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Informatics and
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Using Multilevel Hierarchical Registration Strategy for Mobility Management

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ABSTRACT

This paper proposes a multilevel hierarchical registration strategy for mobility management in highly mobile distributed environments to facilitate UPCS. The proposed strategy is based on distributed hierarchical databases in telecommunication networks to form a hierarchical tree: the lowest-level nodes of tree are *service nodes*, and the other nodes are *address information nodes*. Our strategy registers personal information in *service nodes* and keeps track of roaming users' address information in *address information nodes*, respectively. A send-on-demand protocol of personal information for reducing transaction and lock time of user's home database, and real-time updates and queries in *service nodes* are investigated. Furthermore, the proposed strategy has been evaluated not only for mobile communication services, but also for worldwide personal communication services in mobility data acquisition, ubiquitous services availability, registration information recovery, and network changes' aspects.

*To whom all correspondence should be addressed. This work was supported in part by the National Science Council, Republic of China, under Contract NSC84-2213-E009-006.

INFORMATION SCIENCES **89**, 63–76 (1996)

655 Avenue of the Americas, New York, NY 10010

0020-0255/96/$15.00
SSDI 0020-0255(95)00224-D

Finally, a cost analysis model demonstrates the feasibility of database memory size, updates cost, queries cost, and communications cost in our proposal.

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1. INTRODUCTION

With the recent developments in the field of wireless access and hand-held portables, the rapidly expanding technology of Personal Communication Services is to enable users the capability of ubiquitous communicating with each other regardless of the geographic location of either party. The existing techniques for identifying users and locating portables are to match and to page the portables [3]. Paging the portables has two purposes. One is to announce the service area identifier for portables. From the broadcasted service area identifier, the portables can determine whether they should register in this new location and deregister their old location. The other purpose is to wake up the portables once the calls are coming. An existing technique used in the conventional cellular network [1, 2, 8] usually partitions the communication coverage into many service areas with associated databases that include service information. The biggest challenge presented by this technique is the mobility management of portables, users, and services [10].

Many researchers have found that mobility management problems are typically the integration of personal and portable profile database management, portable and user location registration strategies, ubiquitous services availability, and communication protocol technologies [5–10]. The issue of database queries for tracking mobile users has been discussed in [5] by partitioning the users' location knowledge across the network. This approach conceals two drawbacks. The partition of user mobility patterns to maintain a certain degree of knowledge about users' whereabouts is an optimal partitioning problem that minimizes the expected cost of querying and updating. The optimal partitioning problem makes this approach not easily implemented. Query processing is another disadvantage in the presence of imprecise knowledge about the locations of users.

Hierarchical information handling and information localization schemes in the framework of Intelligent Network have been discussed in [4]. These hierarchical schemes have been proved to be better for adding a new network to the networks already providing services, for autonomously updating the database contents, and for universal accessing capabilities. However, this approach should make copies from the central database to local databases frequently. The consistency of replicated data will be difficult to maintain, and the semantic interoperation between databases is another unsolvable technique. The drawbacks of hierarchical schemes have been partially solved by an efficient tracing and fully distributed location registration strategy [11]. Unfortunately, that location registration algorithm has not considered the mobility management of service, and interworking between service logic and the interworking between service logic and service data over a network boundary. It only demonstrated the registration strategy of portables.

However, a huge amount of processing for database queries and registration would be crucial to provide Universal Personal Communication Services (UPCS) on a worldwide scale. Especially, a location registration strategy for portable and user in the focal issue in mobility management since the registration strategy depends on the network architecture and protocol functions evolution that dramatically affects the personal or portable profile management and the ubiquitous availability of services. However, portable and user location registration strategies commonly proposed are two-level hierarchical registration strategies [1, 2, 7], which are a system of home and visitor databases to keep track of portable and user locations. In addition, service information wherein users may have subscribed to an incoming call screening or speed dialing feature should be migrated to the nearest database addressed by the exchange serving users. Our idea is that service information should accompany users for real-time queries and updates, and avoid semantic interoperation between distributed hierarchical databases.

This paper proposes a multilevel hierarchical registration strategy to support data management in highly mobile distributed environments. We are concerned with the layered network architecture and associated databases. Section 2 describes the proposed network architecture and algorithms for hierarchical registration. Section 3 demonstrates the efficiency of mobility management on portables, users, and services. An easy cost computation demonstrates the feasibility of our proposal in Section 4.

2. OUR HIERARCHICAL APPROACH

2.1. THE NETWORK ARCHITECTURE

The telecommunication network is logically a hierarchical, multiway tree topology, as shown in Figure 1. The layered hierarchy of the telecommunication network is local-level network, transit-level network, and global-level network. The transit-level network can be a transcontinental network, and the global-level network can be a number of satellite communication systems. As the database plays the control role of offering

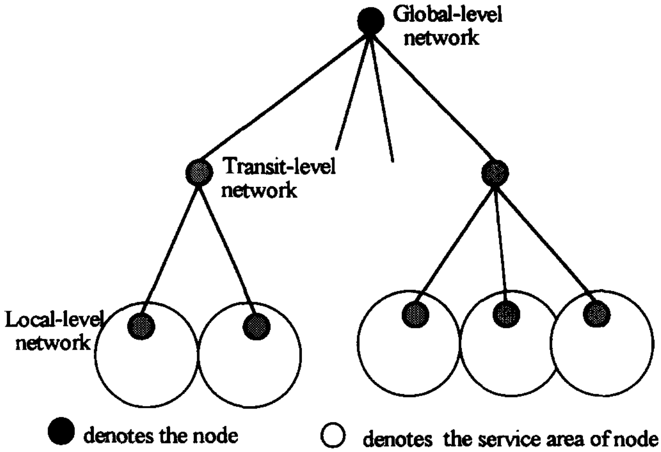

Fig. 1. The hierarchical tree-like network architecture.

services, the database is really the brain of network [10]. It can be seen that one database can dominate and direct many exchanges. Furthermore, the database for UPCS emphasizes the mobility management. Thus, database connection and the operation relationship are key issues addressed in this paper. We assume that the local-level network is a subset of the Public Switched Telephone Network, Integrated Services Digital Network (ISDN), broadband ISDN, or mobile network. These local-level networks can be a layered structure, and the databases of the local-level network cover all the *service areas* of users. For convenience of analysis, we need the following definitions.

DEFINITION 1. *Service areas* are the coverage regions of the lowest level of databases (the lowest level of nodes in Figure 1). In addition, *service area* is also the granularity unit of registration and updates.

DEFINITION 2. Each *service area* has a unique identifier. Let SA_i^m be the *service area i* controlled by database *m*; then $SA^m = \bigcup_i SA_i^m$.

Initially, the portable has two types of location information. One is *home location* (the portable's subscription location), and the other is *visitor location* (the portable's current location). Normally, *home location* is static and cannot be changed after the time of subscription. On the other hand, *visitor location* will be changed dynamically if, and only if, the received location area identifier (LAI) is different from *visitor location*. The portable receives the service area identifier (SAI) from the broadcasting channel as an LAI. The portable will compare this LAI with the location information stored in the portable. Once LAI is not equal to the home location identifier, the portable updates this visitor location with the LAI. From Definition 1, the portable invokes the portable mobility management procedure. By the way, the portable has to access service information and to exercise the service mobility feature on the network side. The next section will describe our proposed multilevel hierarchical tree for service mobility.

2.2. *CONSTRUCTION OF HIERARCHICAL TREE*

The proposed multilevel hierarchical tree is shown in Figure 2 with the portable B as an example. Each node in the tree topology is a database node. There are two types of databases in our proposal. The lowest level of nodes (horizontal databases) is *service nodes*. The nodes (databases) except for the lowest level are *address information nodes*. *Service nodes* cover all the *service areas*, and these nodes can be an HLR and VLR in IS-41 and GSM [1, 2], In brief, *service nodes* have all user's service information and execute service logic as a response to queries from the exchange, e.g., Service Switching Point or Mobile Switching Center. The *address information nodes* have two kinds of special information: one is the Directory Information Table (DIT) for registering the closest subordinate nodes. The DIT is useful for the shortest routing path in traversing the tree topology. The Forward Address Chain (FAC) is designed as a detailed address pointer which is similar to a pointer of the pointer forwarding scheme in

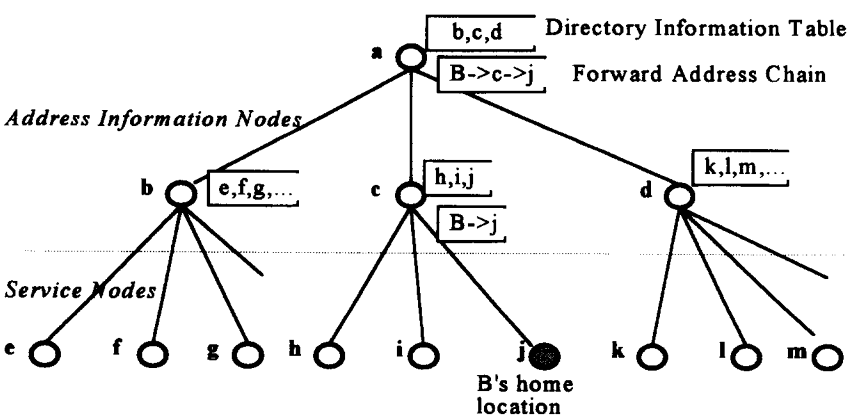

Fig. 2. The proposed multilevel hierarchical tree.

[7]. The FAC points to the roaming nodes of users. Therefore, the FAC table is useful for two purposes: the call originating database can quickly acquire the exact position of call terminating database and make a shortest routing path, and new *service nodes* can acquire personal information from users' old *service nodes*.

The proposed strategy has bottom-up registering and deregistering properties. All service executions are of interaction between *service nodes* and their associated exchanges. *Address information nodes* are of address and information forwarding registration or deregistration only, and do not invoke service interaction. Therefore, the memory sizes of *address information nodes* are minimum. *Address information nodes* are intelligent highway system for *service nodes*. There is obviously no semantic interoperation problem between *address information nodes* and *service nodes*.

2.3. *STATIC DATA AND DYNAMIC DATA*

From the service provision point of view, exchanges should arm call model and trigger points for dialing number, and *service nodes* have service execution programs and service information about users. Therefore, we assume that call model and trigger points in the exchanges, and service execution programs in *service nodes* conform to international standards such as the relationship of SSP and SCP [10, 11]. Thus, our idea concentrates on the mobility management issue of service information.

Generally, service information consists of dynamic data and static data. Dynamic data are created and changed with time such as location information. On the contrary, static data are created in the service subscription procedure and maintained unchangeable. Static data include user profile, service profile, portable profile, and charging profile. In other words, this information is user-oriented information. Therefore, dynamic data can be created freely, and static data should be moved elsewhere for realizing service mobility.

2.4. *THE ALGORITHMS*

This section presents algorithms that achieve the mobility management of portables, users, and services. Our algorithms are not only suitable for portable users, but for users who can register or deregister themselves by public telephone sets. However, we demonstrate the portable's case here. All mobility management procedures are initiated by the portables' moving. For ease of discussion, we will describe the proposed algorithm in four steps: DIT and FAC table construction, users roaming, portable and user registration, and service information creation. The algorithm of our hierarchical registration strategy is described as follows.

Step 1. (Construction) All of the databases are interconnected as a distributed hierarchical tree proposed in Section 2.2 by way of a high-speed data link. Take Figure 2 as an example: DIT(a) = {b, c, d}; DIT(c) = {h, i, j}; DIT(d) = {k, l, m, ...}; FAC(a) = {B → c → j, ...}; FAC(c) = {B → j, ...}; and FAC(d) = ∅.

Step 2. (Roaming) The portables are moving from one *service node* to another. If the power of the portable is on, the portable will receive the broadcasted LAI of *service node*. The portable will compare this LAI, e.g., ω, with the *visitor location* memorized in the portable. If *visitor location* is not equal to ω, then the portable performs Step 3.

Step 3. (Registration) The portable sends a message to this new *service node*. *Service node* creates location information (dynamic data) for this new comer, and sends an information registration message to its *address information node*. The *address information node* examines the FAC table; if the content of the FAC table of this portable directly points to *service node*, then it updates FAC table; otherwise, it modifies the FAC table and redirects this registration message upward or downward, depending on the FAC content. In our example (Figure 3), FAC(d) = {B → k}; FAC(a) = {B → d → k, ...}; FAC(c) = {B → out, ...}; and FAC(j) = {B → out}.

Step 4. (Send-on-demand) The deregister *service node* sends personal information (static data) as a response to new *service node* along with the hierarchical path.

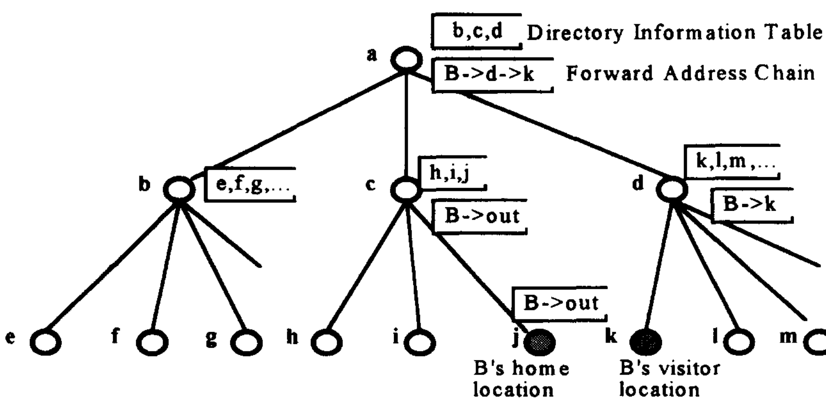

Fig. 3. A forward address chain registration example.

With the above definitions and algorithm, it can be seen that the shortest routing path exists between the user home database and the visitor database. Thus, we have the following theorem.

THEOREM 1. *With information on DIT and FAC, the send-on-demand protocol assures that personal information is routed along with the shortest path in the proposed network topology.*

3. EVALUATION OF GLOBAL DATA MANAGEMENT

As mentioned in Section 2, the proposed hierarchical tree is simple and efficient. There have been real-time location tracking, updating, and registration features, but no maintenance of replication. The hierarchical topology of databases is also scaleable and configurable. We illustrate the following issues to examine its efficiency of data management.

3.1. MOBILITY DATA UPDATING

As discussed in Section 2.3, static data are retrieved from the home *service node* and dynamic data are created locally. Dynamic data are updatable while the portable is moving. *Service nodes* proposed in this paper are really mobility data stores. These nodes store all of the service information for users served in their *service areas*. From Definition 1, the visitors' *service nodes* are the granularity unit of registration and update. These registrations and updates operate in the sense of real time. However, there is no mobility data updating in the home *service nodes* and *address information nodes*. Further, the semantic interoperation between the distributed hierarchical databases is only dependent on the interface standard of the communication protocol.

3.2. DATA ACQUISITION DURING QUERYING DATABASE

In some cases, *service node* receives the users' call setup request with registration at the same time. As mentioned in our algorithm, caching service information in visitor *service node* is completed after the registration procedure. Therefore, visitor *service node* suspends the call setup request until the completion of the registration procedure. This call suspension results in incorporating data acquisition into querying *service node* (horizontal database) [5]. The distributed hierarchical databases and registration algorithm proposed here solve this type of query processing with data acquisition. Our algorithm for this type of query is very natural to complete in two steps: registering the location first, and then serving the query from the copied personal information.

The speed in retrieving personal information from home *service node* (old) to visitor *service node* (new) is dependent on the transmission medium and message length. Regardless of the processing time in intermediate nodes, we know that the transcontinental terrestrial radio link only takes 10–20 ms propagation delay. Even the satellite link has a propagation delay of about one quarter of a second with a 50 Mbps data stream. Therefore, the performance of data acquisition is reasonable and acceptable in our proposal.

3.3. SERVICE MOBILITY

The target of this paper is to present a solution of mobility management for portables, users, and services. Service mobility is also the most difficult among these three kinds of mobility. In our algorithm, service information, especially personal information, is roaming with users. Wherever users locate, service information follows and is stored in the nearest *service node*. Service mobility in this sense is ubiquitous and seamless services of course.

3.4. RECOVERY

In some cases, the visitor *service node* may lose the visitors' service information; *service node* will recover a piece of information from the users' "primary copy" in their home *service nodes*. However, the proposed hierarchical tree is a fully distributed architecture, and complies with the rules of location independence, replication independence, and DBMS independence. The recovery control is simple enough, and only remote caches personal information again while users are repowering on or making a call.

3.5. NETWORK EXPANSION

Tree topology is a connected acyclic graph. An acyclic graph is also termed a forest. In this paper, the network expansion is similar to connecting two forests. The only difference between network expansion in our topology and two forest connections is that two forests can be formed as a forest by way of an edge, but two hierarchical trees are unified as one by way of two links and one additional *address information node*. There are no modifications in the existing *address information nodes*, except for the reconfiguration of the DIT and FAC table in the new node.

4. COST ANALYSIS

The proposed multilevel hierarchical registration strategy should be simple, efficient, and cost-effective. Simplicity and efficiency are easier to examine from network topology. Cost-effectiveness is the most important point for proving the feasibility of the proposed strategy. The cost analyses considered in this section are database memory size, updates cost, queries cost, and communications cost.

4.1. DATABASE MEMORY SIZE

Consider the cost analysis model in Figure 4, and assume that users and traffic patterns are of uniform distribution. For simplicity, we let the population of users be the sizes of memory equivalently. Let X_i denote the database memory size for users in SA^i, P_i denote the probability of user roaming outside SA^i, and M_i denote the branch number of subtree $i+1$.

In our proposed hierarchical tree, there are two types of memory sizes to be determined: the memory size for *address information node* in each level, and the memory size for each *service node*. Therefore, the mandatory memory size for users in the *address information node* is

$$X_1 = P_0 M_0 X_0, \quad X_2 = P_1 M_1 X_1, \quad \text{and} \quad X_k = \left(\prod_{i=0}^{k-1} P_i M_i \right) X_0. \qquad (1)$$

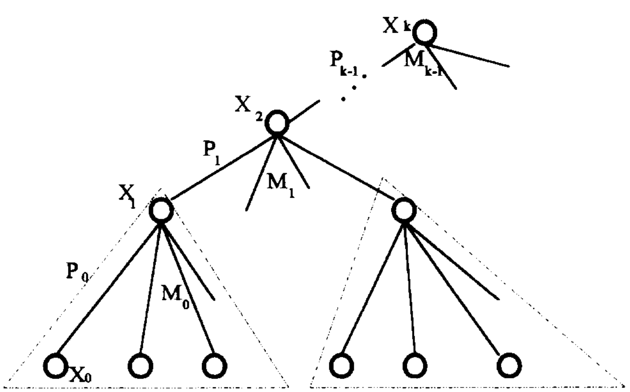

Fig. 4. A cost analysis model.

It can be seen that the memory size for the DIT table is a small mandatory portion, but the memory size for the FAC table varies while users are roaming.

The visitor roaming users with home locations outside this SA^i contribute the varying portion of memory size of $\{X_i\}_{1 \leqslant i \leqslant k}$. Let $TRU(X_i)$ be the total roaming users in this SA^i; then from Eq. (1), we have $TRU(X_i) =$ home roaming users + visitor roaming users =

$$P_{i-1}M_{i-1}X_{i-1} + \sum_{j=i}^{k-2} \frac{(1-P_{j+1})P_jM_jX_j}{M_j - 1} + \frac{X_k}{M_{k-1} - 1}, \tag{2}$$

where $i = 1, \dots, k-1$.

The higher the level of tree, the less the roaming probability across *service area*. Therefore, the probability has $P_0 \geqslant P_1 \geqslant \cdots \geqslant P_{k-1}$ property, and the database memory in each node X_i has the rule $X_1 \geqslant X_2 \geqslant \cdots X_k$. Thus, we have

$$\begin{aligned} TRU(X_i) &\leqslant P_{i-1}M_{i-1}X_{i-1} + \frac{k(1-P_{i+1})P_iM_iX_i}{M_i - 1} \\ &\leqslant 2P_{i-1}M_{i-1}X_{i-1}, \quad \text{as } M_i = M_{i-1} = M \text{ and } \frac{P_{i+1}}{P_i} \to 0 \\ &\leqslant P_0M_0X_0 \\ &= X_1, \qquad \text{where } i = 2, \dots, k-1. \end{aligned} \tag{3}$$

This implies that the memory size for the FAC table in *address information node* has an upper bound of registering X_1 users. Similarly, the memory size for each *service node* is dependent on the population size of home users, X_0, and FAC table size. Therefore, by Eqs. (2) and (3), we have the following theorem.

THEOREM 2. *Total roaming users in proposed address information nodes have* $\{TRU(X_i) \geqslant TRU(X_{i+1})\}_{2 \leqslant i \leqslant k-1}$ *and* $\{TRU(X_i) \leqslant X_1\}_{i=1,\dots,k}$.

In addition, we have the total service users, $TSU = (\prod_{i=0}^{k-1} M_i)X_0$, in our model. If we let $X_0 = 100{,}000$, $M_0 = 100$, and $M_1 = 10$, then $TSU =$ 100,000,000. In this case ($k = 2$), the model is the same as that proposed in [11]. Furthermore, there are 300 million telephones in the world; we can service them in our model with the value of $k = 3$.

4.2. UPDATES COST

The update operations manipulated in *address information nodes* are only FAC table modifications since the DIT table is configured only once the hierarchical topology is changed. The volume of FAC table modification is dependent on the size of roaming users in each node. Among these *address information nodes* in the tree topology, the maximum update volume, about $P_0M_0X_0$, will occur in the X_1 nodes. However, [11] has proved the feasible update capability in these X_1 nodes to cover 100 million portables.

The other updates from portables' registration are operated in *service nodes*. Because these nodes contain all the service information, these update operations are real-time and cost-effective in distance traveling measure. On this distributed processing architecture, it is quite easy and not costly to find a database fast enough to handle X_0 users in each *service node*.

4.3. QUERIES COST

Each time the user makes a call or the portable enters a new *service node*, querying activities occur between exchange and *service node*, and queries even occur with data acquisition between visitor *service node* and home *service node*. The queries cost is dependent on the number of querying messages.

In the case of queries with data acquisition, query messages are subject to the roaming probability P_i and branch factor M_i. Therefore, it is obvious that query messages should be less than either query messages in the centralized database scheme or query messages in the home database scheme. The query cost between exchange and *service node* is only a function of users, X_0, and traffic behavior; moreover, the cost is minimized while *service node* and exchange are collocated. Therefore, queries' costs in our approach are minimal.

4.4. COMMUNICATIONS COST

In our hierarchical registration strategy, we manipulate service information by way of a send-on-demand protocol from deregistered *service node* to new service node. As in Theorem 1, information copy flows along the shortest path because of the DIT table and FAC information. There is no write-back operation from deregistered *service node* to home *service node*, and there is also no remote forward copy from home *service node* to new *service node*. There is only a one-way shortest path communications cost occurring between deregistered *service node* and new *service node*.

Assume branch factor $M_i = M$ and total N nodes in the proposed tree topology; then the depth of tree is $\log_M N$. Thus, we have maximum communications cost in $2(\log_M N - 1)$ steps for X_k users. It is important to point out that there is about a $\{1 - M_2 M_3 \dots M_{k-1} X_2 / TSU\} = \{1 - P_0 P_1\}$ percentage of users with two steps' communications cost. Therefore, the proposed strategy for providing UPCS is of minimal communications cost.

5. CONCLUSION

In this paper, we propose a multilevel hierarchical registration strategy for UPCS. The proposed hierarchical tree is simple and efficient for real-time location tracking, location updating, and registration, but no maintenance of data replication. The feasibility of our proposal has been examined by database memory size, updates cost, queries cost, and communications cost in our proposed cost analysis model.

In addition, there is no semantic interoperation between distributed hierarchical databases. The proposed tree topology is also scaleable and configurable. Thus, it is practical to realize our model in the real world. Finally, our approach creates location information freely, and personal information can accompany users with a send-on-demand data migration protocol to achieve the essence of mobility management of portables, users, and services.

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Received 10 October 1994; revised 1 March 1995