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碩 士 論 文

IMS 緊急電話之位置回報機制

Active Location Reporting for Emergency Call
in UMTS IP Multimedia Subsystem

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摘　　要

在UMTS (Universal Mobile Telecommunications System) 系統中，網際網路IP多媒體子系統(IP Multimedia Subsystem; IMS) 負責提供多媒體服務。在IMS中，緊急電話是由E-CSCF (Emergency-Call Session Control Function) 所建立。E-CSCF會根據發話者所在位置轉接緊急電話到最近的公眾安全應變中心(Public Safety Answering Point; PSAP)。在緊急電話建立完成後，PSAP會透過位置輪詢(Location Polling)機制來持續追蹤發話者的位置。本論文針對位置追蹤進行效能分析，並提出主動位置回報(Active Location Reporting)機制以提升位置追蹤的效能。研究結果顯示，主動位置回報機制在效能上較位置輪詢機制有顯著地改善。

Active Location Reporting for Emergency Call in UMTS IP Multimedia Subsystem

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Abstract

The *IP Multimedia Core Network Subsystem* (IMS) provides multimedia services for Universal Mobile Telecommunications System (UMTS). In IMS, an emergency call is established by an *Emergency-Call Session Control Function* (E-CSCF). The E-CSCF dispatches the call to the nearest *Public Safety Answering Point* (PSAP) according to the location of the caller. After emergency call setup, the caller's location is tracked by the PSAP through Location Polling. This thesis investigates the performance of location tracking. Then we propose the Active Location Reporting scheme to improve the performance of location tracking. Our study indicates that the Active Location Reporting scheme may significantly outperform the Location Polling scheme.

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Hsiao-Han Wang

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Chapter 1

Introduction

Universal Mobile Telecommunications System (UMTS) is one of the major standards for the third generation (3G) mobile telecommunications. In UMTS, the *IP Multimedia Core Network Subsystem* (IMS) provides multimedia services by utilizing the *Session Initiation Protocol* (SIP) [8].

Figure 1.1 illustrates a simplified UMTS network architecture [5, 4, 10]. This architecture consists of a *Radio Access Network* (RAN; Figure 1.1 (a)), the *General Packet Radio Service* (GPRS) core network (Figure 1.1 (b)) and the IMS network (Figure 1.1 (c)). The *Home Subscriber Server* (HSS; Figure 1.1 (2)) is the master database containing all user-related subscription information. The *Serving GPRS Support Node* (SGSN; Figure 1.1 (3)) is responsible for packet delivery to and from *User Equipments* (UEs; Figure 1.1 (1)). The *Gateway Mobile Location Center* (GMLC; Figure 1.1 (4)) supports *Location Service* (LCS). The GPRS core network connects to the IMS network through *Gateway GPRS Support Nodes* (GGSNs; Figure 1.1 (5)). To establish a data session, a *Packet Data Protocol* (*PDP*) *Context* must be activated before a UE can access the IMS network. A *Public Safety Answering Point* (PSAP; Figure 1.1 (6)) dispatches emergency calls according to the types of emergent events (e.g., fire). When the UE originates an emergency call, the call is established by an *Emergency-Call Session Control Function* (E-CSCF; Figure 1.1 (7)), which dispatches the call to the nearest PSAP according to the location of the UE.

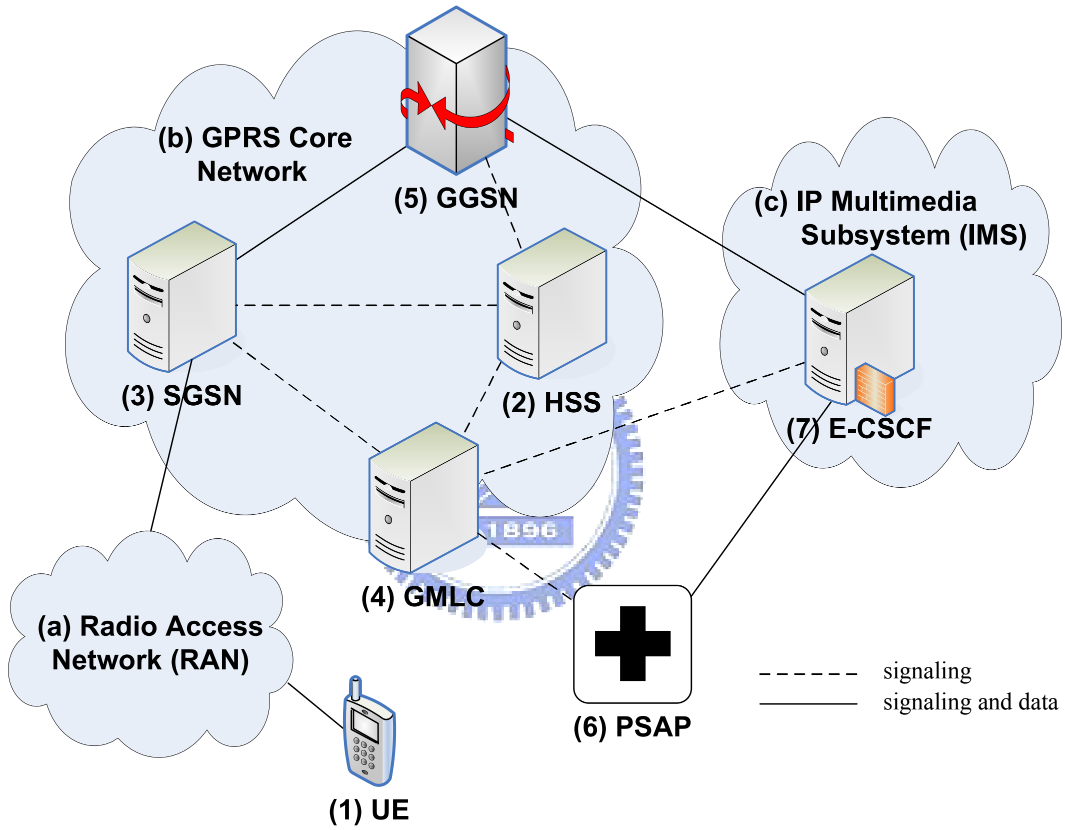

Figure 1.1: The UMTS Network Architecture

The LCS utilizes one or more positioning methods between the RAN and the UE to determine the location of a UE. Four positioning methods are specified in 3GPP TS 25.305 [2]. These methods are briefly described as follows:

The Cell-ID-based method determines the UE's position based on the coverage of Service Areas (SAs). An SA includes one or more cells (base stations). At most one-cell-sized accuracy (about 500 meters) can be achieved when the SA includes only one cell.

The Observed Time Difference of Arrival (OTDOA) method utilizes trilateration to determine the UE's position. At least three concurrent downlink signals from different cells are measured in the UE. The time differences among the signal arrivals are calculated to form hyperbolic curves. The intersection of these curves is then used to indicate the UE's position. This method provides location accuracy within 50-150 meters.

The Assisted Global Positioning System (A-GPS) method speeds up GPS positioning by downloading GPS information through the RAN. Execution of A-GPS positioning only requires several seconds while execution of normal GPS positioning requires 30 seconds to several minutes. GPS modules are installed in both the UE and the RAN. This method provides location accuracy within 5-15 meters.

The Uplink Time Difference of Arrival (U-TDOA) method evolves from the OTDOA method. This method utilizes uplink signals instead of downlink signals. A normal uplink signal from the UE is measured in different cells, and no extra signal is required. Same calculation process as OTDOA is then conducted to find out the UE's position. Since the measurement and the calculation process are exercised only in the RAN, this method does not require any modification to the mobile phone. This method provides location accuracy within 50-150 meters.

Without loss of generality, we consider the Cell-ID-based method in this thesis (the Cell-ID-based method supports all kinds of UEs, while other methods may require UEs to measure extra signal). The conclusions also apply to other positioning methods. This thesis is organized as follows. Chapter 2 describes IMS emergency call setup and location tracking. Then we propose the Active Location Reporting scheme to improve the performance of location tracking. In Chapter 3, we propose analytic and simulation models to study the performance of location tracking. The proposed analytic model is validated against simulation experiments. Based on the simulation experiments, Chapter 4 investigates the performance of location tracking.

Chapter 2

Emergency Call Setup and Location Tracking

This chapter describes the IMS emergency call setup and location tracking procedures. We first elaborate on the call setup procedure and the Location Polling scheme proposed in 3GPP [1, 3]. Then we propose the Active Location Reporting scheme that improves the performance of location tracking.

2.1 Emergency Call Setup

Before the IMS emergency call is set up, the UE has attached to the network through the RAN. Figure 2.1 illustrates IMS emergency call setup message flow defined in 3GPP [1] with the following steps:

Step CS-1. The UE performs PDP context activation that establishes the IP connectivity to the IMS through the GPRS network [10].

Step CS-2. The UE sends the SIP INVITE message to the E-CSCF. This message includes the supported positioning methods of the UE (i.e., Cell-ID-based in our example).

Step CS-3. The E-CSCF uses the received information to determine a GMLC and sends the Emergency Location Request message to the GMLC, which includes all UE-related

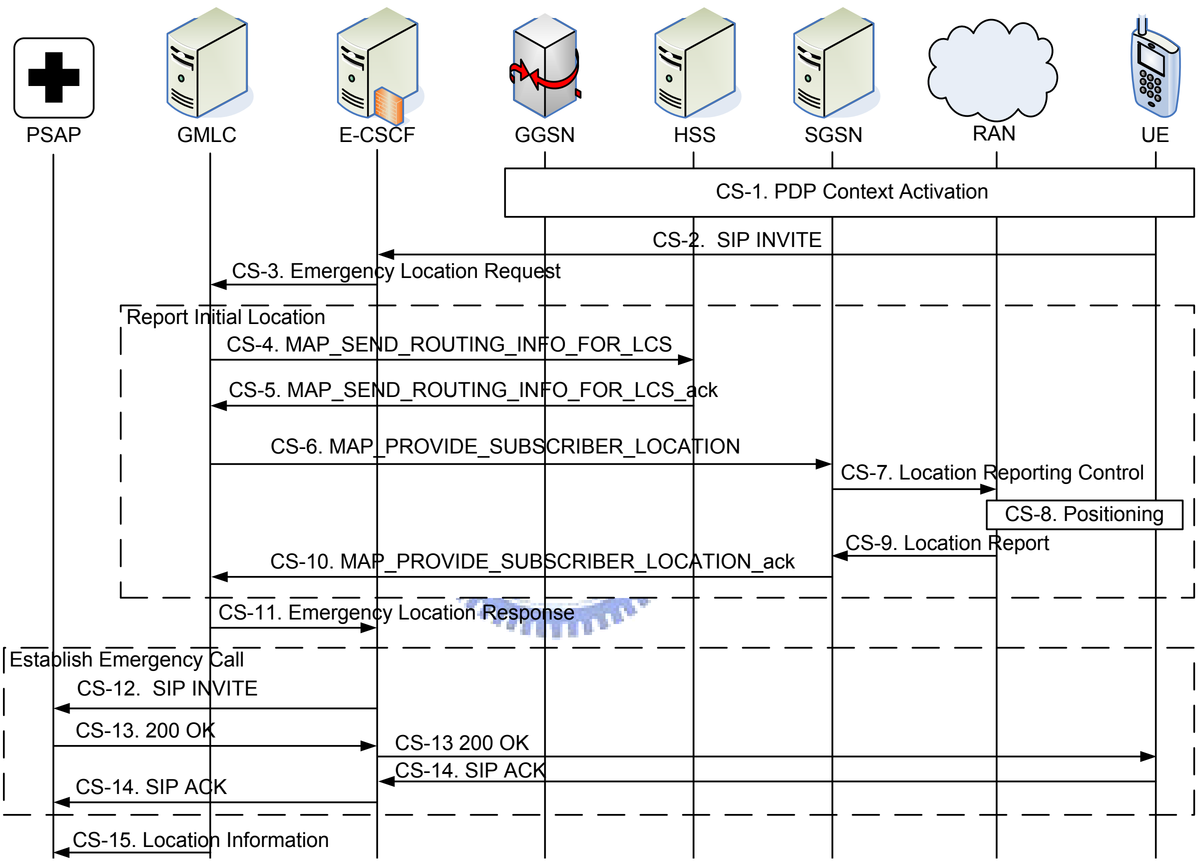

Figure 2.1: IMS Emergency Call Setup

information received at Step CS-2.

Steps CS-4 and 5. The GMLC exchanges the MAP_SEND_ROUTING_INFO_FOR_LCS and MAP_SEND_ROUTING_INFO_FOR_LCS_ack message pair with the HSS to obtain the SGSN address for the UE.

Step CS-6. The GMLC sends the MAP_PROVIDE_SUBSCRIBER_LOCATION message to the SGSN to request the UE's location. In this message, the locationEstimateType parameter is set to "initialLocation".

Step CS-7. Upon receipt of the MAP_PROVIDE_SUBSCRIBER_LOCATION message, the SGSN sends a Location Reporting Control message to the RAN to trigger the positioning procedure. In this message, the Request Type is set to "report directly".

Step CS-8. The RAN and the UE exercise the Cell-ID-based positioning procedure to obtain the location estimate information of the UE (i.e., the SA identity of the UE).

Step CS-9. The RAN returns the Location Report message with the SA identity to the SGSN.

Step CS-10. The SGSN returns the SA identity to the GMLC through the MAP_PROVIDE_SUBSCRIBER_LOCATION_ack message.

Step CS-11. The GMLC selects a suitable PSAP according to the SA of the UE and replies the Emergency Location Response message with the selected PSAP address to the E-CSCF.

Steps CS-12-14. The E-CSCF forwards the SIP INVITE to the PSAP. The PSAP and the UE exchange the 200 OK and the SIP ACK messages through the E-CSCF. After the PSAP has received the SIP ACK message, the emergency call is established.

Step CS-15. The GMLC sends the location information obtained at Step CS-10 to the PSAP after the call has been established.

2.2 Location Polling

A UE may move during an emergency call, and the PSAP may need to monitor the UE's location in real time. In 3GPP TS 23.271 [3], the UE's location is monitored through a polling procedure where the PSAP periodically queries the UE's location. In each polling query, the following steps are executed (see Figure 2.2).

Step LP-1. The PSAP sends the Location Information Request message to the GMLC.

Steps LP-2-8. These steps are similar to Steps CS-4-10 in Figure 2.1 except that the parameter locationEstimateType in the MAP_PROVIDE_SUBSCRIBER_LOCATION message is set to "currentLocation".

Step LP-9. The GMLC returns the SA identity of the UE to the PSAP.

Steps LP-10-12. When the emergency call is terminated, the E-CSCF exchanges the Emergency Location Release and Response message pair with the GMLC to terminate location tracking.

2.3 Active Location Reporting

In the Location Polling scheme, if the UE does not change its location between two queries, the second query is wasted. On the other hand, if the UE has moved to several new locations between two location queries, then the PSAP may lose track of the UE. To resolve this issue, we propose the Active Location Reporting scheme that reports the UE's location upon change of its SA. Our scheme introduces two new locationEstimateTypes "initiateActiveReport" (to trigger Active Location Reporting) and "terminateActiveReport" (to terminate Active Location Reporting) in the MAP_PROVIDE_SUBSCRIBER_LOCATION message, and one new LCS event type "ActiveReporting" (to indicate the Active Location Reporting event). At emergency call setup, the locationEstimateType is set to

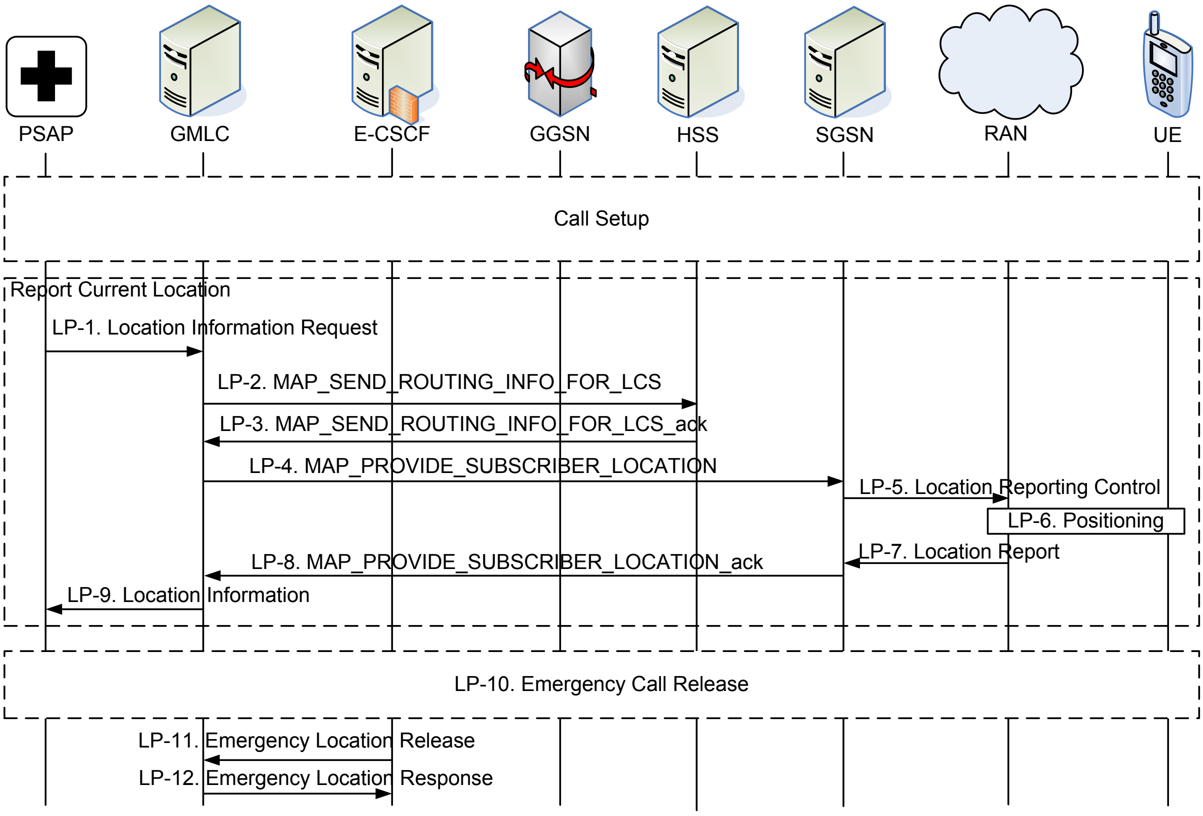

Figure 2.2: Location Polling

"initiateActiveReport" at Step CS-6, and the Request Type is set to "change of service area" at Step CS-7. Since the IP connectivity exists during the IMS emergency call, the UE is in the Cell-Connected state and is tracked by the RAN at the cell level [10]. Therefore, the RAN can detect the movement of the UE at the cell level and report the new SA identity to the SGSN. In this approach, the GMLC maintains a UE-PSAP mapping table, and the (UE, PSAP) pair is stored in the GMLC at Step CS-11. Therefore, the GMLC does not need to query the HSS to obtain the SGSN address of the UE (therefore, Steps LP-2 and LP-3 are eliminated). The Active Location Reporting scheme is illustrated in Figure 2.3 with the following steps:

Step ALR-1. When the UE moves to a new SA, the RAN detects this movement at the cell tracking mode [10] and then triggers the positioning procedure.

Step ALR-2. After the positioning procedure is executed, the UE's SA identity is obtained.

Step ALR-3. The RAN sends the Location Report message with the SA identity of the UE to the SGSN.

Step ALR-4. The SGSN sends the MAP_SUBSCRIBER_LOCATION_REPORT message with the SA identity to the GMLC.

Step ALR-5. From the UE-PSAP mapping table, the GMLC retrieves the PSAP address of the UE stored at Step CS-11 and then sends the updated location information to the PSAP.

When the emergency call is terminated, the following steps are executed.

Step ALR-6. When the IMS call is released, the UE moves from the Cell-Connected mode to the Idle mode, and the RAN no longer tracks the movement of the UE [10].

Step ALR-7. The E-CSCF sends the Emergency Location Release message to the GMLC to terminate location tracking.

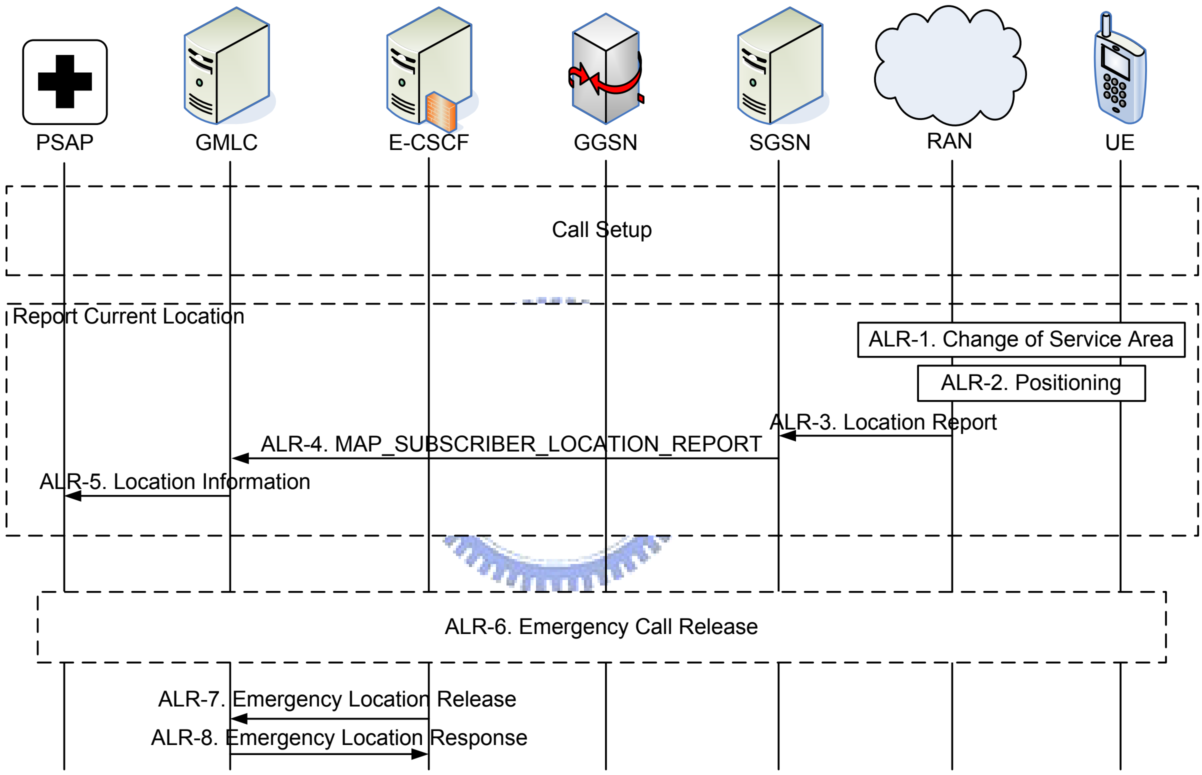

Figure 2.3: Active Location Reporting

Step ALR-8. The GMLC returns the Emergency Location Response message to the E-CSCF and then deletes the (UE, PSAP) mapping from the UE-PSAP table.

The major difference between Active Location Reporting and Location Polling is at Steps ALR-1 and ALR-2. Active Location Reporting is triggered when the RAN detects the movement of the UE (through the standard tracking procedure at the Cell-Connected mode). Note that the HSS query (see Steps LP-2 and LP-3 in Figure 2.2) is not required for the Active Location Reporting scheme because of the active reporting of the RAN. The GMLC needs to maintain the (UE, PSAP) mapping so that when a UE changes the SA, the GMLC can report the location update to the corresponding PSAP.

Chapter 3

Modeling of Location Polling

This chapter proposes analytic and simulation models to study the performance of location tracking. Let N be the number of queries between two SA crossings. Five output measures are considered.

- α: the probability of *mis-tracking* for an SA crossing. An SA crossing is mis-tracked if there is no query between this SA crossing and the next SA crossing, and therefore the system does not know that the user has moved to this SA. It is clear that $\alpha = Pr[N = 0]$.

- T_i: the expected *invalid* period. The invalid period is defined as the period between when an SA crossing occurs and when the next query arrives under the condition that $N \geq 1$. In this period, the system does not know that the user has moved (i.e., the location known by the system is obsolete and therefore is "invalid").

- V_i: the variance of the invalid periods

- β: the probability that *redundant* queries exist between two SA crossings (i.e., $\beta = Pr[N > 1]$). It is clear that redundant queries create extra network traffic without providing useful location information.

- $E[N|N > 1]$: the expected number of queries between two SA crossings under the condition that $N > 1$. In other words, $E[N|N > 1] - 1$ is the expected number of redundant queries.

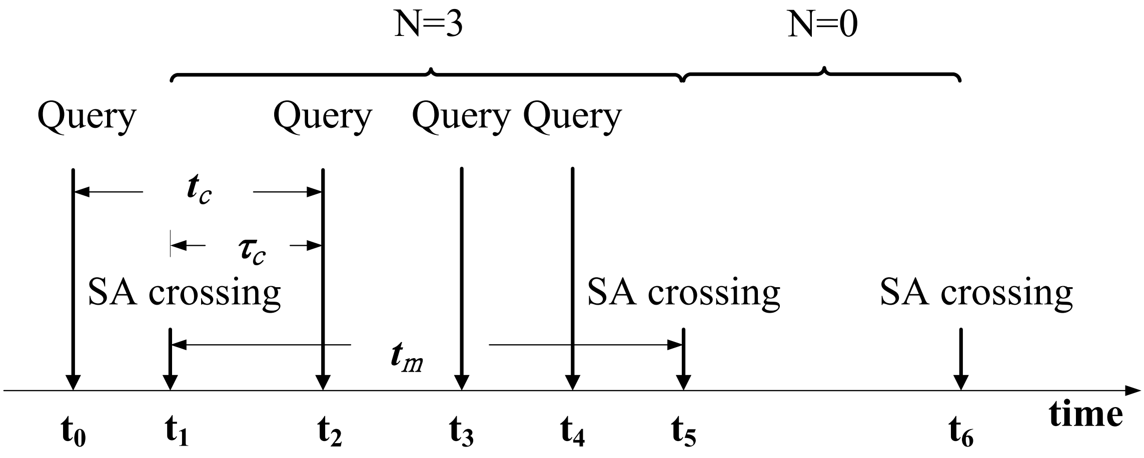

Figure 3.1: Timing Diagram for Location Polling

The smaller the above output measure values, the better the performance of location tracking. It is clear that for the Active Location Reporting scheme, optimal performance is achieved for these output measures, that is, $\alpha = 0$, $T_i = 0$, $V_i = 0$, and $\beta = 0$. On the other hand, the above output measure values are not 0 for the Location Polling scheme. This chapter studies α, T_i, V_i, β and $E[N|N > 1]$ for Location Polling. Then we investigate if Active Location Reporting (the optimal case) significantly outperforms Location Polling.

3.1 Analytic Model

Figure 3.1 illustrates the relationship between location queries and user movements. The UE changes its SA at t_1, t_5 and t_6, and the PSAP queries the UE's location at t_0, t_2, t_3 and t_4. In this example, $N = 3$ between t_1 and t_5, and $N = 0$ between t_5 and t_6. Let the SA residence time $t_m = t_5 - t_1$ be a random variable with the density function $f_m(\cdot)$ and the Laplace transform $f^*_m(\cdot)$. Let the inter-query interval $t_c = t_2 - t_0$ be a random variable with the exponential distribution with the mean $1/\lambda$ (i.e., the query stream forms a Poisson process). Then α is derived as

$$\alpha = Pr[N = 0] = \int_{t_m=0}^{\infty} e^{-\lambda t_m} f_m(t_m) dt_m = f^*_m(\lambda) \tag{3.1}$$

If t_m has the Gamma distribution with mean $1/\mu$ and variance V_m, then (3.1) is re-written as

$$\alpha = \left(\frac{1}{V_m\mu\lambda + 1}\right)^{\frac{1}{V_m\mu^2}}$$

The Gamma distribution is selected because it has been shown that the distribution of any positive random variable can be approximated by a mixture of Gamma distributions (see Lemma 3.9 in [9]). Following the past experiences [6, 11, 12], we can obtain the SA residence time samples from the commercial mobile telecommunication operation, and then use the statistical tools to fit the sample data by the Gamma distribution.

In Figure 3.1, $\tau_c = t_2 - t_1$ is the invalid period for the SA residence time interval $[t_1, t_5]$. In this period, the PSAP is not aware of the SA crossing at t_1. Since the query stream is a Poisson process, the density function $r_c(\cdot)$ for invalid period τ_c is the same as that for t_c because of the memoryless property for the exponential distribution. Consider the conditional density function $r_{c|N\geq 1}(\tau_c)$ where the PSAP issues at least one query in the SA residence time. From (3.1) and because $Pr[N \geq 1] = Pr[\tau_c \leq t_m]$, we have

$$r_{c|N\geq 1}(\tau_c) = \left[\frac{1}{1 - f_m^*(\lambda)}\right] \int_{t_m=\tau_c}^{\infty} r_c(\tau_c) f_m(t_m) dt_m \tag{3.2}$$

Based on (3.2) and the memoryless property of exponential distribution, we derive the expected invalid period T_i as

$$\begin{aligned} T_i &= E[\tau_c | N \geq 1] \\ &= \int_{\tau_c=0}^{\infty} \tau_c r_{c|N\geq 1}(\tau_c) d\tau_c \\ &= \left[\frac{1}{1 - f_m^*(\lambda)}\right] \left[\left.\frac{df^*(s)}{ds}\right|_{s=\lambda}\right] + \frac{1}{\lambda} \end{aligned} \tag{3.3}$$

If t_m has the Gamma distribution, (3.3) is re-written as

$$T_i = \frac{1}{\lambda} - \frac{1}{\mu(V_m\mu\lambda + 1)^{\frac{1}{V_m\mu^2}+1} - V_m\mu^2\lambda - \mu}$$

Similar to the derivation for T_i, we derive the variance V_i of invalid periods as

$$V_i = V[\tau_c | N \geq 1] = \frac{2\mu^2(V_m\mu\lambda+1)^{\frac{1}{V_m\mu^2}+2} - 3V_m\lambda^2\mu^2 - 2\lambda\mu - \lambda^2 - 2\mu^2(V_m\mu\lambda+1)^2}{\lambda^2\mu^2(V_m\lambda\mu+1)^2\left[(V_m\mu\lambda+1)^{\frac{1}{V_m\mu^2}} - 1\right]} - \left[\frac{1}{\lambda} - \frac{1}{\mu(V_m\mu\lambda+1)^{\frac{1}{V_m\mu^2}+1} - V_m\mu^2\lambda - \mu}\right]^2$$

The probability β of redundant queries is derived as

$$\begin{aligned} \beta &= Pr[N > 1] \\ &= 1 - Pr[N = 1] - Pr[N = 0] \\ &= 1 - \int_{t_m=0}^{\infty} \lambda t_m e^{-\lambda t_m} f_m(t_m) dt_m - \alpha \\ &= 1 + \lambda \left[\left. \frac{df_m^*(s)}{ds} \right|_{s=\lambda} \right] - f_m^*(\lambda) \end{aligned} \tag{3.4}$$

If t_m has the Gamma distribution, (3.4) is re-written as

$$\beta = 1 - \left(\frac{1}{V_m\lambda\mu+1}\right)^{\frac{1}{V_m\mu^2}} \left[1 - \frac{\lambda}{\mu(V_m\lambda\mu+1)}\right]$$

Since the query stream is a Poisson process, N has Poisson distribution with mean λt_m. Therefore $E[N|N > 1]$ is derived as

$$\begin{aligned} E[N|N > 1] &= \sum_{n=2}^{\infty} n \left[\frac{\int_{t_m=0}^{\infty} \frac{(\lambda t_m)^n}{n!} e^{-\lambda t_m} f_m(t_m) dt_m}{\beta}\right] \\ &= \frac{\lambda}{\mu} + \frac{V_m\mu^2\lambda^2 + \lambda^2}{\mu^2(V_m\mu\lambda+1)^{\frac{1}{V_m\mu^2}+1} - V_m\mu^3\lambda - \mu^2 - \lambda\mu} \end{aligned}$$

3.2 Simulation Model

This section describes a discrete event simulation model [7] for Location Polling to validate against the proposed analytic model. The following attributes are defined for an event **e**.

- The **type** attribute indicates the event type. A **Query** event represents a query from the PSAP. An **SA Crossing** event represents that the user moves from one SA to another.

- The **time** attribute indicates the time when the event occurs.

In the simulation model, the N_Q counter represents the number of queries occurred in the current SA residence time interval, τ is the invalid period, and t_{SA} is the time when the user enters this SA. The output measures of the simulation are the total number N_{SA} of SA crossings, the total number N_Q^* of queries in SA residence time intervals with more than one query, the number N_0 of SA residence time intervals without any query, the number N_1 of SA residence time intervals with more than one query. Let τ^* be the summation of τ's, and τ_{sq}^* be the summation of τ^2's. From the above output measures, we compute

$$\alpha = N_0/N_{SA},\ T_i = \tau^*/(N_{SA} - N_0),\ V_i = \tau_{sq}^*/(N_{SA} - N_0) - T_i^2,$$
$$\beta = N_1/N_{SA},\ \text{and}\ E[N|N > 1] = N_Q^*/N_1 \qquad (3.5)$$

A simulation clock is maintained to indicate the simulation progress, which is the timestamp of the event being processed. All events are inserted into the event list, and are deleted/processed from the event list in the non-decreasing timestamp order. Figure 3.2 illustrates the simulation flow chart for Location Polling. In this flow chart, Step 1 initializes the output parameters. Step 2 generates the first **Query** and **SA Crossing** events and inserts them into the event list. N_{SA} is incremented by one. At Steps 3 and 4, the first event **e** in the event list is processed based on its type described as follows:

Query: N_Q is incremented by one at Step 5. Step 6 checks if this **Query** event is the first **Query** event occurred in the current SA residence time interval (i.e., $N_Q = 1$). If so, Step 7 computes τ, τ^* and τ_{sq}^*. Step 8 generates the next **Query** event and inserts it into the event list.

SA Crossing: Step 9 checks if there is any **Query** event occurred between this **SA Crossing** event and the previous **SA Crossing** event (i.e., $N_Q > 0$). If not, N_0 is incremented by one at Step 10, and the simulation proceeds to Step 13. If $N_Q > 1$ at Step 11, then N_1 is incremented by one, and N_Q^* is incremented by N_Q at Step

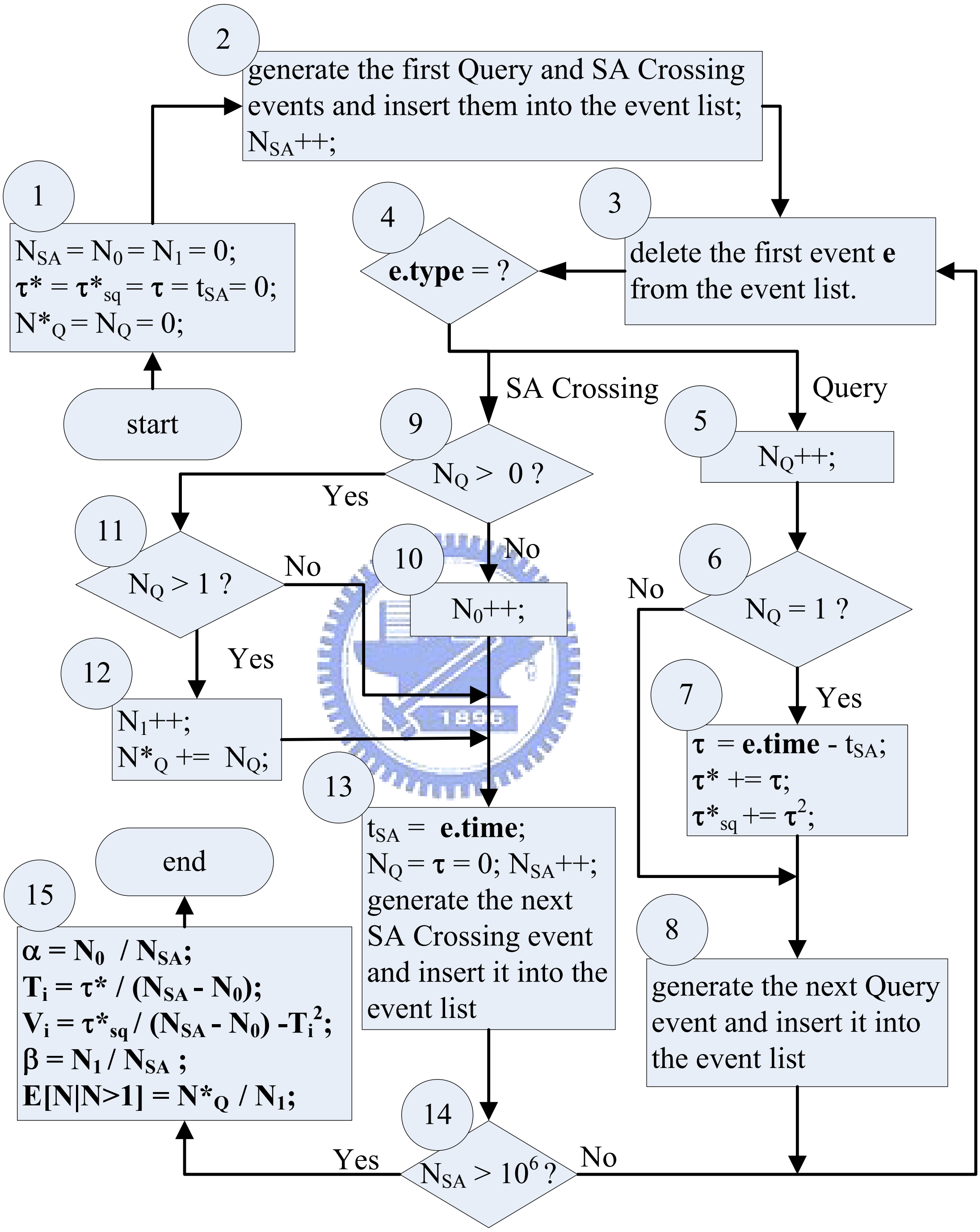

Figure 3.2: Simulation Flow Chart for Location Polling

12. Step 13 sets t_{SA} to the timestamp of the current event (i.e., **e.time**), resets N_Q and τ to 0, generates the next **SA Crossing** event and inserts it into the event list. N_{SA} is incremented by one. Step 14 checks if $N_{SA} > 1,000,000$. If so, Step 15 computes the output measures (3.5), and the simulation terminates.

3.3 Validation

Table 3.1 and Table 3.2 compare the analytic and simulation models under different λ and V_m values, respectively. Table 3.1 lists the discrepancies between the analytic and simulation models, where $V_m = 1/\mu^2$ with various μ values. The table shows that the α descrepancy is within 0.03%, the T_i descrepancy is within 0.1%, the V_i descrepancy is within 0.2%, the β descrepancy is within 0.2%, and the $E[N|N > 1]$ descrepancy is within 0.2%. Table 3.2 lists the discrepancies between the analytic and simulation models, where $\lambda = \mu$ with various V_m values. The table shows that the α descrepancy is within 0.2%, the T_i descrepancy is within 0.3%, the V_i descrepancy is within 0.3%, the β descrepancy is within 0.3%, and the $E[N|N > 1]$ descrepancy is within 0.3%. It is clear that the analytic analysis is consistent with the simulation results.

Table 3.1: Comparison of Analytic and Simulation Models under Different λ Values ($V_m = 1/\mu^2$)

λ	0.1μ	μ	10μ
α (Analytic)	0.90909	0.5	0.090909
α (Simulation)	0.90914	0.5001	0.090910
Discrepancy	0.0063 %	0.0338 %	0.0013 %
T_i (Analytic)	$0.909/\mu$	$0.5/\mu$	$0.0909/\mu$
T_i (Simulation)	$0.907/\mu$	$0.4997/\mu$	$0.0908/\mu$
Discrepancy	0.1374 %	0.0552 %	0.1119 %
V_i (Analytic)	$0.8264/\mu^2$	$0.25/\mu^2$	$0.008265/\mu^2$
V_i (Simulation)	$0.8257/\mu^2$	$0.249/\mu^2$	$0.008271/\mu^2$
Discrepancy	0.0907 %	0.13 %	0.0804 %
β (Analytic)	0.00826	0.25	0.82645
β (Simulation)	0.00828	0.25007	0.82657
Discrepancy	0.1875%	0.0296 %	0.0153 %
$E[N \mid N > 1]$ (Analytic)	2.1	3	12
$E[N \mid N > 1]$ (Simulation)	2.103	2.99	11.99
Discrepancy	0.1794 %	0.0906 %	0.0687 %

Table 3.2: Comparison of Analytic and Simulation Models under Different V_m Values ($\lambda = \mu$)

V_m	$0.001/\mu^2$	$0.1/\mu^2$	$10/\mu^2$	$1000/\mu^2$
α (Analytic)	0.368	0.3855	0.7867	0.99311
α (Simulation)	0.367	0.3851	0.7865	0.99312
Discrepancy	0.1972%	0.0954%	0.0365%	0.0011%
T_i (Analytic)	$0.4181/\mu$	$0.4295/\mu$	$0.6645/\mu$	$0.855/\mu$
T_i (Simulation)	$0.4184/\mu$	$0.4292/\mu$	$0.6641/\mu$	$0.853/\mu$
Discrepancy	0.0741%	0.0850%	0.0530%	0.2531%
V_i (Analytic)	$0.0795/\mu^2$	$0.10421/\mu^2$	$0.551/\mu^2$	$0.835/\mu^2$
V_i (Simulation)	$0.0797/\mu^2$	$0.10429/\mu^2$	$0.552/\mu^2$	$0.836/\mu^2$
Discrepancy	0.2529%	0.0739%	0.0895%	0.1305%
β (Analytic)	0.2642	0.2639	0.1416	0.00589
β (Simulation)	0.2645	0.2638	0.1417	0.00590
Discrepancy	0.1222%	0.0333%	0.0783%	0.2104%
$E[N\|N > 1]$ (Analytic)	2.3929	2.4606	6.55	169.53
$E[N\|N > 1]$ (Simulation)	2.3927	2.4609	6.54	169.03
Discrepancy	0.0079%	0.0134%	0.1137%	0.2926%

Chapter 4

Performance Evaluation

Based on the simulation experiments validated against the analytic model, this chapter investigates the performance of Location Polling. Two types of inter-query intervals can be considered. *Fixed* polling queries the UE's location with a fixed period $1/\lambda$. On the other hand, in *exponential* polling, the inter-query interval has the exponential distribution with mean $1/\lambda$. Assume that the SA residence time t_m has the exponential distribution with mean $1/\mu$ (i.e., the SA crossings form a Poisson process). From (3.1), the probability α for exponential polling is expressed as

$$\alpha = f_m^*(\lambda) = \frac{\mu}{\lambda + \mu} \quad \text{(exponential polling)} \tag{4.1}$$

Since the SA crossings form a Poisson process, the number X of SA crossings in an arbitrary fixed inter-query interval $1/\lambda$ has a Poisson distribution with the mean μ/λ. When $X > 0$, there are $X - 1$ SA residence times without any query. Therefore, the probability α for fixed polling is expressed as

$$\alpha = \frac{E[X-1|X>0]}{E[X|X>0]} = 1 - \frac{\lambda}{\mu}\left(1 - e^{-\mu/\lambda}\right) \quad \text{(fixed polling)} \tag{4.2}$$

Figure 4.1 plots α for fixed and exponential polling approaches based on (4.1) and (4.2). The figure indicates that fixed polling outperforms exponential polling in terms of the α measure. For all cases considered, fixed polling outperforms exponential polling when λ is large (e.g., $\lambda = 10\mu$), while both approaches have similar performance when λ is small. Section 4.1 investigates the performance of Location Polling with exponential inter-query

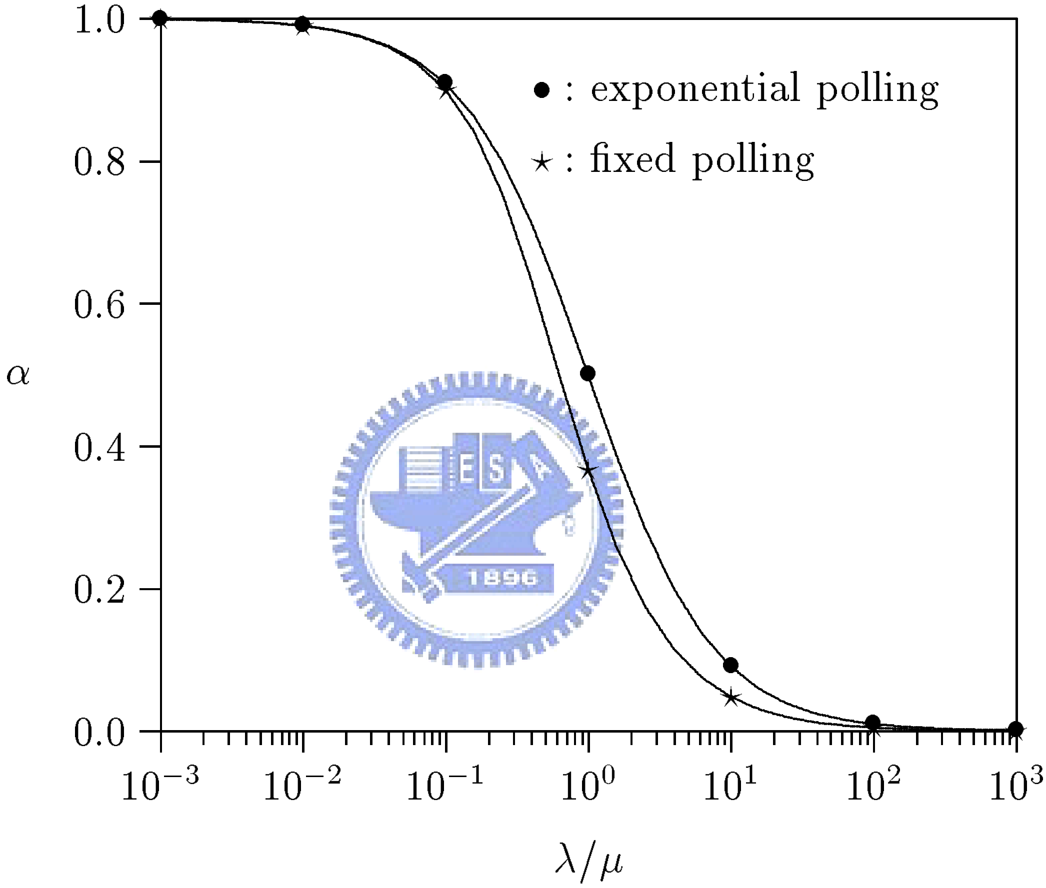

Figure 4.1: Comparing Fixed and Exponential Inter-Query Interval (Poisson SA Crossing Stream with the Rate μ)

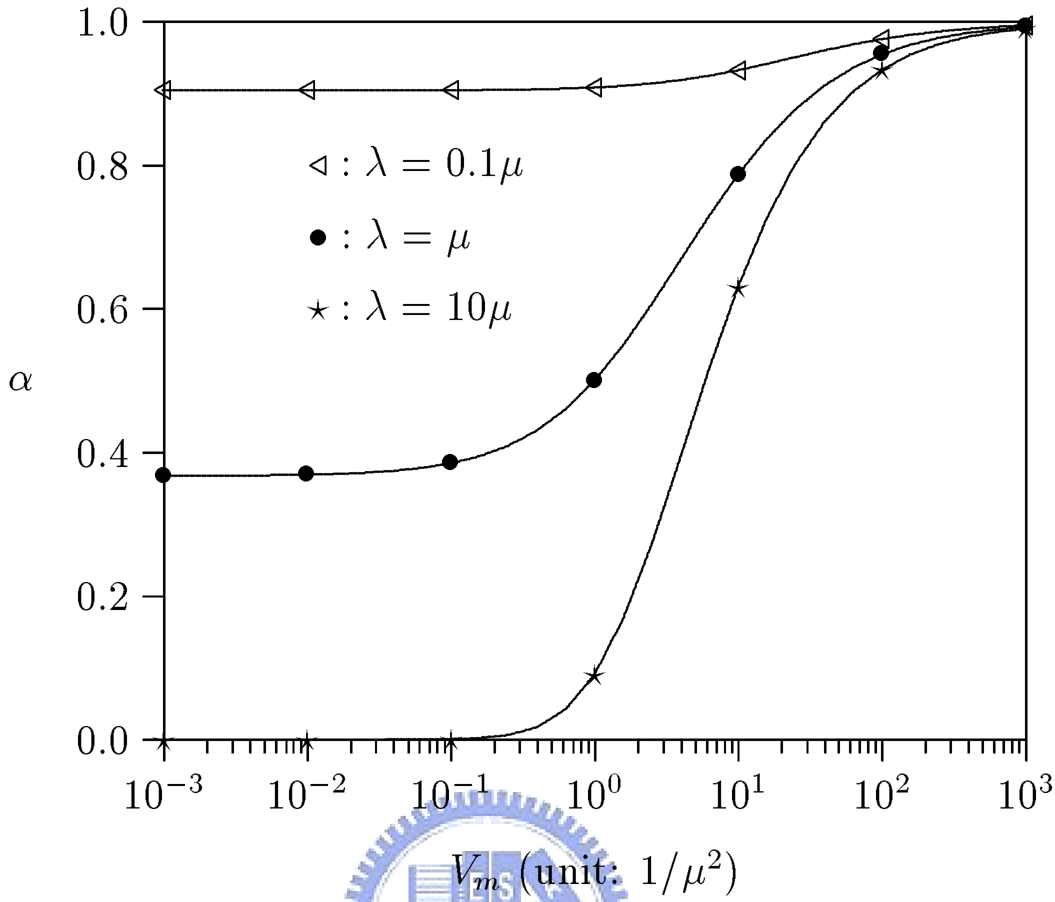

Figure 4.2: Effects of λ and V_m on α for exponential polling

intervals. Section 4.2 investigates the performance of Location Polling with fixed inter-query intervals.

4.1 Exponential Polling

This section investigates the performance of Location Polling with exponential inter-query intervals. The effects of the input parameters are investigated as follows.

Effects of λ and V_m on the mis-tracking probability α : Figure 4.2 plots α for Gamma SA residence times with different variance values. The figure indicates that α increases as V_m increases. This phenomenon is explained as follows. When the SA residence times become more irregular (i.e., V_m increases), we will observe more SA residence times without any query. On the other hand, the number of SA residence

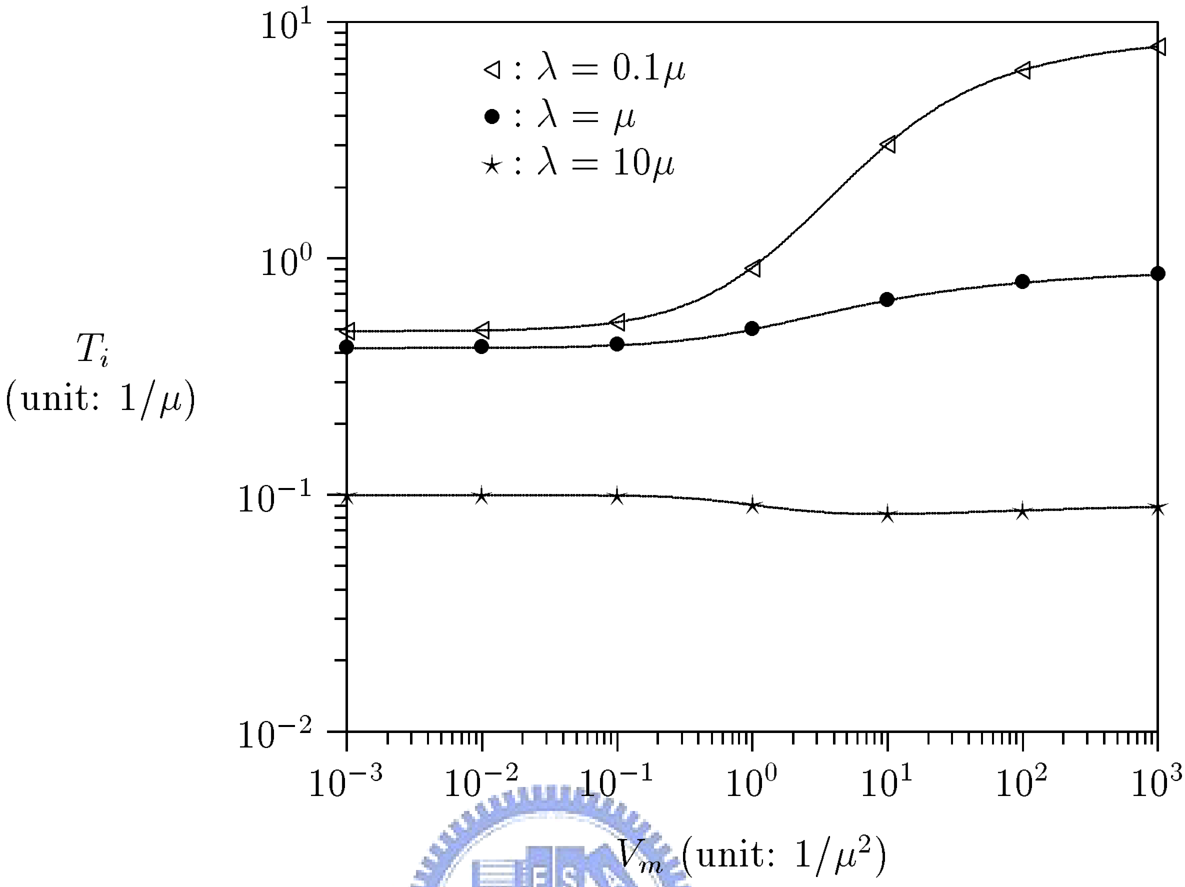

Figure 4.3: Effects of λ and V_m on T_i for exponential polling

times with queries will not increase as V_m increases, but the number of queries in an SA residence time interval will increase. Therefore, larger α is observed. The figure also indicates that when V_m is very large, α is not sensitive to the λ values, and poor accuracy is always observed (i.e., α is large).

Effects of λ and V_m on the expected invalid period T_i : Figure 4.3 plots T_i against λ and V_m. When λ is small (e.g., $\lambda = 0.1\mu$), T_i increases as V_m increases. This phenomenon is explained as follows. As V_m increases, more long and short SA residence time intervals are observed. For short SA residence times, it is likely that $N = 0$, and these intervals will not contribute to τ_c. In other words, when V_m increases, more long τ_c intervals are observed. Therefore, T_i increases as V_m increases. When λ is large (e.g., $\lambda = 10\mu$), T_i becomes less sensitive to V_m.

Effects of λ and V_m on the variance V_i of the invalid period : Figure 4.4 plots V_i

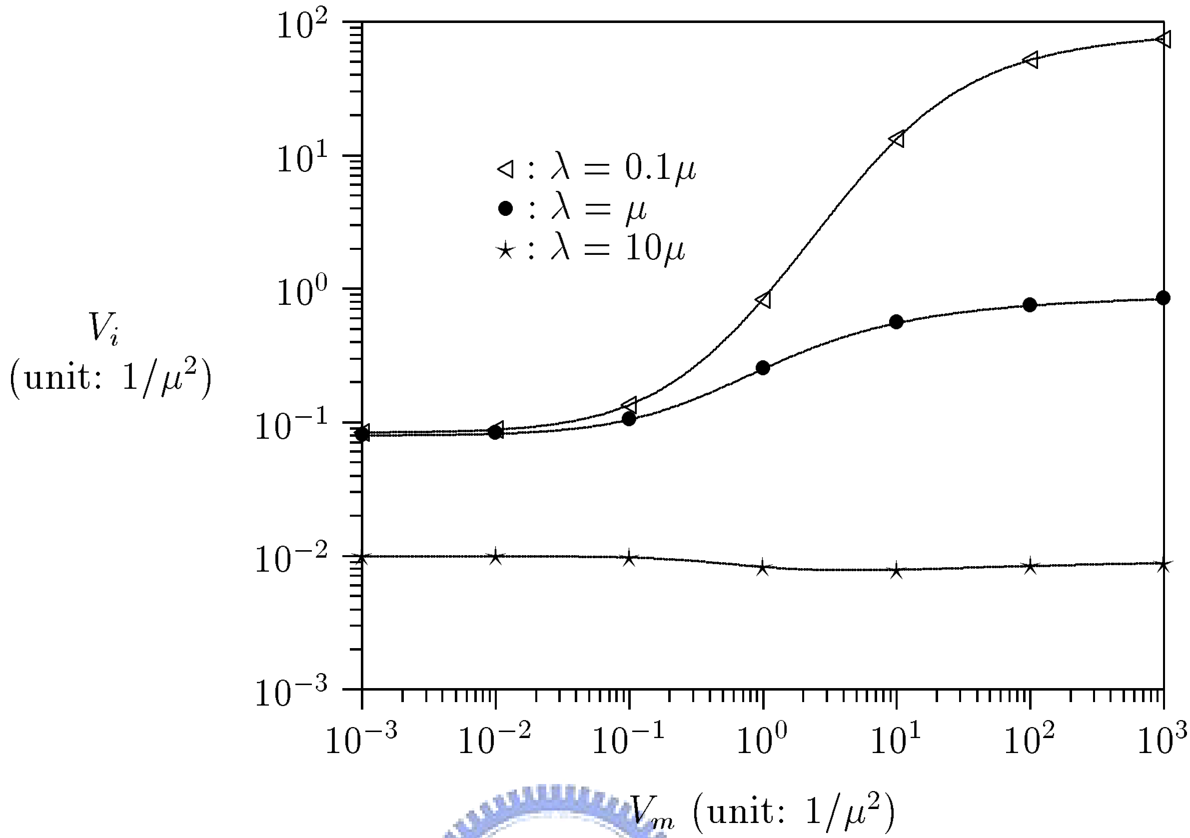

Figure 4.4: Effects of λ and V_m on V_i for exponential polling

against λ and V_m. When λ is small (e.g., $\lambda = 0.1\mu$), V_i increases as V_m increases. When λ is large (e.g., $\lambda = 10\mu$), V_i becomes less sensitive to V_m. This phenomenon is similar to that for T_i.

Effects of λ and V_m on the probability β of redundant query : Figure 4.5 plots β against λ and V_m. The figure indicates that when λ is large (e.g., $\lambda = 10\mu$), β is a decreasing function of V_m. Since $\beta = 1 - \alpha - Pr[N = 1]$, β decreases as α increaces. Therefore, β is a decreasing function of V_m. When λ is small (e.g., $\lambda = 0.1\mu$), β becomes less sensitive to V_m.

Effects of λ and V_m on $E[N|N > 1]$: Figure 4.6 shows that $E[N|N > 1]$ is an increasing function of V_m. This phenomenon is explained as follows. As V_m increases, more long SA residence times are observed. Since query events are more likely to fall on long SA residence times, larger $E[N|N > 1]$ is observed. Therefore, $E[N|N > 1]$ increases as V_m increases. When V_m is small, (i.e., $V_m \leq 1/\mu^2$), $E[N|N > 1]$ is not

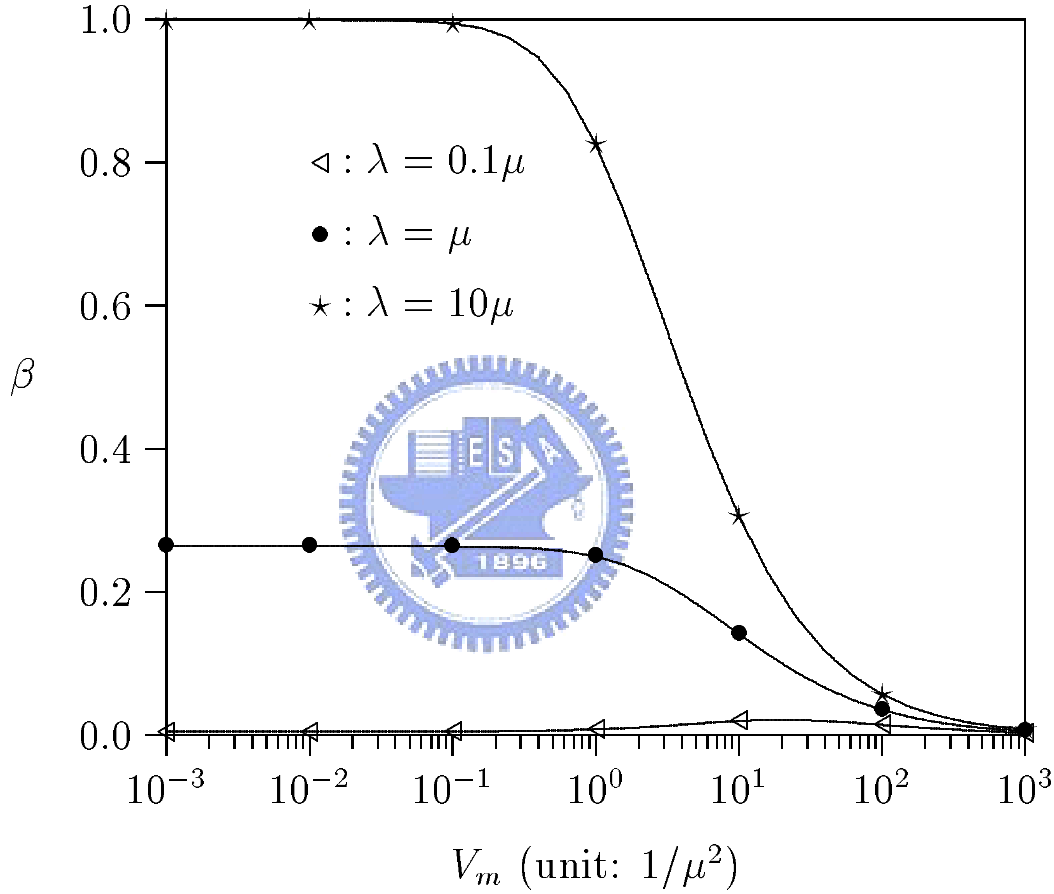

Figure 4.5: Effects of λ and V_m on β for exponential polling

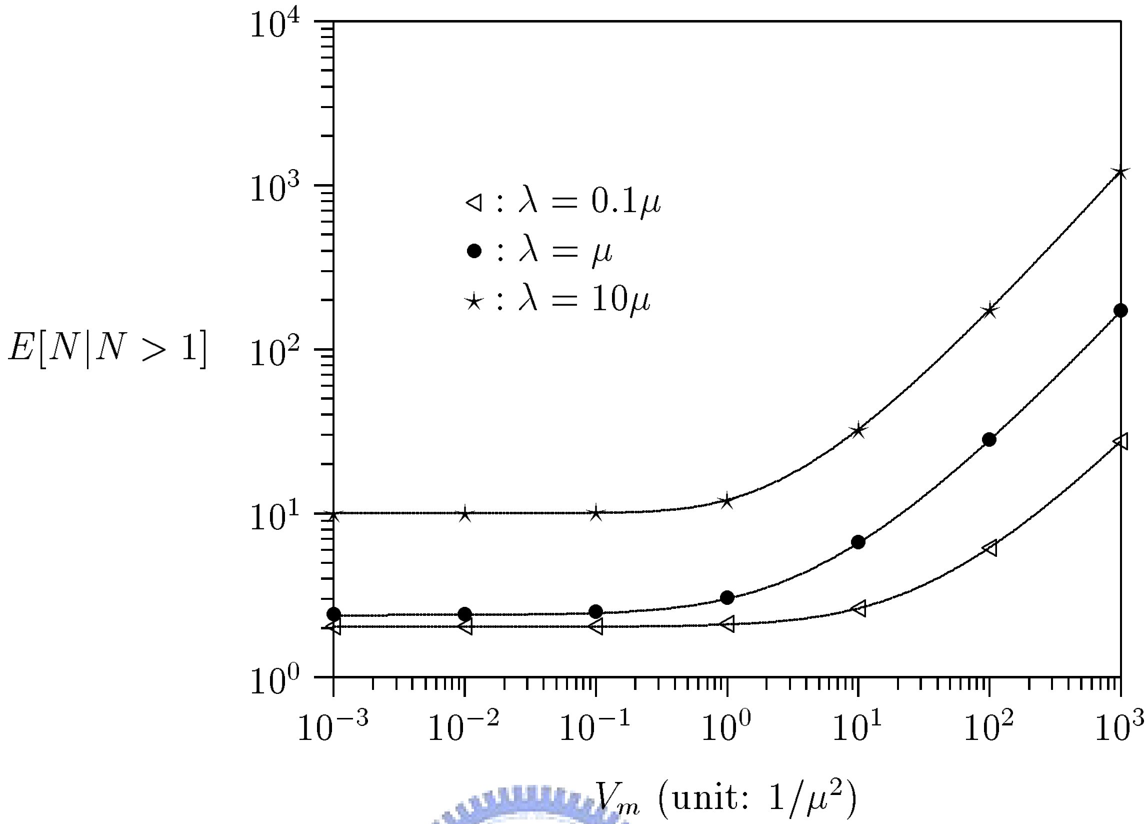

Figure 4.6: Effects of λ and V_m on $E[N|N>1]$ for exponential polling

sensitive to the change of V_m.

4.2 Fixed Polling

This section investigates the performance of Location Polling with fixed inter-query intervals. The effects of the the input parameters are investigated as follows.

Effects of λ and V_m on the mis-tracking probability α : Figure 4.7 plots α for Gamma SA residence times with different variance values. The figure indicates that α increases as V_m increases. When V_m is very large, α is not sensitive to the λ values, and poor accuracy is always observed. This phenomenon is similar to that for the exponential polling. We observe that when $\lambda = \mu$, the α value for fixed polling becomes much smaller than that for exponential polling (see Figure 4.2) when V_m is small (therefore, fixed polling significantly outperforms exponential polling)

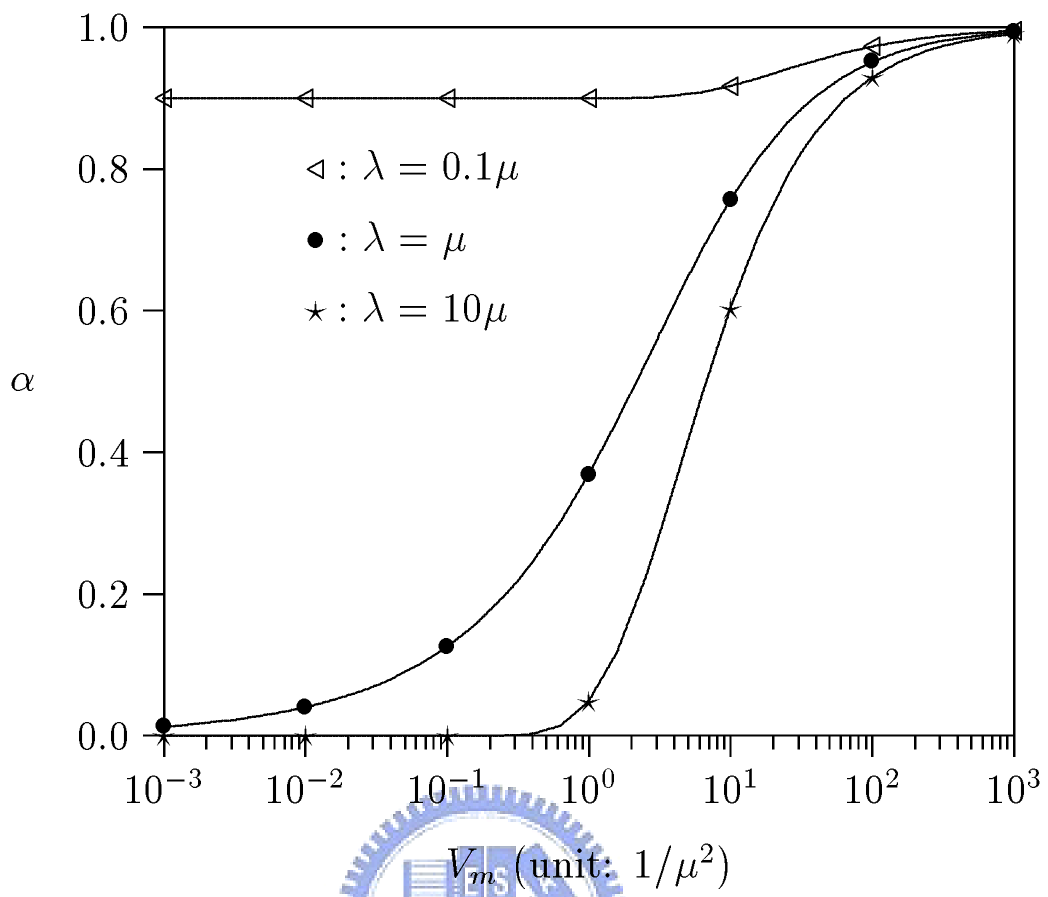

Figure 4.7: Effects of λ and V_m on α for fixed polling

Effects of λ and V_m on the expected invalid period T_i : Figure 4.8 plots T_i against λ and V_m. When λ is small (e.g., $\lambda = 0.1\mu$), T_i increases as V_m increases. When λ is large (e.g., $\lambda = 10\mu$), T_i becomes less sensitive to V_m. This phenomenon is similar to that for expoenetial polling.

Effects of λ and V_m on the variance V_i of the invalid period : Figure 4.9 plots V_i against λ and V_m. When λ is small (e.g., $\lambda = 0.1\mu$), V_i increases as V_m increases. When λ is large (e.g., $\lambda = 10\mu$), V_i becomes less sensitive to V_m. This phenomenon is similar to that for exponential polling.

Effects of λ and V_m on the probability β of redundant query : Figure 4.10 plots β against λ and V_m. When λ is large (e.g., $\lambda = 10\mu$), β is a decreasing function of V_m. When λ is small (e.g., $\lambda = 0.1\mu$), β becomes less sensitive to V_m. This phenomenon is similar to that for exponential polling. However, for $\lambda = \mu$, β increases and then

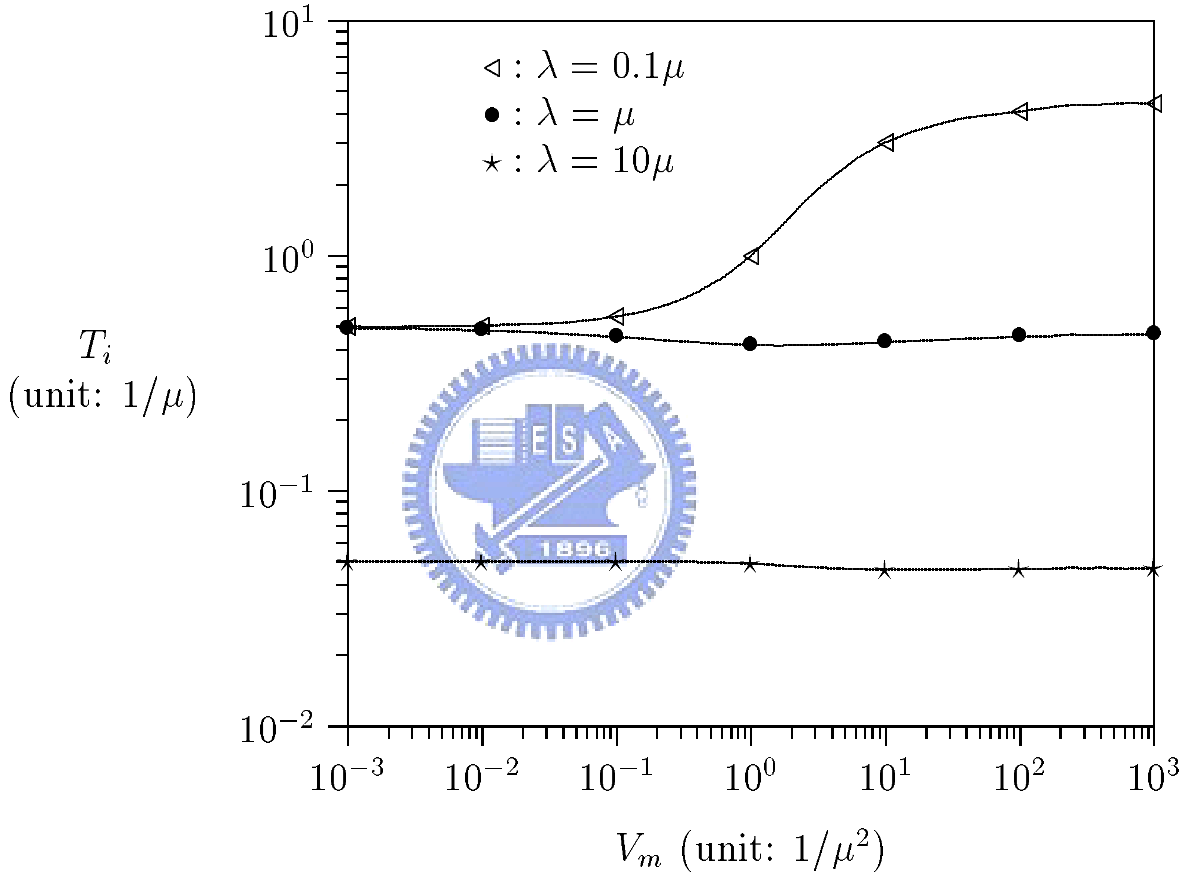

Figure 4.8: Effects of λ and V_m on T_i for fixed polling

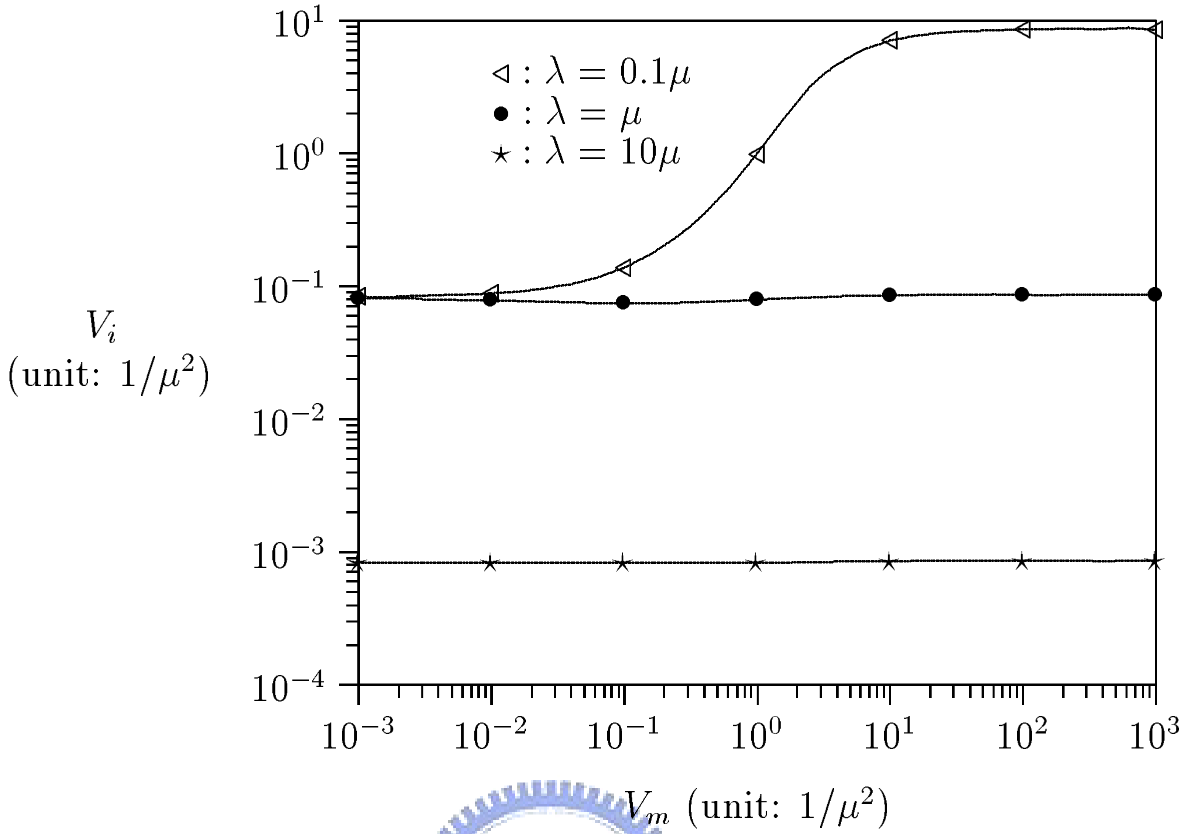

Figure 4.9: Effects of λ and V_m on V_i for fixed polling

decreases as V_m increases. This phenomenon is different from that for exponential polling and is explained as follows. As V_m increases, two effects are observed: (I) More SA residence times without any query are observed, which result in smaller β, (II) More SA residence times with more than one query are observed, which result in larger β. When V_m is small, Effect (II) is more significant (but insignificant for exponential polling), while Effect (I) is more significant when V_m is large. Therefore, β increase and then decrease as V_m increases.

Effects of λ and V_m on $E[N|N>1]$: Figure 4.11 shows that $E[N|N>1]$ is an increasing function of V_m. This phenomenon is similar to that for exponential polling.

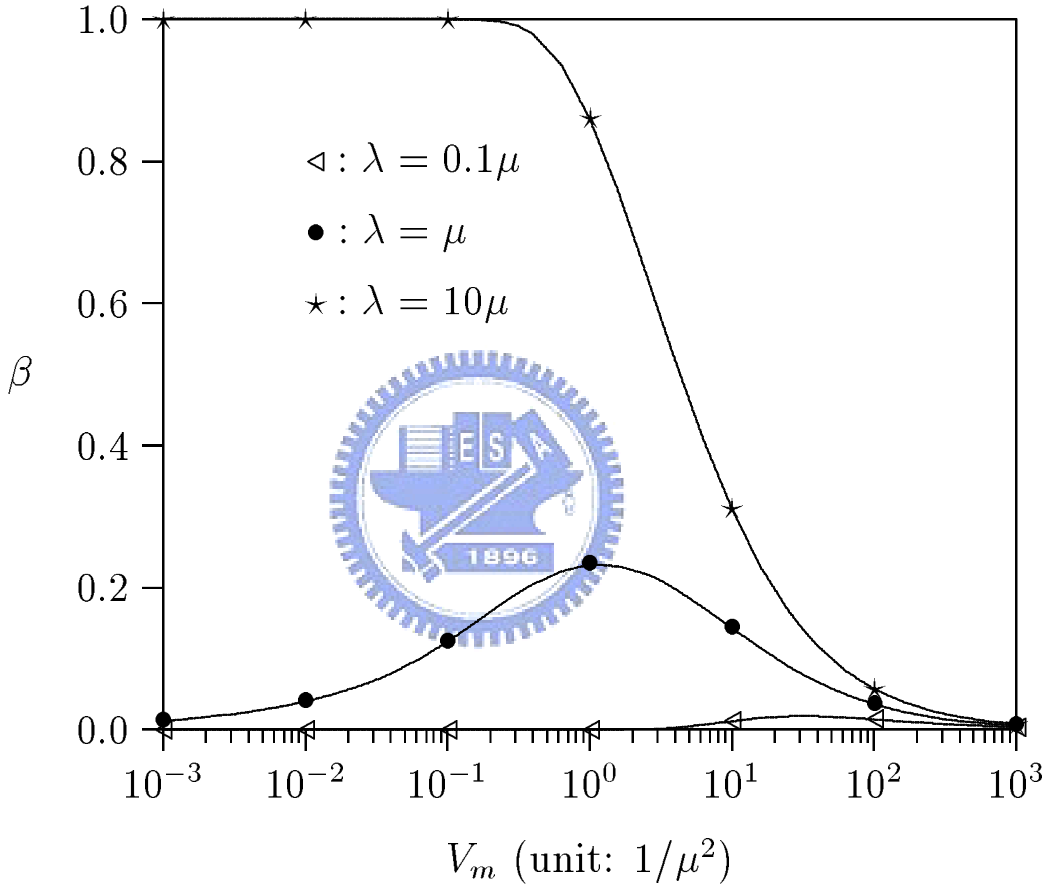

Figure 4.10: Effects of λ and V_m on β for fixed polling

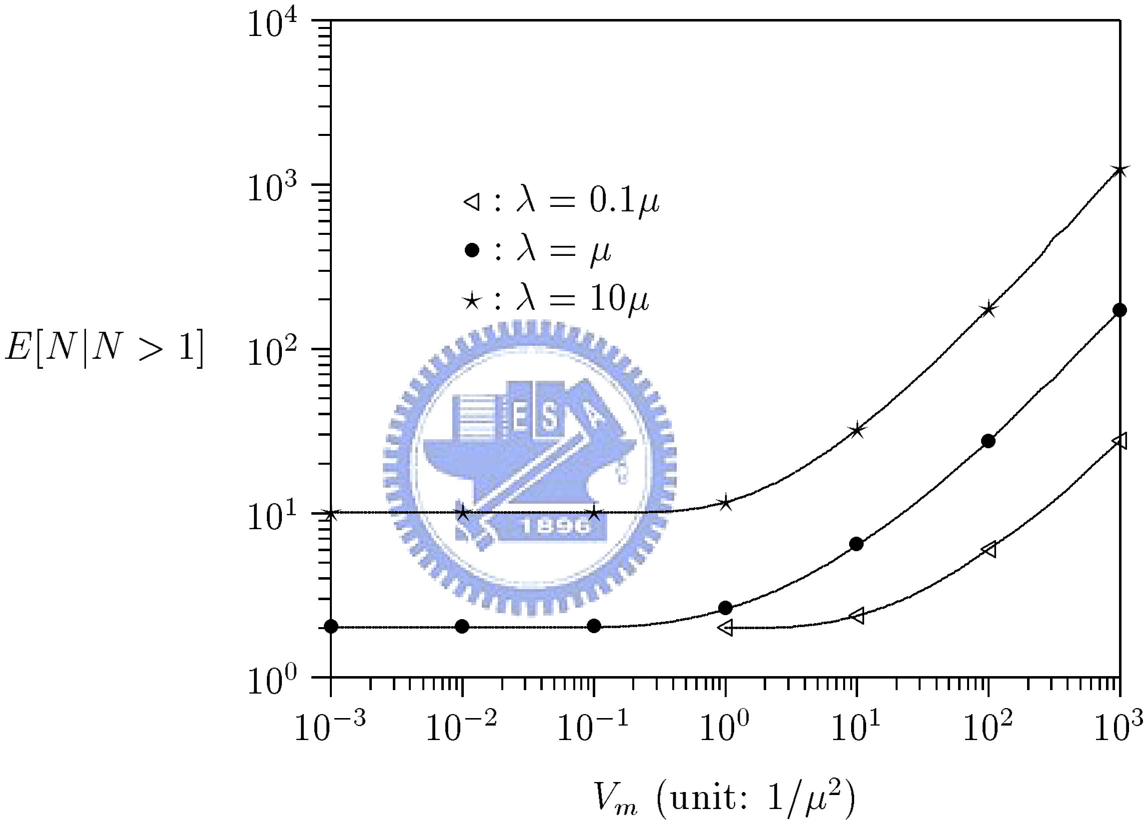

Figure 4.11: Effects of λ and V_m on $E[N|N>1]$ for fixed polling

Chapter 5

Conclusions

This thesis investigated emergency call mechanism for IMS. After an IMS emergency call is established, the caller's location is tracked by the PSAP through Location Polling. This thesis proposed the Active Location Reporting scheme to improve the performance of location tracking. Our study indicated that the Active Location Reporting scheme significantly outperforms the Location Polling scheme. We observed the following results:

- When the query frequency is low (i.e., λ is small) and when the movement is irregular (i.e., when V_m is large), Active Location Reporting significantly outperforms Location Polling in terms of the α (mis-tracking probability) performance.

- When the query frequency is low, Active Location Reporting significantly outperforms Location Polling in terms of the T_i and V_i (for the invalid period) performance.

- When the query frequency is high and when the movement is regular, Active Location Reporting significantly outperforms Location Polling in terms of the β (redundant query probability) performance.

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