Derivation of Cell Residence Times from the Counters of Mobile Telecommunications Switches

Yi-Bing Lin, *Fellow, IEEE,* Ming-Feng Chang, and Chien-Chun Huang-Fu

***Abstract*—In mobile telecommunications, the residence times of users at a cell or a location area are an important input parameter for network planning and performance evaluation of a mobile network. However, measurement of cell residence times in a commercially operated mobile network is not trivial, which typically requires tracing the movement of individual users. In this paper, we show how to use the standard counter values (number of handovers and call traffic) measured in a mobile telecommunications network to derive the cell residence times. These counter values can be obtained directly from telecommunications switches. Therefore, we can provide a quick and simple solution to compute cell residence times.**

***Index Terms*—Cell residence times, Little's Law, mobility management, telecommunications.**

I. Introduction

MOBILE telecommunications service allows users to receive phone calls or access Internet during movement. To provide telecommunications-grade quality of service, several models for the residence time defined as the connection time spent by a mobile terminal within one location have been proposed (see [1] and the references therein). However, it is more essential to consider user residence times at a location (how long a user, with or without phone conversation, stays in a location) when a mobile operator conducts network planning and performance evaluation of mobile telecommunications networks [2]-[4]. In such a network, the users are tracked by the mobility management mechanism so that the network can connect incoming calls to the users through *Base Stations* (BSs). For this purpose, BSs in the service area are grouped into *Location Areas* (LAs). The users are tracked at the accuracy of a LA coverage, and when an incoming call arrives, all BSs in that LA will page the user. This mobility management mechanism provides the position information of a user at the accuracy of one LA coverage that may include 10-100 BSs, which can be used to derive the residence time of a user at a LA. However, there are two problems: this mechanism cannot derive user's residence time at a cell (the radio coverage of one BS or a sector of the BS). Also, the mechanism requires to identify specific users in deriving their residence times.

Four techniques for tracking mobile users at the cell level are specified in 3GPP TS 25.305 [5]. Details of these methods are elaborated here for the reader's benefit: The *Cell-ID-based* method determines a mobile user's position based on the coverage of one or more cells. The *Observed Time Difference of Arrival* (OTDOA) method utilizes trilateration to determine a mobile user's position through at least three concurrent downlink signals from different cells. The *Assisted Global Positioning System* (A-GPS) method speeds up GPS positioning by downloading GPS information of a mobile user through the radio access network. The *Uplink Time Difference of Arrival* (U-TDOA) method evolves from OTDOA, which utilizes uplink signals instead of downlink signals.

The above techniques can effectively monitor the movement of specific mobile users at the cost of modifications to telecommunications network (and the exercise of such techniques can be very expensive). Other techniques such as vehicle detectors and GPS-based vehicle probes [6] are capable of measuring the cell residence time with extra hardware equipment such as detectors and GPS devices. When the detectors and the GPS probes are not available, the cell residence times can be estimated by the cellular floating vehicle data technique [7],[8] where the telecommunications network needs to spend extra effort to identify specific users and track their movements.

In this paper, we propose a simple approach to derive the cell residence times by only using the standard counter values that are already provided by the mobile telecommunications switches such as *Mobile Switching Centers* (MSCs) and *Serving General Packet Radio Service Support Nodes* (SGSNs) [9]. Our approach does not need to identify individual users and therefore does not cause any customer privacy problem (in identifying mobile users under investigation).

II. Cell Residence Time Prediction Model

In [10] we have proposed a spread prediction model that estimates how people spread using the counters of telecommunications switches. This paper follows a similar architecture, and re-iterates it as follows. Fig. 1 illustrates a mobile telecommunications service area covered by several BSs. In this figure, a circle represents a cell, and a mobile phone represents a user moving around the cells. If a user in conversation moves from one cell to another, then the call connection must be handed over from the old cell to the new cell. When a call arrives at a user or when he/she performs a handover, the activity is recorded by the MSC/SGSN. The mobile telecommunications network collects the statistics of the activities for every Δt interval typically ranging from 15 minutes to several hours.

Manuscript received May 23, 2011; revised July 25, 2011; accepted September 12, 2011. The associate editor coordinating the review of this letter and approving it for publication was T. Hou.

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This work was supported in part by NSC 98-2221-E-009-059-MY2, NSC 100-2221-E-009-070, TL-99-G103, Chunghwa Telecom, IBM, ITRI, and MoE ATU plan.

Digital Object Identifier 10.1109/TWC.2011.100611.110963

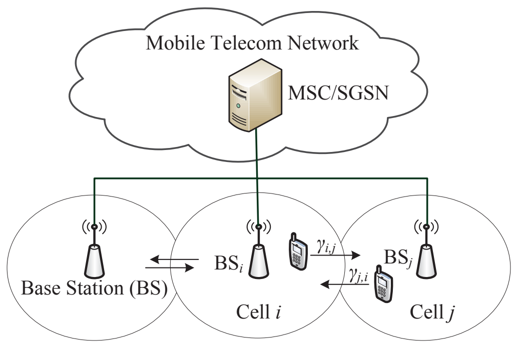


Fig. 1. A simplified mobile telecommunications network.

The above statistics are collected by several standard counters maintained in MSC/SGSN. Two of them are the number of handovers in and out of the cells and the voice/data *traffic* (in Erlang) of the cells. For time τ define $\Delta\tau$ as the timeslot $(\lfloor\frac{\tau}{\Delta t}\rfloor\Delta t, \lfloor\frac{\tau}{\Delta t}+1\rfloor\Delta t)$. Suppose that a mobile user in conversation moves from cell i to cell j at time τ, then he/she contributes to one handover out of cell i , and one handover into cell j in timeslot $\Delta\tau$. The MSC/SGSN counts the number $\gamma_{i,j}(\tau)$ of handovers from cell i to cell j in timeslot $\Delta\tau$.

Call traffic is typically measured by "Erlang" that represents the continuous use of one voice path. Let $\rho_i(\tau)$ be the minutes of traffic of cell i in $\Delta\tau$; that is, $\rho_i(\tau)$ is the number of calls arriving at cell i in $\Delta\tau$ times the expected call holding time (measured in minutes).

When a user arrives at cell i in timeslot $\Delta\tau$, let $R_i(\tau)$ be the residence time before the user moves out of the cell. Then the expected value $E[R_i(\tau)]$ can be derived by Little's Law $N = \lambda R$ [11], where N is the expected number of users in a system, λ is the arrival rate of the users, and R is the expected response time that a user stays in the system. For cell i in timeslot $\Delta\tau$, we can re-write Little's Law as

$$E[N_i(\tau)] = \lambda_i(\tau)E[R_i(\tau)] \tag{1}$$

In (1) the expected value $E[N_i(\tau)]$ of users at cell i in timeslot $\Delta\tau$ is derived as follows. Let $E[t_c]$ be the expected call holding time and $E[t_a]$ be the expected inter-call arrival time. Then

$$\rho_i(\tau) = \frac{E[N_i(\tau)]E[t_c]\Delta t}{E[t_a]} \tag{2}$$

In (2), $(1/E[t_a])$ is the call arrival rate of a mobile user and $E[t_c](\Delta t/E[t_a])$ is the minutes of traffic contributed by a user in timeslot $\Delta\tau$. Since there are $E[N_i(\tau)]$ users in cell i at timeslot $\Delta\tau$, the net minutes of traffic $\rho_i(\tau)$ can be expressed as (2), and with re-arrangement, we have

$$E[N_i(\tau)] = \frac{\rho_i(\tau)E[t_a]}{E[t_c]\Delta t} \tag{3}$$

In (1), $\lambda_i(\tau)$ is derived as follows. In timeslot $\Delta\tau$, there are $\lambda_i(\tau)\Delta t$ users moving into cell i. Among these users, $(E[t_c]/E[t_a])$ of them are in call conversation. In other words, $(\lambda_i(\tau)\Delta tE[t_c]/E[t_a])$ users hand over into cell i in timeslot $\Delta\tau$. Since the number of handovers into cell i in timeslot $\Delta\tau$ is $\gamma_i(\tau) = \sum_{j,j\neq i}\gamma_{j,i}(\tau)$, we have

$$\gamma_i(\tau) = \frac{\lambda_i(\tau)\Delta tE[t_c]}{E[t_a]}$$

or

$$\lambda_i(\tau) = \frac{\gamma_i(\tau)E[t_a]}{E[t_c]\Delta t} \tag{4}$$

Substitute (3) and (4) into (1) to yield

$$\frac{\rho_i(\tau)E[t_a]}{E[t_c]\Delta t} = \left\{\frac{\gamma_i(\tau)E[t_a]}{E[t_c]\Delta t}\right\}E[R_i(\tau)]$$

or

$$E[R_i(\tau)] = \frac{\rho_i(\tau)}{\gamma_i(\tau)} \tag{5}$$

Equation (5) has a simple form that can be quickly computed through the counter values of the commercially operated telecommunications switches (or gateways).

III. Numerical Examples

In this section, we use (5) to derive the "predicted" cell residence times $E[R_{p,i}(\tau)]$, and compare them with the "real" cell residence times $E[R_{r,i}(\tau)]$. From a commercial mobile telecommunications service area in Hsinchu, Taiwan, we have collected $\gamma_i(\tau)$ and $\rho_i(\tau)$ statistics, where $\gamma_i(\tau)$ is 53.96 movements per hour and $\rho_i(\tau)$ is 4.103 Erlangs per hour (i.e., Δt = 1 hour). From (5), we have $E[R_{p,i}(\tau)] = 4.103/53.96 \approx 5$ (minutes). In this paper, we do not reveal the actual base station layout in Hsinchu due to the Personal Information Protection Act in Taiwan. Instead, we present the results based on a cell layout of the Manhattan Street fashion. In our simulation setting, there are 49 cells (i.e., 7×7 cells) where every cell has 4 neighbors (the boundary cells have 2 or 3 neighbors and the users visiting these cells will bounce back). After a user resides in a cell for a while, he/she moves to one of the four neighboring cells with a randomly generated probability for heterogeneous routing. The call arrivals follow Poisson process with the expected inter-call arrival time $E[t_a] = 2$ hours. We assume that the number of users in the network is 24000.

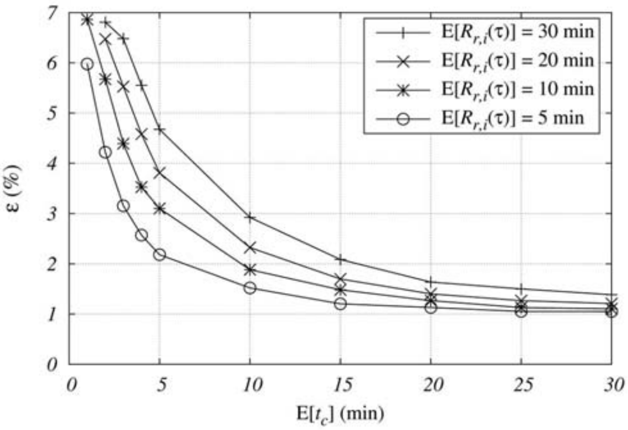
In our simulation, phone calls (connected to a MSC) are represented by $E[t_c] \leq 5$ minutes, and data sessions (connected to a SGSN) are represented by $E[t_c] \geq 10$ minutes. The cell residence time $R_i(\tau)$ has an arbitrary distribution. Define the inaccuracy of (5) or error ε as

$$\varepsilon = \left|\frac{E[R_{r,i}(\tau)] - E[R_{p,i}(\tau)]}{E[R_{r,i}(\tau)]}\right| \tag{6}$$

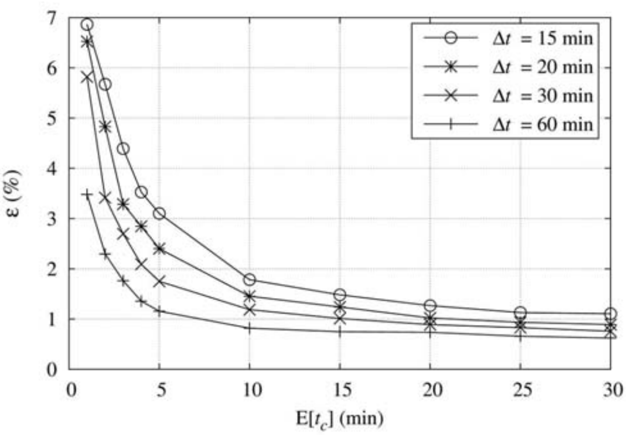
Inaccuracy of (5) (i.e., ε) is affected by the number of handovers observed. It is clear that if only few handovers are observed in Δt, (5) is less accurate because there is not enough samples to reflect $\gamma_i(\tau)$ to $\lambda_i(\tau)$. That is, we have the following fact:

Fact 1. Error ε decreases as $\gamma_i(\tau)$ increases.

The number of handovers $\gamma_i(\tau)$ is affected by $E[t_c]$, $E[t_a]$, $E[R_{r,i}(\tau)]$ and Δt. It is clear that with a larger Δt, more handovers are collected in the timeslot. Also, if a user stays



(a) $\Delta t = 15$ minutes



(b) $E[R_{r,i}(\tau)] = 10$ minutes

Fig. 2. Effects of $E[t_c]$, $E[R_{r,i}(\tau)]$ and Δt ($E[R_{r,i}(\tau)]$ is exponentially distributed).

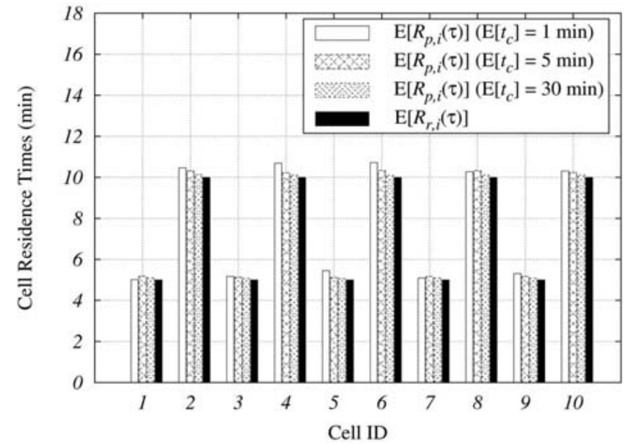


Fig. 3. Effect of changing $E[R_{r,i}(\tau)]$ for different cells ($\Delta t = 15$ minutes and $R_{r,i}(\tau)$ is exponentially distributed).

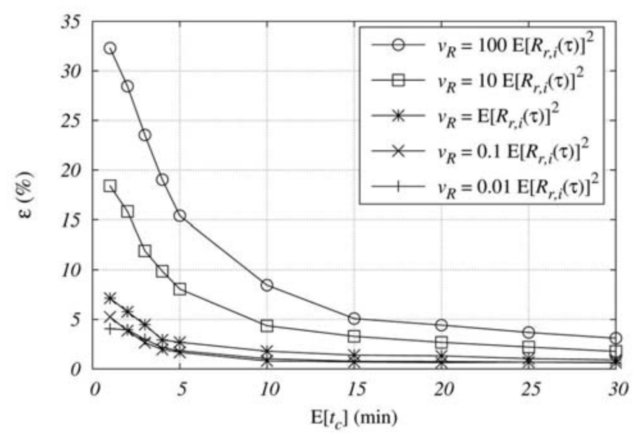


Fig. 4. Effects of v_R ($E[R_{r,i}(\tau)] = 10$ minutes, $\Delta t = 15$ minutes and $R_{r,i}(\tau)$ has a gamma distribution).

in a cell for a short time (i.e.,$E[R_{r,i}(\tau)]$ is small), then he/she is more likely to hand over. Finally, the probability that a user is in a conversation at any time instant is $E[t_c]/E[t_a]$. Therefore, we have the following fact.

Fact 2. The number of handovers $\gamma_i(\tau)$ increases if (a) $E[t_c]$ increases, (b) $E[t_a]$ decreases, (c) $E[R_{r,i}(\tau)]$ decreases, or (d) Δt increases.

Fig. 2 (a) plots ε against $E[t_c]$ and $E[R_{r,i}(\tau)]$, where $\Delta t = 15$ minutes and $R_{r,i}(\tau)$ is exponentially distributed. The figure indicates that ε is reduced as $E[t_c]$ increases or $E[R_{r,i}(\tau)]$ decreases (Fact 1 and Fact 2 (a) and (c)). Fig. 2 (b) plots ε against Δt where $E[R_{r,i}(\tau)] = 10$ minutes. The figure indicates that ε is reduced as Δt increases (Facts 1 and Fact 2 (d)). In all scenarios, ε is less than 10% in general, and is less than 2% if $E[t_c] > 15$ minutes. Note that when a smaller Δt is selected, the computed $E[R_{p,i}(\tau)]$ is more "real-time" at the cost of degrading the accuracy.

We have also conducted simulations where $E[R_{r,i}(\tau)]$ is different for different cells. In our scenario,

$$E[R_{r,i}(\tau)] = \begin{cases} 5 \text{ minutes}, & \text{if cell ID is odd} \\ 10 \text{ minutes}, & \text{if cell ID is even} \end{cases} \quad (7)$$

Based on (7), Fig. 3 plots the $E[R_{r,i}(\tau)]$ and the $E[R_{p,i}(\tau)]$ values (for $E[t_c] = 1$, 5, and 30 minutes) of the first 10 cells. The ε performances are similar to those in Fig. 2 (a) where $\varepsilon \approx 6\%$ for $E[t_c] = 1$, $\varepsilon \approx 2\%$ for $E[t_c] = 5$, and $\varepsilon \approx 1\%$ for $E[t_c] = 30$. Same results are observed for other cells, and are not presented.

Fig. 4 plots ε against v_R, the variance of the Gamma $R_{r,i}(\tau)$ distribution. The figure indicates that ε increases as v_R increases. The effect of v_R becomes insignificant as $E[t_c] > 15$ minutes. Same results are observed for other distributions such as Normal and Weibull distributions, and the results are not presented.

Fig. 5 shows the effect of changing $E[R_{r,i}(\tau)]$ every 2 hours. In our scenario,

$$E[R_{r,i}(\tau)] = \begin{cases} 5 \text{ minutes}, & \text{if } \lceil \text{time/ 2 hr} \rceil \text{ is odd} \\ 10 \text{ minutes}, & \text{if } \lceil \text{time/ 2 hr} \rceil \text{ is even} \end{cases} \quad (8)$$

Based on (8), Fig. 5 plots the $E[R_{r,i}(\tau)]$ curve (the solid curve) and the $E[R_{p,i}(\tau)]$ curves for $E[t_c] = 1$, 5, and 30 minutes. The curves indicate that (5) can capture the changing of $E[R_{r,i}(\tau)]$. During the short periods of $E[R_{r,i}(\tau)]$ transitions, ε can be as large as 40%, and after the transition periods, ε ranges from 2% to 10%.

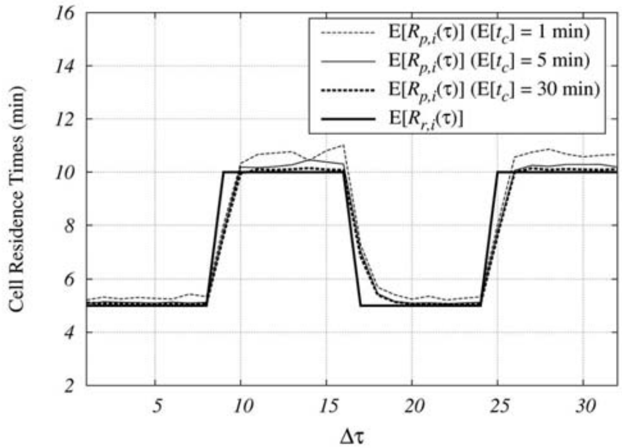


Fig. 5. Effect of changing $E[R_{r,i}(\tau)]$ ($\Delta t = 15$ minutes and $R_{r,i}(\tau)$ is exponentially distributed).

IV. Conclusion

Cell residence time is an important input parameter typically used in network planning and performance modeling of mobile telecommunications networks. However, obtaining cell residence times from a commercially operated mobile network is not trivial. Based on Little's Law, this paper derives a simple equation to compute cell residence time by using handover rates and call traffic of a cell. These two statistics can be obtained from standard mobile telecommunications switches at the granularity of the measurement interval ranging from 15 minutes to 1 hour.

For most parameter values considered in this paper, the errors of the derived residence times (Equation (5)) are limited to 10%, and for long call holding times, the errors are less than 2%. For real experiments in a road of Taoyuan, Taiwan, we compared the derived residence times from the statistics of telecommunications network with the data from the vehicle detectors. The errors range from 3.89% to 12.81%. Our study indicates that Equation (5) can appropriately compute the cell residence times with very low computation cost. As a final remark, this work is pending US, European, China, and Taiwan patents.

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