an LA after entering the new LA,

t_c : cell residence time exponentially distributed with mean $1/\theta$,

t_{LA} : LA residence time of UE with mean $1/\lambda$, given that it resides in an LA with $S_{n,n}$ cell crossings,

p : probability that when the UE moves into a new cell from an old cell, the new and old cells belong to the same LA.

When the UE movements between cells are described by the 1-dimensional Markov chain proposed in [9], $S_{n,n}$ can be expressed as following.

$$S_{n,n} = \frac{3n^2 - 3n + 1}{2n - 1}, \qquad n = 1, 2, 3, \ldots \tag{1}$$

where n is the radius of an LA. In the LA of n = 3 in Fig. 1, an UE requires a registration when the UE enters the new LA

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after the mean of $S_{3,3} = 3.8$ cell crossings while residing in the old LA.

By definition, since

$$S_{n,n} = \frac{E[t_{LA}]}{E[t_c]} = \frac{\theta}{\lambda}, \tag{2}$$

The LA crossing rate can be obtained as following.

$$\lambda = \frac{\theta}{S_{n,n}} = \frac{\theta(2n-1)}{3n^2-3n+1} \tag{3}$$

From the relationship between the rate for cell and LA crossings, and the probability p, it follows that

$$\lambda = (1-p)\theta \tag{4}$$

Thus,

$$p = 1 - \frac{\lambda}{\theta} = \frac{3n^2-5n+2}{3n^2-3n+1} \tag{5}$$

Finally, Wang et al. [9] also have shown that if cell residence time follows an exponential distribution with mean $1/\theta$, the LA residence time also follows an exponential distribution with mean $1/\lambda$.

$$\mathrm{E}[t_{LA}] = \frac{1}{\lambda} = \frac{3n^2-3n+1}{\theta(2n-1)} \tag{6}$$

The variance for the exponential distribution is $Var(t_{LA}) = 1/\lambda^2$ [1,8].

III. RAPTOR Visual Simulation

To verify the analytical result, computer simulation is performed by RAPTOR [6]. The RAPTOR (stands for Rapid Algorithmic Programming Tool for Ordered Reasoning) is a free flowcharting software package. It provides interface for users to create executable flowcharts. Instead of writing program codes which might cause syntax errors, the main algorithm is represented by flowcharts, in which the simulation flowchart is constructed as partly shown in Fig. 2.

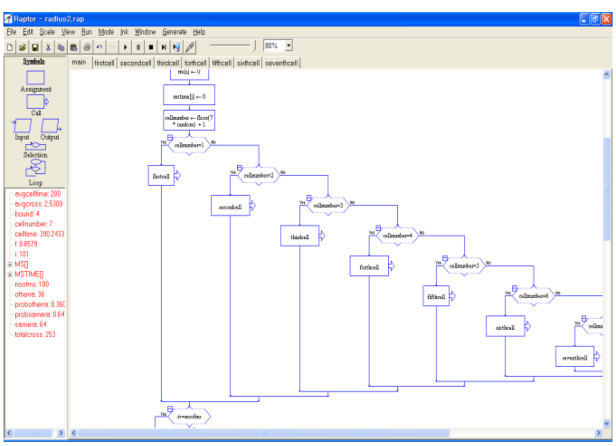

Figure 2. RAPTOR simulation.

For the LA in Fig. 1, at first, an UE is randomly located (or powered-on) in one cell among cells (cell 8 ~ 19) located in ring 3. Then, selecting one boundary for 6 directions after residing in old cell during exponential time, the UE moves to another cell. In the exponential distribution of t_c, the density function, $F_{t_c}(t)$ is

$$F_{t_c}(t) = \int_0^t \theta e^{-\theta t} dt = 1 - e^{-\theta t} \tag{7}$$

Denote u by the real-value randomly generated in [0, 1). Since the function $F_{t_c}(t)$ is uniformly distributed in [0, 1), the cell residence time is obtained as following by $1 - e^{-\theta t_c} = u$.

$$t_c = -\frac{1}{\theta} \times ln(1-u) \tag{8}$$

When the UE moves into the new cell or new LA, the crossing rate of cell or LA are updated, respectively. In particular, when the UE moves into the LA boundary (another LA) in the circled numbers in Fig. 1, the LA residence time is calculated as the sum of cell residence times crossed by UE. In the simulation, the parameter values for 10,000 UEs are obtained and compared with Wang's method. In summary, the simulation is performed as the following steps: *i*) select an entering boundary in cells of ring (n-1), *ii*) select a cell boundary among 1~6, *iii*) the UE resides in the cell with the time t_c obtained in Eq. (8), *iv*) calculate the number of cell crossings, *v*) if the moving target cell is other LA, then calculate the LA residence time, otherwise calculate the sum of cell residence time with selecting another cell boundary.

IV. Numerical Results

Table I shows the expected number of cell crossing rate of UE required to move out of an LA after entering the new LA. Note that the crossing rate in Wang's analysis can be obtained from Eq. (1) independently of cell residence time. From the results, it is observed that the difference ratio of Wang's method to the simulation results ($|Wang - Simulation|/Simulation$) is 1.0%, 0.9%, 1.5% for n = 2, 3, 4, respectively.

TABLE I. CELL CROSSING RATE ($S_{n,n}$)

n	Wang	Cell residence time ($1/\theta$ sec)						
		1	5	10	15	20	25	30
2	2.333	2.294	2.344	2.366	2.352	2.305	2.323	2.356
3	3.800	3.827	3.885	3.813	3.825	3.733	3.800	3.790
4	5.286	5.373	5.205	5.283	5.289	5.458	5.132	5.251

The results for the LA crossing rate are shown in Table II. It is also observed that the difference ratio for two methods is 0.9%, 1.1%, 1.8% for n = 2, 3, 4, respectively.

TABLE II. LA CROSSING RATE (λ)

n	$1/\theta$ (sec)	1	5	10	15	20	25	30
2	Wang	0.429	0.086	0.043	0.029	0.021	0.017	0.014
	Simulation	0.436	0.085	0.042	0.028	0.022	0.017	0.014
3	Wang	0.263	0.053	0.026	0.018	0.013	0.011	0.009
	Simulation	0.261	0.051	0.026	0.018	0.014	0.010	0.009
4	Wang	0.189	0.038	0.02	0.019	0.013	0.009	0.008
	Simulation	0.185	0.039	0.019	0.013	0.009	0.008	0.006

In Table III, we obtain the mean of LA residence time of UE. We can see that the two results give the same mean with the difference within 1.8% for all n's cases.

From those results, we observe that the analysis for the crossing rate in Wang's study is adequate. Finally, the variance of LA residence time for each radius (n) is as shown in Fig. 3.

We can see that the Wang's method gives a significant difference from that of simulation results. In Fig. 3, difference ratio is evaluated as 10.6%, 35.0%, 50.7% for n = 2, 3, 4, respectively. Note that the difference increases as the radius increases.

TABLE III. MEAN OF LA RESIDENCE TIME ($E[t_{LA}]$)

n	$1/\theta(sec)$	1	5	10	15	20	25	30
2	Wang	2.33	11.67	23.33	35.00	46.67	58.33	70.00
	Simulation	2.30	11.72	23.55	35.30	46.17	57.93	70.38
3	Wang	3.80	19.00	38.00	57.00	76.00	95.00	114.00
	Simulation	3.83	19.46	38.05	56.87	73.84	95.56	113.42
4	Wang	5.29	26.43	52.86	79.29	105.71	132.14	158.57
	Simulation	5.40	25.91	53.02	78.76	109.23	128.26	156.14

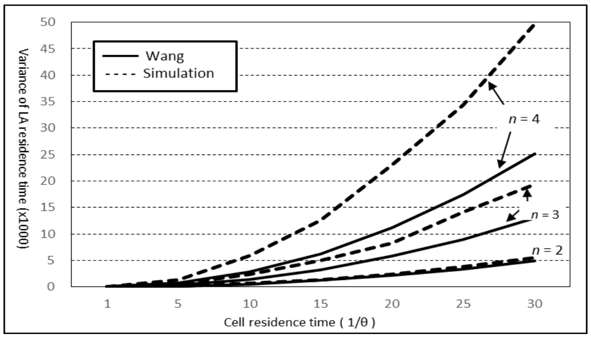

Figure 3. Variance of LA residence time.

Some continuous distributions are characterized by values (point statistics) of their functions of their parameters [1,8]. One such function that has been used is the coefficient of variation of a distribution, $\delta = \sqrt{Var(t_{LA})}/E[t_{LA}]$ where $Var(t_{LA})$ is variance and $E[t_{LA}]$ mean, respectively. From the value of δ, we can estimate the distribution. That is, if we are considering the exponential distribution as a modeling distribution, we would look for a value of δ near 1. On the other hand, δ>1 (or δ <1) might suggest gamma, Weibull or Erlang with shape parameter value smaller than 1 (or greater than 1). Table IV shows the values of δ. From the values, it is observed that the coefficient has values with greater than 1 as the radius increases, then the LA residence time might suggest gamma or Weibull distribution with shape parameter less than 1.

TABLE IV. COEFFICIENT OF VARIATION (δ)

$1/\theta$	1	5	10	15	20	25	30
$n = 2$	1.06	1.04	1.08	1.06	1.05	1.07	1.05
$n = 3$	1.24	1.24	1.27	1.24	1.23	1.25	1.23
$n = 4$	1.44	1.43	1.45	1.42	1.39	1.45	1.43

V. CONCLUSIONS

Under the fluid-flow model, Wang et al. [9] presented the analytical results for three parameter values: cell crossing rate, location area (LA) crossing rate, and LA residence time of user equipment (UE). They showed that, if cell residence time is exponentially distributed, then the LA residence time is also exponentially distributed. They also presented the wrong results for the performance of movement-based registration scheme with Markov chain method which is applied for only exponentially distributed. Note that the shape of distribution composed of exponential distribution is near by a gamma or Weibull. In this paper, we obtained simulation results for a hexagonal cells. For the simulation model, we used the RAPTOR software based on the visual flowchart interface. We also showed that, through the values of coefficient of variation, the LA residence time follows the gamma or Weibull rather than exponential. Numerical results showed that the crossing rate and mean of LA residence time in Wang's analytical method are identical with the simulation. However, the variance of LA residence time between the two methods is significantly different (10.6% ~ 50.7%). It was also observed that the difference increases as the LA size increases. In conclusion, the performance for the new registration scheme proposed by Wang should be re-evaluated.

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