Cost-Optimized Location and Service Management Scheme for Next-Generation Mobile Networks

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***Abstract*—We propose a cost-optimized location and service management scheme for next-generation mobile networks (NGWN), where a per-user service proxy is created in order to serve as a gateway between the mobile user and all client-server applications engaged by the mobile user. The service proxy is always co-located with the mobile user's location database during a location handoff, a service handoff also ensues to co-locate the service proxy with the location database. This allows the proxy to know the location of the mobile user at all times in order to reduce the network communication cost for service delivery. We analyze four integrated location and service management schemes. Our results indicate that the centralized scheme performs the best when the mobile user's service to mobility ratio (SMR) is low and ν (session to mobility ratio) is high, while the fully distributed scheme performs the best when both SMR and ν are high. Through analytical results, we demonstrate that different users with vastly different mobility and service patterns should adopt different integrated location and service management methods to optimize system performance.**

Keywords-Location Management; Service Management; LTE Networks; SMR.

I. INTRODUCTION

Location and service managements have often been separately addressed in literature [1]-[3]. For location management, the most popular scheme in Long-Term Evolution (LTE) networks is the MME-Cell scheme where each Mobile User (MU) has a Mobility Management Entity (MME). Whenever a MU enters a Cell, the system updates its MME location database so that when a call arrives, the MME location database knows exactly which Cell contains the MU. Variations to the basic MME-Cell scheme have been proposed in recent years to process location update and search operations more efficiently, e.g., Local Anchor (LA) [4], Forwarding and Resetting [5], Two-Level Pointer Forwarding [6], and Hybrid Replication with Forwarding [7], etc. These location management schemes are designed to handle location update and search operations without consideration to service management.

In this paper, we investigate the notion of integrated location and service management for minimizing network cost without making the assumption of fully replicated servers within cell in the LTE network. Instead, we target general personalized services in the LTE network including personal banking, stock market and location-dependent services for which the MU will communicate with a backend server.

Based on the concept of using a per-user service proxy as a gateway between the MU and all client-server applications engaged by the MU concurrently [8], the proxy keeps track of service context information such as the current state of the execution for maintaining service continuity. Similarly to Chen et al. [9], we always co-locate the MU's service proxy with the MU's location database, which stores the current location of the MU, so that the service proxy knows the current location of the MU at all times so as to eliminate the cost associated with tracking the user location on behalf of the server applications for data delivery. Whenever the MU moves across a registration area boundary, a location handoff occurs for the location management system to update the location database. If a location hand-off results in moving the MU's current location database to stay closer to the MU, then the associated service handoff will also move the service proxy to the same location [10].

In this paper, we investigate and analyze integrated location and service management schemes. These schemes derive from the basic MME-Cell and LA schemes for location management, and the personal service proxy scheme for service management in the LTE network. We are motivated to investigate and identify the best cost-optimized location and service management scheme that can be applied on an individual user basis to minimize the overall cost incurred to the LTE network per time unit for the servicing location and service operations of all users. The amount of cost saving is relative to the speed of the LTE network and is proportional to the number of users, so the benefit is especially pronounced for slow and congested networks with a large number of mobile users.

The rest of the paper is organized as follows. Section 2 provides a description of the related work. Section 3 describes in detail the four integrated schemes to be investigated and analyzed in the paper. Section 4 analyzes the cost incurred under each our schemes and presents analytical results with simulation validation. Finally, Section 5 summarizes the paper.

II. RELATED WORK

The seamless management of user mobility is an issue that involves every OSI [1]-[2] layer, from layers 1 and 2 (handover between cells), through layer 3 (routing updates in the network core), up to the application layer (persistence of transport connections and user state, delay-tolerant operation). The Internet Protocol suite did not originally include any support for end-point mobility. Over the years, a whole family of Mobile IP (MIP) procedures were introduced in an attempt to provide mobility support in a backward-compatible way. On the other hand, current cellular standards, such as LTE, have all been designed with mobility in mind and integrate the appropriate support in the core network. The cellular control plane includes elements that store and maintain the state of the terminal while its association to the network persists, and oversees the creation of appropriate bearers to seamlessly provide applications with the illusion of a constant connection between the mobile terminal and the network.

TABLE I. TERMINOLOGY.

Acronym	Meaning
LTE	Long Term Evolution 3/4G cellular network
MME	Mobility Management Entity
UE	User Equipment (cellular terminal)
eNB	Extended Node B (base station w/ controller)
SGW	Service Gateway (interface to IMS / phone system)
TA	Tracking Area (scope for initial UE paging attempt)
TAL	Tracking Area (TA) List
HSS	Home Subscriber Server
ECM	Evolved Packet System Connection Management
DHT	Distributed Hash Table

The MME for LTE network supports the most relevant control plane functions related with mobility: it authenticates the User Equipment (UE) as it accesses the system, it manages the UE state while the users are idle, supervises handovers between different base stations (extended Node B, eNB), establishes bearers as required for voice and Internet (packet data network, PDN) connectivity in a mobile context, generates billing information, implements so called lawful interception policies, and oversees a large number of features defined in its extensive 3GPP specifications. Table 1 summarizes the relevant acronyms that will be used throughout this paper.

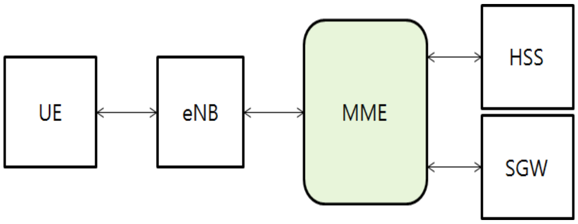


Figure 1. Schematic representation of the main logical MME interface.

All network events involve control plane messaging procedures require the interaction of one or more entities, besides the UE and the MME. The ones relevant to our interests are the eNB, which manages the air interface toward the UE, and the Service Gateway (SGW), a control plane element that acts as a global mobility anchor, managing the entire data plane within a large geographic region (usually spanning several TAs). The messaging sequences are codified by the 3GPP standards as logical interfaces, such as S-1 (eNB to SGW) and S-11 (SGW to MME). Fig. 1 schematically illustrates the interfaces supported by the MME, which are detailed in [11]-[12].

Mobile IP [13] allows a MU to maintain ongoing connections while roaming among IP subnets and requires the MU to inform its Home Agent (HA) of the new Foreign Agent (FA) address whenever it moves from one subnet to another. The function of a HA within a Mobile IP is similar to a Home Location Register (HLR) in Personal Communication System (PCS) networks for location management. Similar to the LA scheme in PCS networks, a variant of Mobile IP, called Mobile IP dynamic regional registration [14], has been proposed to group FAs into a gateway foreign agent (GFA) dynamically to minimize signaling costs in Mobile IP. These solutions, although elegant, solve only location management issues. For service management, a delivery protocol using a service proxy has been proposed to provide the reliable delivery of messages to MUs. However, the proxy used to forward messages to a MU must explicitly track the location of the MU, so extra communication costs are incurred to notify the proxy when the MU moves across a location registration area boundary.

III. COST-OPTIMIZED LOCATION AND SERVICE MANAGEMENT SCHEME

A. Network Architecture

We first describe a LTE system model for location management services. Then we describe an extended system model for integrated location and service management. We consider the LTE network architecture as shown in Fig. 2 where the LTE service areas are divided into Registration Areas (RAs).

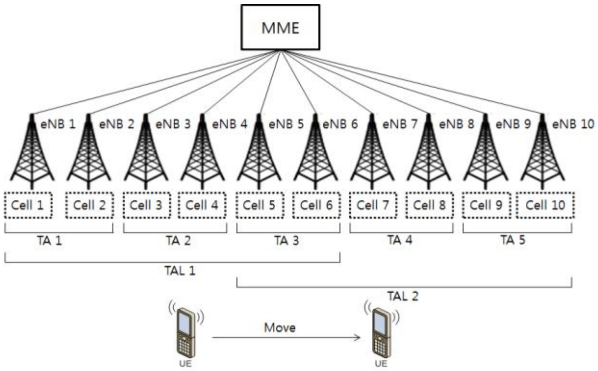


Figure 2. LTE Mobility Management Architecture.

We assume that a particular MU will remain in a Cell before moving to another. For simplicity, the residence time is assumed to be exponentially distributed with an average rate of σ. Such a parameter can be estimated using the approach described by Yang and Lin [15] on a per-user basis. We also assume that the inter arrival time between two consecutive calls to a particular MU, regardless of the current location regarding the MU, is exponentially distributed with an average rate of λ.

TABLE II. PARAMETERS.

Parameter	Description
λ_s	The average rate at which the UE is being called.
λ_m	The average rate at which the UE moves across Cell boundaries.
γ	The average rate at which the UE requests services.
ν	call to mobility ratio, e.g., λ_s/λ_m
SMR	service request to mobility ratio, e.g, γ/λ_m
T	The average round trip communication cost between a Cell and the MME (or between a Cell and the server) per message.
τ_1	The average round trip communication cost between the anchor and a Cell in the anchor area per message.
τ_2	The average round trip communication cost between two neighboring anchor areas per message.
τ_3	The average round trip communication cost between two neighboring Cells per message.
M_{CS}	The number of packets required to transfer the service context.
N_S	The number of server applications concurrently engaged by the UE.
P_{InA}	The probability that a UE moves within the same anchor area when a Cell boundary crossing movement occurs.
P_{OutA}	The probability that a UE moves out of the current anchor area when a Cell boundary crossing movement occurs.

When applying the anchor scheme to the cost-optimized location and service management, the cost model must include not only location update/search costs, but also the communication cost between a UE and its servers. Also, to deliver responses from a server to a UE through the proxy, the proxy must know the UE's current location. It is desirable not to query the MME to obtain the location information because of the high communication cost. Thus, for an integrated local anchor scheme to serve both location and service handoffs, whenever the UE moves to a new anchor area, it may be desirable to also migrate the service proxy to the new anchor area to be "co-located" with the new anchor in an anchor area, so that the service proxy can query the anchor to know the current location of the UE without going to the MME. Consequently, both a location handoff and a service handoff would occur when the UE crosses an anchor boundary in the integrated scheme. A service handoff that migrates the service proxy involves two operations, namely, an address-change operation to inform all application servers of the location change, and a service context transfer. The cost of the address change operation per server is T. The service context transfer is unique for the service handoff operation, with the amount of context information being application dependent. The context transferred may include both static context information such as user profile and authentication data as well as dynamic context information such as files opened, objects updated, locks and time-stamps, etc. Let τ_2 be the average communication cost between two neighboring anchor areas (per packet), and M_{CS} be the number of packets required to transfer the service context. We list the system parameters considered in the paper in Table 2, including user parameters and application-specific parameters (such as M_{CS}). Their effects on the performance of Cost effective location and service management schemes are to be analyzed in the paper.

Note that for the case in which a UE concurrently interacts with multiple servers, there would still only be one per-user service proxy co-located with the location database under our proposed integrated schemes. In this case, the service rate parameter γ would reflect the aggregate rate at which the UE makes requests to these multiple services, while the context transfer cost parameter, M_{CS}, would reflect the aggregate context transfer cost for moving the service context information of multiple concurrent services from one location to another.

B. Operational Structures

In this section, we discuss four possible schemes, i.e., centralized, fully distributed, dynamic anchor, and static anchor for integrated location and service management.

We illustrate the centralized scheme in Fig. 3 (left). As the MU moves from Cell A, Cell B and subsequently to Cell C, the MME and the service proxy are updated to point to Cell B and then to Cell C sequentially.

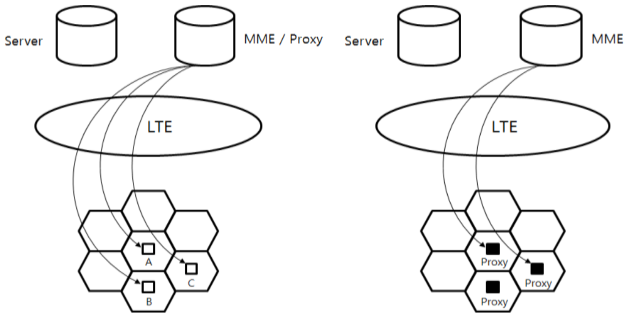


Figure 3. Centralized (left) and Full Distributed (right) Schema.

We illustrate the fully distributed scheme in Fig. 3 (right). When the MU moves from Cell A to Cell B, the service proxy migrates from Cell A to Cell B, and the MME and the server are updated to point to Cell B. The subsequent move to C behaves similarly. To service a location search request (not initiated from the current Cell), the MME database is accessed first to know the current Cell (A, B, or C) and then the MU is found within the current Cell. When the service proxy needs to forward replies to the MU, no additional searching cost is required to find the current Cell, since the service proxy is located in the current Cell.

Under the dynamic anchor scheme, a location anchor is used for location management such that the anchor changes whenever the MU crosses an anchor boundary. In addition, the anchor may also change its location within an anchor area when a call delivery operation is serviced. The service proxy dynamically moves with the anchor and is always collocated with the anchor. In Fig. 4, when a MU moves within anchor area 1 from Cell A to Cell B, only the local anchor in Cell A is updated to point to the current location. Thus, the location update to the MME and application servers is avoided. Suppose that a call arrives after the MU moves into Cell C. The call will invoke a search operation in the MME database and a subsequent search operation in the anchor. Once the call is serviced, the MME database will be updated to point to Cell C; the anchor and the service context are moved from Cell A to Cell C; and the application servers are informed of the address change. Later, if the MU subsequently moves from Cell C to Cell D due to an inter-anchor movement, the MME database will be updated to point to Cell D, which will subsequently become the new anchor after the service context is transferred to it. Data delivery from the server will pass through the service proxy co-located with the anchor to reach the MU.

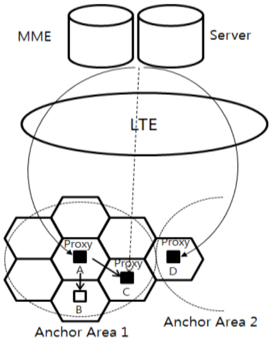


Figure 4. Dynamic Anchor Schema.

Under the static anchor scheme, the service proxy is again co-located with the anchor. However, the anchor will remain at a fixed location as long as the MU remains in the same anchor area. The only condition under which the anchor would move (along with the service context transferred) is when the MU moves across an anchor boundary. The procedures for processing the location update, call delivery, and service requests are the same as in the dynamic anchor scheme except that upon a successful call delivery, the anchor's location remains unchanged. Thus, there is no need to migrate the service proxy to the current serving Cell (if they are not the same) after serving a call delivery operation.

IV. PERFORMANCE ANALYSIS

In this section, we develop analytical models for evaluating and comparing various integrated schemes introduced in Section 3. We first define the communication cost analysis model for two states in the LTE system.

For analysis, the two-dimensional hexagonal random walk model [11]-[13] has been adopted. The LTE system can be assumed to be configured as a hexagonal network with a cell having radio coverage of an eNB. The UE moves from one cell to another, and its movement is modeled based on the two-dimensional hexagonal random walk model. In this model, a hexagonal cell structure is modeled and the cells are classified in a 6-layer cluster shown in Fig. 5. We assume that an UE resides in a cell unit for a specified time period and then moves to any of the neighboring cells with equal probability. Using this, a one-step transition matrix of this random walk can be derived by letting $P(x,y)(x',y')$ be the one step probability from state (x,y) to (x',y'). Table 3 describes the system parameters for performance analysis.

TABLE III. SYSTEM PARAMETERS FOR PERFORMANCE ANALYSIS.

Parameter	Description
$C_{ServInM}$	The average cost of performing an intra-anchor location update operation when the UE changes its Cell within the same anchor area.
$C_{ServOutM}$	The average cost of performing an inter-anchor location update operation when the UE moves out of the current anchor area.
$C_{ServCvdC}$	The cost to handle a call delivery operation when the current Cell is the same as the anchor Cell.
$C_{ServNonCvdC}$	The cost for handling a call delivery operation when the current Cell is different from the anchor Cell.
$C_{ServCvdS}$	The cost to handle a service request when the anchor resides in the current serving Cell.
$C_{ServNonCvdS}$	The cost to handle a service request when the anchor is different from the current serving Cell.
$C_{servInM}$	The average cost of performing an intra-anchor location update operation when the UE changes its Cell within the same anchor area.
$C_{servOutM}$	The average cost of performing an inter-anchor location update operation when the UE moves out of the current anchor area.
C_{ServC}	The cost to handle a call delivery.
C_{ServS}	The cost to handle a service request.

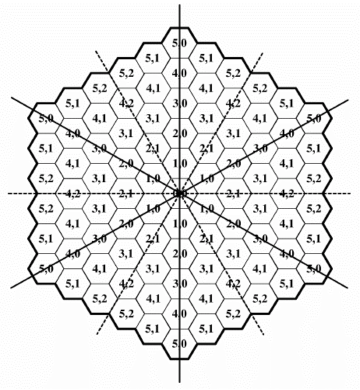


Figure 5. Hexagonal cell structure for performance analysis.

From [11]-[13], we can model the signaling cost of two mobility states in an LTE system: LTE_ACTIVE where the network directs UE to the serving cell and the UE is ready to perform Uplink/Downlink transport with very limited access delay, and LTE_IDLE where the UE in a low power consumption state, could be tracked in the Tracking Area and be able to travel to LTE_ACTIVE at approximately 100ms.

We first parameterize the performance models developed by means of a hexagonal network coverage model for describing a LTE network to evaluate the performance of the cost-optimized location and service management schemes proposed in order to identify conditions under which one scheme could perform the best when given a set of parameters characterizing a UE's mobility and service behaviors [15]. We use a hexagonal network coverage model to describe a LTE network where cells are assumed to be hexagonally shaped, with each cell having six neighbors. At the lowest level of Fig. 5, an n-layer Cell covers $3n^2-3n+1$ cells where n is equal to either two or three. For a LTE system described by the hexagonal network coverage model as such, it can be shown that [11] with random movements, the probability that a UE moves within the same anchor area, that is, the probability of an intra-anchor movement, as the UE moves across a Cell boundary, is given by (1):

$$P_{InA}=\frac{3n^2-5n+2}{3n^2-3n+1} \tag{1}$$

Thus, the probability of an inter-anchor movement, when the UE moves across a Cell boundary, is given by (2):

$$P_{OutA}=1-\frac{3n^2-5n+2}{3n^2-3n+1}=\frac{2n-1}{3n^2-3n+1} \tag{2}$$

Without loss of generality, consider $n=2$ for *n*-layer Cells, TAL, TA and MME composing the LTE. Then, the probability P_{InR} that a UE moves within the same TAL, that is, the probability of an intra-TAL movement, when the UE moves across a Cell boundary, is given by (3):

$$P_{InR}=\frac{21n^2-27n+10}{7\left(3n^2-3n+1\right)} \tag{3}$$

Let C_{ta} be the cost of searching UE in a Cell. Let C_{mme} be the cost of transmitting a message between TA/TAL and MME. The communication between MME and a Cell will traverse through the Cell-TA/TAL-MME path sequence. Let C_{lte} be the cost of transmitting a message between a Proxy and Application Server, or a MME and Application Server. So, we define that network cost T between a specific Cell and Application Server will be equal to C_{lte}. For the centralized scheme, there are no additional parameters to parameterize. For the fully distributed scheme, we need to parameterize τ_3 standing for the average communication cost between two neighboring Cells. With reference to the LTE network shown in Fig. 1, the communication cost between two Cells within the same TA/TAL (with probability P_{InA}) is $2C_{ta}$; the communication cost between two Cells out of the same TA/TAL but within the same MME (with probability $P_{InR}-P_{InA}$) is $2\left(C_{ta}+C_{mme}\right)$; the communication cost between two Cells out of the same MME (with probability $1-P_{InR}$) is $2C_{ta}+2C_{mme}+C_{lte}$. Therefore, τ_3 can be parameterized as (4):

$$\begin{aligned}\tau_3=2C_{ta}\times P_{InA}+2\left(C_{ta}+C_{mme}\right)\times\left(P_{InR}-P_{InA}\right)+\\ \left(2C_{ta}+2C_{mme}+C_{lte}\right)\times\left(1-P_{InR}\right)\end{aligned} \tag{4}$$

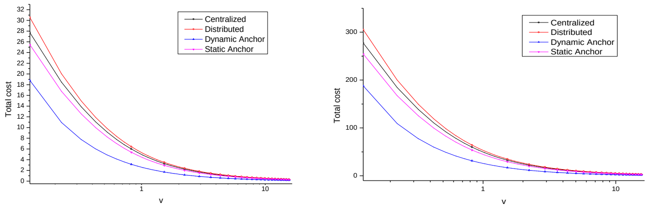
For the dynamic anchor scheme, we need to parameterize τ_1 for the average communication cost between the anchor Cell and another Cell (other than the anchor Cell itself) in an anchor area, as well as τ_2 for the average signaling communication cost between two neighboring TA/TAL areas. In (5), τ_1 is equal to the communication cost between two Cells within the same TA/TAL. To calculate τ_2, two scenarios are considered: the communication between two Cells within the same TA/TAL with cost $2\left(C_{ta}+C_{mme}\right)$ and the communication between two Cells out of the same TA/TAL with cost $2C_{ta}+2C_{tal}+C_{lte}$.

$$\begin{gathered}\tau_1=2C_{ta}\\ \tau_2=2\left(C_{ta}+C_{mme}\right)\times\frac{P_{InR}-P_{InA}}{1-P_{InA}}+\left(2C_{ta}+2C_{mme}+C_{lte}\right)\times\frac{1-P_{InR}}{1-P_{InA}}\end{gathered} \tag{5}$$

For the static anchor scheme, we need to parameterize τ_1 for the average communication cost between the anchor Cell and any Cell (including possibly the static anchor Cell itself) in an anchor area, as well as τ_2 for the average signaling communication cost between two neighboring TA/TAL areas, in as (6). Since the static anchor scheme does not track the location of the MU within an anchor area, the MU can reside in each Cell with equal probability. Thus, for a LTE network with $n=2$ where each TA/TAL has 7 Cells.

$$\begin{gathered}\tau_1=2C_{ta}\times\frac{6}{7}+0\times\frac{1}{7}=C_{ta}\times\frac{12}{7}\\ \tau_2=2\left(C_{ta}+C_{mme}\right)\times\frac{P_{InR}-P_{InA}}{1-P_{InA}}+\left(2C_{ta}+2C_{mme}+C_{lte}\right)\times\frac{1-P_{InR}}{1-P_{InA}}\end{gathered} \tag{6}$$

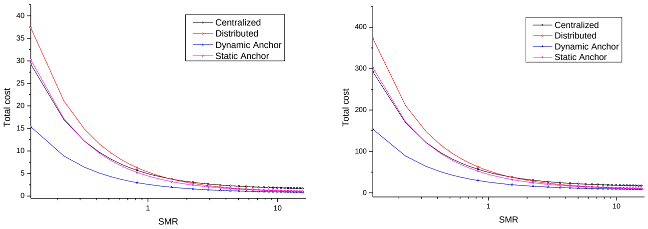
We present numerical data obtained based on our analysis for a LTE network consisting of a 2-layer Cell, TA/TAL and MME as shown in Fig. 1 modeled by the hexagonal network coverage model. Performances of the centralized, fully distributed, dynamic anchor, and static anchor schemes in the LTE network in terms of the communication cost incurred to the network per time unit as a function of CMR and SMR under identical network signaling-cost conditions, whereby all costs are normalized with respect to the cost of transmitting a message between a Cell and its MME, i.e., $C_{ta}=0.5$, such that $C_{mme}=1$ and $C_{lte}=6$.



(a) $\lambda_s=0.1$ (b) $\lambda_s=1$

Figure 6. Total Cost Under Different SMR (Session) Values.

Fig. 6 shows the cost incurred to the LTE network per second as a function of the UE's ν for cost effective schemes. The *X* coordinate represents the value in the range [0.1 16] with the call arrival rate λ_s fixed at 0.1, 1 while changing the mobility rate λ_m. When the ν value is low, both the centralized and fully distributed schemes perform worse than the dynamic and static anchor schemes. This is attributed to the fact that the total cost rate is dominated by mobility-related cost factors at low ν at which the mobility rate is much higher than the call arrival rate. Specifically, the centralized scheme performs badly in this condition because of the high cost for servicing location update operations as these operations need to access the MME in the centralized scheme. The fully distributed scheme does not performs well at low ν because with a high mobility rate, the location update cost and the context transfer cost are high in the fully distributed scheme. At very high ν, the centralized scheme performs the best followed by the dynamic anchor over fully distributed and in the last place the static anchor scheme. The dynamic anchor performs better than the static anchor in this extreme case because in the dynamic anchor scheme the anchor collocated with the service proxy is close to the UE. Thus, the cost for service requests and location updates due to movements within an anchor area is low. Another reason is that when a call arrives and the anchor Cell is not the current serving Cell, the dynamic anchor scheme will update the MME after the call is serviced and move the anchor to the current Cell. This keeps the MME database up-to-date and keeps the anchor close to the UE. As a result, it reduces the call delivery cost since the system is able to find the UE quickly on subsequent calls, the effect of which is especially pronounced when ν is high.



(a) $\gamma = 0.1$ (b) $\gamma = 1$

Figure 7. Total Cost Under Different SMR (Service) Values.

In Fig. 7, as the SMR increases, the cost rate under all four schemes increase because when the mobility rate γ is fixed. At very high SMR, however, the fully distributed scheme performs the best among all followed by the dynamic anchor over the static anchor and centralized because in the fully distributed scheme, the UE's service requests can be serviced quickly by the local service proxy located in the current Cell database.

V. CONCLUSION

In this paper, we investigated the concept of cost effective location and service management with the objective to reduce the overall communication cost for servicing mobility-related and service-related operations by the integrated LTE network environment. Our analysis result shows that the dynamic anchor scheme performs the best in most conditions except when the context transfer cost is high (when the server is heavy). The centralized scheme performs the best at low SMR and high ν. Also, the fully distributed scheme performs the best at high SMR and high ν. The static anchor scheme is a relatively stable scheme, performing reasonably well under a wide range of parameter values examined in the paper. These results mean that different users with vastly different mobility patterns should adopt different cost-optimized location and service management scheme for the better system performance.

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