Performance Evaluation of Location Update Schemes for MANET

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Abstract: *In this paper, we have developed an analytical model to evaluate the performance of home agent, quorum based, and grid location service update schemes using Markov chain. The model evaluates the performance in terms of the cost of updates and queries. The cost of updates is computed in terms of the hops used in updating a location. The model also considers selective queries for destination search to compute the cost of queries, such that the cost of queries is computed in terms of the hops used in searching for destination. Finally, the average total cost that includes the update cost and query cost is determined. In the model, moving node initiates a location update using a distance based triggering strategy. The average total cost is determined for different threshold distances. The analytical results show that the home agent location update scheme outperforms quorum based and grid location service location update schemes.*

Keywords: *Markov chain, location update, home agent, quorum, grid location service.*

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1. Introduction

Mobile Ad hoc NETworks (MANET) are a set of autonomous wireless mobile nodes that do not require a pre-established infrastructure. Each node in the network acts both as a router and an end system. For message forwarding in MANET various routing algorithms have been proposed to take care of frequent topological changes. Some algorithms use the information of entire network for routing and they are known as topology based routing algorithm. Other algorithms use information about the physical location (position) of the participating nodes [3, 4, 12, 18, 20]. These algorithms are known as position based routing algorithms for which location updates are essential.

Position based routing algorithms assume that each node knows its physical location that can be obtained using Global Positioning System (GPS) [13]. A node in the network also maintains database of location information of other nodes. Such node is referred to as location database server. Efficient location update schemes [15] are needed for maintaining up to date information in the location servers. These schemes should replicate location information in order to minimize database servers' failures and network partitioning [7]. Distribution of location information should involve minimum resources of the network in updating and retrieving of the information.

In this paper, we have evaluated the performance of home agent, quorum based, and grid location Service update schemes analytically using Markov chain model. The general approach is similar to that in [6, 11, 16, 17]. In the model, a distance based triggering strategy is used to trigger a location update for moving nodes in the network. Further, the model also considers selective queries for destination search to compute the average total cost that includes the update cost and query cost. To study the impact of varying the threshold distances on these update schemes, we have used different threshold distances.

Next, section describes research work done in the area of location update schemes. In section 3, we explain system description of location update scheme in details. Section 4, discusses the Markov chain model for the location update schemes. The estimation of location update and query request costs is described in section 5. Analytical results along with comparisons between update schemes are presented in sections 6 and 7. Finally, the work has been concluded in section 8 with findings of the work.

2. Related Work

In the literature, home agent, quorum based, and grid location service have been three popular location update schemes [15]. These update schemes have been evaluated and compared experimentally [9].

Stojmenovic proposed home agent based strategy for location updates and destination search [16]. In this scheme, each node designates a certain circular area as its home region, and informs other nodes about it. Therefore, when the node moves away to a new location, it sends regularly its location update messages only to the nodes located within its home region using greedy routing algorithms [18]. For destination search, the source node sends a query message toward its home agent, which supplies the latest available location information about the destination. Then using this up to date location information, the request is forwarded toward destination to complete the destination search.

The concept of quorum systems is known from information replication in databases and distributed systems. Information updates are sent to a group of available nodes called quorum, and information requests or queries are sent to another quorum. Therefore, updated information can be found only in the nodes available at the intersection of quorums.

Given a set S of location database servers, a quorum system is a set of m subsets of S whose union is S and intersection is non empty, namely $S_0, S_1, \ldots, S_{m-1}$ [7]:

$$\bigcup_{i=0}^{m-1} S_i = S$$

$$S_i \cap S_j \neq \Phi, \qquad for \quad 0 \leq i, j \leq m-1$$

Stojmenovic and Pena described a quorum based location information management scheme in [17]. This scheme is based on replicating location information of a node at multiple nodes acting as location database servers along north and south directions of the node updating its location servers, i.e. a column at current location of the updating node with certain thickness of reporting. In this scheme, absolute connectivity based strategy is used for triggering location updates [7]. Therefore, a location update is triggered whenever a threshold value of number of links (broken or created) is reached. For location update a moving node forwards a message containing its new location information to all nodes located to north and south directions (in a column) of its current location. A source node begins the destination search by sending two query messages. One of these messages is sent in the east and west directions (in a row) of the source node with certain thickness of the row, looking for most up to date location information of destination location. At least one location server can be found at intersection of the updating column and the row in which destination search is performed. The location information obtained from destination search is then used to continue a route search for the destination. Other message can be sent directly from source to destination using available location information with the source node itself.

Li, Jannotti, De Couto, Karger, and Morris described a new distributed location database service called Grid's Location Service (GLS) [8, 11]. In this scheme, they divide the network area into a hierarchy of squares. In this hierarchy, n-order squares contain exactly four (n-1)-order squares. Each node maintains a location database of all other nodes within the local first-order square. The location database is constructed with the help of periodic position broadcasts restricted to the area of the local first-order square only. For first order and higher order squares, each node selects a small set of nodes as its location database servers with ID's closest and greater than the ID of the node. Therefore, each node periodically updates its location database servers with its current location information using geographic forwarding algorithm.

A node sends its new location information to the location servers without knowing their actual identities, by using a predefined ordering on node identifiers and a predefined geographic hierarchy. A node can direct a location query to a known node with the ID nearest to the ID of the destination node by using the predefined identifier ordering and the predefined geographic hierarchy. A node updates its order-i servers after each movement of a particular distance ($2^{i-2}\, d$). For example, a node updates its order-2 location servers every time it moves a particular threshold distance d since last update.

3. Systems Description

In this section, we consider two-dimensional mobility model as in [6, 10]. In model, nodes can move in any direction within the given network area. While a node is moving, it can trigger a location update using an appropriate triggering strategy. In this model, we have used a distance based triggering strategy. In this strategy, a node triggers a location update when it crosses a given threshold distance, i.e., it crosses the boundary of a sub area defined as the network width times twice of the threshold distance around the current location of the node in north and south directions. Therefore this location update strategy ensures that a node is located within a sub area that is twice of the threshold distance from the last updating location of the node. For example, in Figure 1, if node A moves straight to either its left or right, the node is in the same sub area 0 twice of L_0 since threshold distance is L_0. In case the node crosses L_0, it triggers a location update and transmits its location information to its location servers based on the location update scheme under consideration. Now this node has its new sub area 0 twice of L_0 around its new position.

In this model, we have considered cases for different threshold distances L_0, L_1, L_2, and L_d to study the impact of varying these distances on the update schemes For these threshold distances, the sub areas are referred to as sub area 0, sub area 1, sub area 2, … sub area d respectively. The sub area 0 has distance twice L_0, sub area 1 has distance twice L_1, and sub area 2 has distance twice L_2 in the north and south directions of a given node A in the network as shown in Figure 1. Therefore, sub area d has distance twice L_d. the Figure 1 also shows that when a node has moved from position A to position B, it updates all its location servers according to the location update scheme considered.We have used a distance based triggering strategy to trigger a location update. This location update strategy ensures that a node is located in a sub area within a threshold distance *d* from the last updating location. Therefore, a moving node updates its location servers when it crosses a threshold value of distances L_0, L_1, L_2 or L_d for sub areas 0, 1, 2, 3, or *d.*

For destination query, a source node sends a destination request query for all location servers of the destination node. The search for destination continues using this location information obtained from the location servers in sub area 0. If this search fails, the destination search is continued in the sub areas 1, 2, and *d* based on the threshold distance considered.

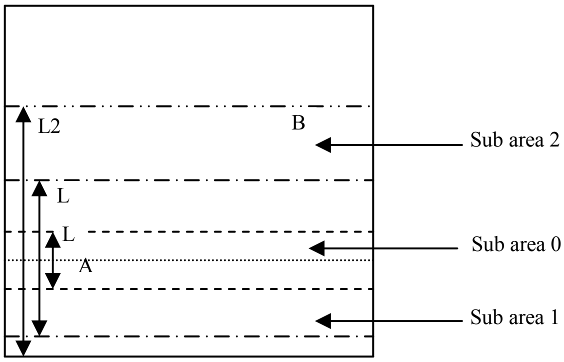

Figure 1. Structure of the model.

3.1. Home Agent Update Scheme

Figure 2 shows the system for home agent update scheme. When a node has moved from position *A* to position *B*, the node updates all nodes located in the home region of the node *A*.

For destination query, a source node sends a destination request query for all location servers available in home region of the destination node. The search for destination continues using the location information obtained from the location servers in sub area 0. If this search fails, the destination search is continued in the sub areas 1, 2, and *d* based on the threshold distance considered.

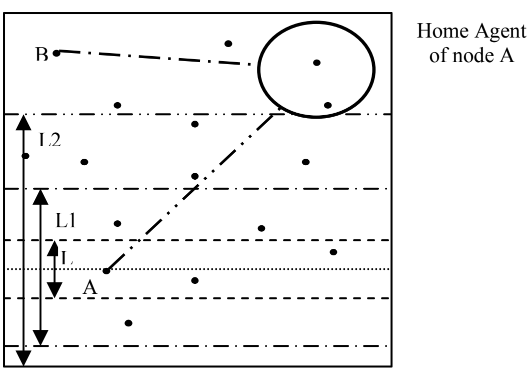

Figure 2. Structure of home agent model.

The location information obtained from the location servers in sub area 0. If this search fails, the destination search is continued in the sub areas 1, 2, and *d* based on the threshold distance considered.

3.2. Quorum Based Update Scheme Model

Figure 3 shows the system for quorum based update scheme [17]. When a node has moved from position *A* to position *B* and crossing the threshold distance L_1, it updates all nodes in a column along its north and south directions shown by shaded area.

For destination query, a source node sends a destination request query for all location servers available in a row positioned along east and west directions of the source node. The intersection of location query row and location update column results in some nodes working as location servers for destination. The search for destination continues using

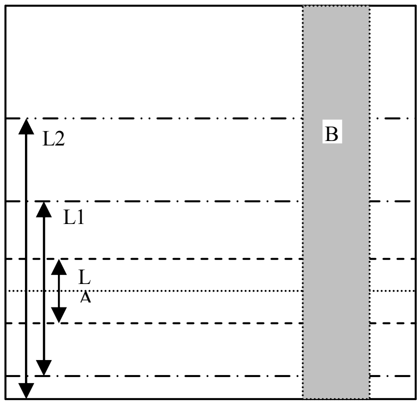

Figure 3. Structure of quorum based model.

3.3. Grid Location Service Update Scheme

Figure 4, shows the system for grid location service update scheme. When a node has moved from position *A* to position *B*, the node updates all its location servers with ID greater and closest to the ID of the node located in different squares of all order-squares.

For destination query, a source node sends a destination request query for location servers available in the squares of 1st order square, 2nd order square, 3rd order square, and sth order square of the source node. The search for destination continues using the location information obtained from the location servers in sub area 0. If the search fails, the destination search is continued in the sub areas 1, 2, and *d* with respect to destination based on the threshold distance considered.

4. Markov Chain Model

In this work, we have used a random walk mobility model. In this model, a moving node travels to one of its neighboring sub areas with probability *q* or stays at the current sub area with probability *1 – q*.

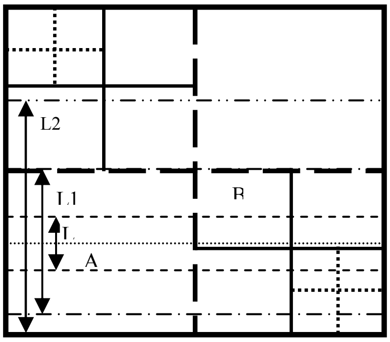

Figure 4. Structure of GLS model.

We have formed a discrete-time Markov chain model to capture the mobility and query arrival patterns of a moving node in two-dimensional network [6, 14, 19]. Figure 5 shows the state diagram of Markov chain model when the threshold distance for triggering a location update is *d*. The state of the Markov chain *i* (*i* =0, 1, 2 … *d*) is defined as the distance between the current location of the moving node and its last updating location from where the node has updated its location servers. The transition probability $mi_{i,i+1}$ represents the probability at which the distance of the moving node from its last updating location increases in north or south directions. The transition probability $md_{i,i-1}$ represents the probability at which the distance of the moving node from its last updating location decreases in north or south directions. The request query arrival probability is denoted by λ. transitions from a given state to one of its neighboring states represent movements of the node away from its current sub area. A state transition to state 0 represents either the arrival of request query or the triggering of location update when the threshold distance *d* is reached.

The transition probabilities of the discrete-time Markov chain are given as:

$$mi_{i,i+1} = q/4 \qquad 0 \le i \le d \tag{1}$$

$$md_{i,i-1} = q/4 \qquad i > 0 \tag{2}$$

We assume that p_0, p_1, p_2, and p_d are the steady state probabilities (limiting or equilibrium probabilities) of states 0, 1, 2, and *d* when the maximum threshold distances are L_0, L_1, L_2, and L_d, respectively. The balance equations for Markov chain are given as

$$p_0\ mi_{0,1} = p_1\ md_{1,0} + p_d\ mi_{d,d+1} + \lambda \sum_{i=1}^{d} p_i \tag{3}$$

$$p_d\ (mi_{d,d+1} + md_{d,d-1} + \lambda) = p_{d-1}\ mi_{d-1,d} \tag{4}$$

$$p_i\ (mi_{i,i+1} + md_{i,i-1} + \lambda) = p_{i-1}\ mi_{i-1,i} + p_{i+1}\ md_{i+1,i} \quad \text{for } 0<i<d \tag{5}$$

$$p_0 + p_1 + \cdots\cdots\cdots + p_{d-1} + p_d = 1 \tag{6}$$

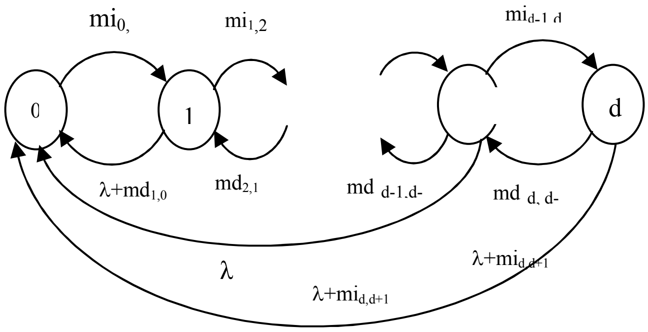

Figure 5. State diagram of Markov chain model.

We have calculated the steady state probabilities of Markov chain given the balance equations (3-6) and the transition probability equations (1-2) [2].

5. Location Update and Query Request Costs

We use the steady state probabilities calculated in section three to determine the cost of both location updates and query requests for a given threshold distance *d*. We assume that the cost for updating location servers of a moving node is *U*. We consider that the network is a random graph with fixed transmission range. The mean hop count is the average distance between any pair of nodes or the average path length [1, 5] is given by the formula

$$h \approx \frac{\ln(n)}{\ln(k)} \tag{7}$$

where *h* is the distance between two nodes in terms of hop counts, *n* is the number of the nodes in the network, and *k* is the connectivity of the network (i.e. the average number of neighbors of a node in the network).

The cost for query request in sub area 0 is Q_0,

$$Q_0 = \left(1+\left\lfloor \frac{2*L_0}{R} \right\rfloor\right)*\left(1+\left\lfloor \frac{w}{R} \right\rfloor\right) \tag{8}$$

And in any of the remaining sub areas is *Q*.

$$Q = 2*\left(\left(1+\left\lfloor \frac{L_i}{R} \right\rfloor\right)*\left(1+\left\lfloor \frac{w}{R} \right\rfloor\right)+h\right) \tag{9}$$

where *w* is the width of the network, and L_i is the threshold distance of the sub area *i*, *R* is the transmission range of the node, and *h* is distance between sub area 0 and any one of the remaining sub areas.

5.1. Home Agent Update Scheme

In home agent update scheme, when a moving node crosses the threshold distance *d*, it sends location update messages to all nodes located within its home region. Therefore, the update cost of the square home region for home agent model is the sum of number of transmissions in terms of hop count needed to cover the square home region with circles of radius equal to transmission range and the cost between the source node and its home region. Therefore, the update cost U is given by

$$U = \left(1 + \left\lfloor \frac{l}{R} \right\rfloor\right) * \left(1 + \left\lfloor \frac{l}{R} \right\rfloor\right) + h \quad (10)$$

where l is length of the square of home region, and R is the transmission range of a node in the network. Therefore, the average location update cost for a threshold distance d denoted by $C_u(d)$ is given by:

$$C_u(d) = p_d \; mi_{i,i+1} \; U \quad (11)$$

For query of a destination, a source node sends query message for destination information in the home region of the destination. In this case it is same as U (since the update cost and the query cost are approximately same). This cost also includes the distance in terms of hop count between location server and sub area 0 and the cost in sub areas 0, 1, 2, ...*d*.

The average destination query cost for a threshold distance d denoted by $C_Q(d)$ is given by:

$$C_Q(d) = \lambda \left(U + h + p_0 * Q_0 + \sum_{i=1}^{d} (p_i * Q) \right) \quad (12)$$

Therefore, the average total cost for a threshold distance d denoted by $C_T(d)$ is given by:

$$C_T(d) = C_U(d) + C_Q(d) \quad (13)$$

5.2. Quorum Based Update Scheme

In Quorum based update scheme, when a moving node crosses the threshold distance d, it sends location update messages to all nodes located within its column. Therefore, the update cost of a column for quorum based model is the number of transmissions in terms of hop count needed to cover the column with circles of radius equal to transmission range.

$$U = \left(1 + \left\lfloor \frac{w}{R} \right\rfloor\right) * \left(1 + \left\lfloor \frac{l}{R} \right\rfloor\right) \quad (14)$$

where w *and* l are the thickness and length of the column, and R is the transmission range. Therefore, the average location update cost for a threshold distance d denoted by $C_u(d)$ is given by:

$$C_u(d) = p_d \; mi_{i,i+1} \; U \quad (15)$$

For a query of destination, a source node queries for destination information in the row along the east and west directions of the source. In this case, it is same as U (since the updating column and searching row are of the same size). This cost also includes the distance in terms of hop count between location server and sub area 0 and the cost in sub areas 0, 1, 2, ...*d*.

The average destination query cost for a threshold distance d denoted by $C_Q(d)$ is given by:

$$C_Q(d) = \lambda \left(U + h + p_0 * Q_0 + \sum_{i=1}^{d} (p_i * Q) \right) \quad (16)$$

Therefore, the average total cost for a threshold distance d denoted by $C_T(d)$ is given by:

$$C_T(d) = C_U(d) + C_Q(d) \quad (17)$$

5.3. Grid Location Service Update Scheme

In grid location service update scheme, when a moving node crosses the threshold distance d, it sends location update messages to all location servers located in different order squares from 1st order square up to sth order square. In this case, we have considered $s = 4$. Therefore, the update cost of the location servers in the four order squares for grid location service model is the sum of location update cost in each order square from one to four. The location update cost in the 1st order square is the number of transmissions in terms of hop count needed to cover the 1st order square with circles of radius equal to transmission range. The update cost between the source and any one of the remaining order squares is the sum of the cost of updating three location servers and the search cost to identify the location servers in that order square.

$$\begin{aligned} U = & \left(1 + \left\lfloor \frac{l}{R} \right\rfloor\right) * \left(1 + \left\lfloor \frac{l}{R} \right\rfloor\right) \\ & + 3 * \left(\left(1 + \left\lfloor \frac{l}{R} \right\rfloor\right) * \left(1 + \left\lfloor \frac{l}{R} \right\rfloor\right) + h \right) \\ & + 3 * \left(\left(1 + \left\lfloor 2 * \frac{l}{R} \right\rfloor\right) * \left(1 + \left\lfloor 2 * \frac{l}{R} \right\rfloor\right) + h \right) \\ & + 3 * \left(\left(1 + \left\lfloor 4 * \frac{l}{R} \right\rfloor\right) * \left(1 + \left\lfloor 4 * \frac{l}{R} \right\rfloor\right) + h \right) \end{aligned} \quad (18)$$

where l is the length of the square, R is the transmission range of the node, and h is the distance between the source and a square of and order square.

Therefore the average location update cost for a threshold distance d denoted by $C_u(d)$ is given by:

$$C_u(d) = p_d \; mi_{i,i+1} \; U \quad (19)$$

For query of a destination, the source node sends query message for destination information in the location servers starting from the 1st order square to 4th order square which is almost the same as the update cost U. Further, this cost includes the distance in terms of hop count h between location server and sub area 0, and the cost in sub areas 0, 1, 2, ...*d*.

The average destination query cost for a threshold distance d denoted by $C_Q(d)$ is given by:

$$C_Q(d) = \lambda \left(U + h + p_0 * Q_0 + \sum_{i=1}^{d} (p_i * Q) \right) \quad (20)$$

Therefore, the average total cost for a threshold distance d denoted by $C_T(d)$ is given by:

$$C_T(d) = C_U(d) + C_Q(d) \quad (21)$$

6. Analytical Results and Discussions

In this section, we present numerical results for home agent, quorum based, and GLS update schemes obtained by using some selected values for input parameters. In home agent update scheme, we have considered that the side of a square representing home region of a node is 264 meters [21]. Further, in quorum based update scheme, we have considered that the size of the update column is almost equal to that of the home region of the home agent update scheme. Further, the thickness of the column to be updated and the thickness of row to be searched are assumed equal. Also, for GLS update scheme, we have taken the side of the 1st order square to be equal to 250 meters.

6.1. Moving Probability

Here, we have studied the impact of varying moving probability of nodes in the network on the average total cost. We have considered four cases. First case includes one sub area, second includes three sub areas, third includes five sub areas, and the forth includes ten sub areas. In this case, we have considered the degree of the network k= 8, the number of nodes is n=200, the probability of query arrival λ=0.01, and varied the probability of moving between 0.0 and 0.5. Figures 12, 13, and 14 shows that as the probability of moving increases, the average total cost increases.

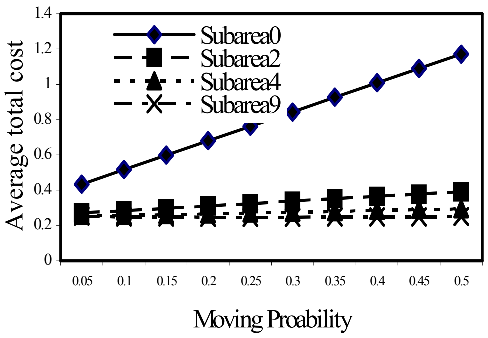

Figure 12. Probability of moving for home agent.

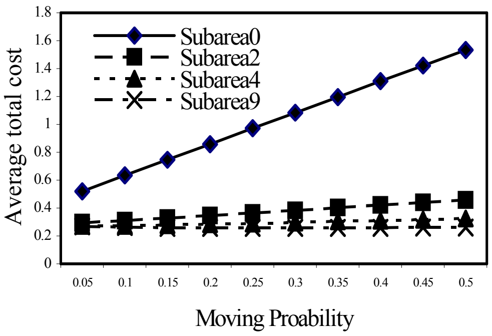

Figure 13. Probability of moving for quorum.

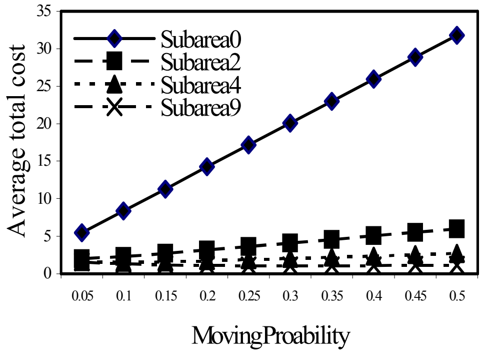

Figure 14. Probability of moving for GLS.

6.2. Query Arrival Probability

Here we have studied the impact of varying the probability of query arrival of nodes in the network on the average total cost. We have considered four cases, i.e. for one sub area, three sub areas, five sub areas, and ten sub areas. Here, the degree is kept at k=8, the number of nodes in the network n=200, the probability of moving q=0.1, and varied the probability of query arrival between 0 and 0.1. Figure 15, 16, and 17 shows as the probability of query arrival increases, the average total cost increases.

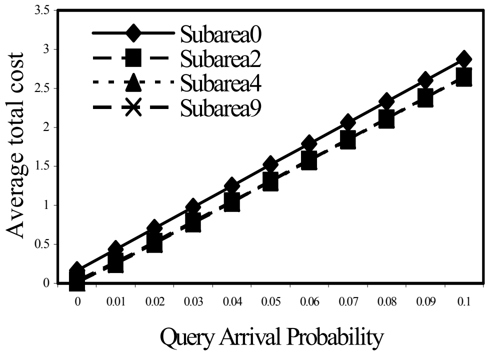

Figure 15. Probability of query arrival for home agent.

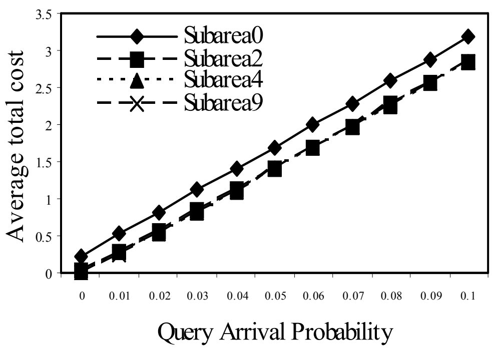

Figure 16. Probability of query arrival for quorum.

6.3. Degree of the Network

Here we have studied the impact of varying the degree of the network on the average total cost. Here, we have taken the probability of moving *q* =0.1, the query arrival probability λ=0.01, the number of nodes in the network *n*=200, and varied the degree of the network as 4, 6, 8, 10, … 20. Figures 18, 19, and 20 shows that as the degree increases, the average total cost decreases. It is clear that, the scheme with minimum threshold distance L_0 has maximum average total cost.

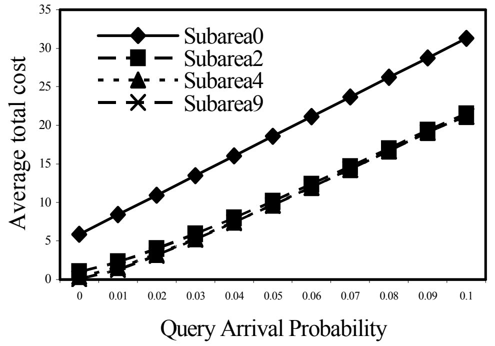

Figure 17. Probability of query arrival for GLS.

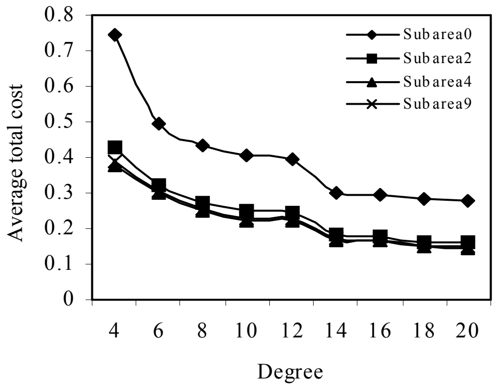

Figure 18. Degree of the network for home agent.

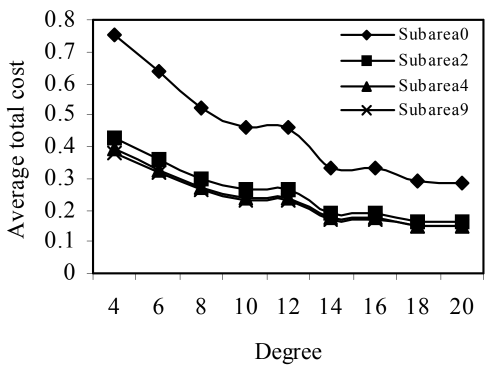

Figure 19. Degree of the network for quorum.

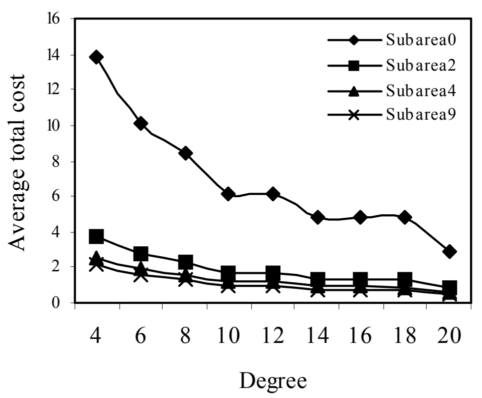

Figure 20. Degree of the network for GLS.

6.4. Number of Nodes of the Network

Here, we have studied the impact of varying the number of nodes of the network on the average total cost. We have fixed the transmission range of the network at 200 meters, the probability of moving q =0.1, the query arrival probability λ=0.01, the density of the network is kept constant at 0.0001 nodes per square meter, and vary the number of nodes in the network as 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000. Figure 21, 22, and 23 shows that as the number of nodes increases, the average total cost increases. It is clear that, the scheme with minimum threshold distance L_0 has maximum average total cost.

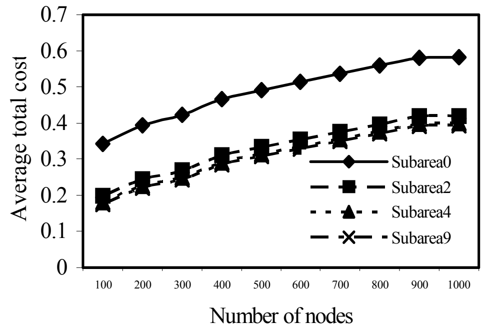

Figure 21. Number of nodes for home agent.

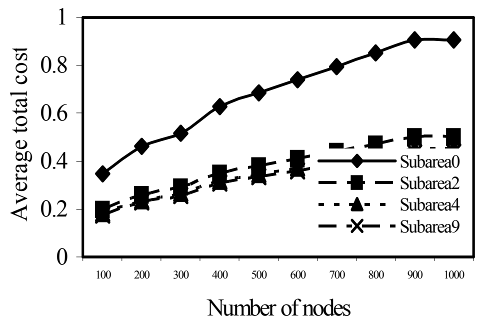

Figure 22. Number of nodes for quorum.

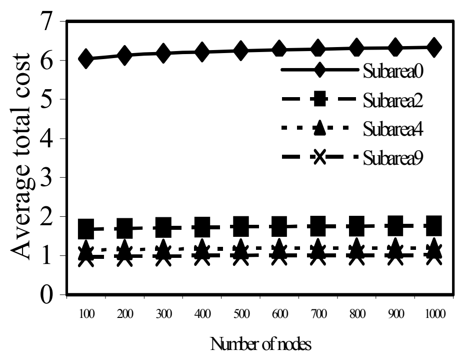

Figure 23. Number of nodes for GLS.

7. Comparison of Location Update Schemes

In this section, we have compared the location update schemes under investigation based on the analytical results for density based approach. This comparison is done for threshold distance L_0 corresponding to one sub area only in the network. Figure 24, shows the analytical results of home agent, quorum based and grid location service update schemes for density approach. It is clear that grid location service update scheme has the maximum average total cost and home agent update scheme has minimum average total cost.

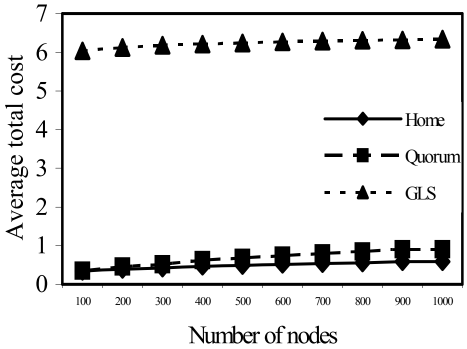

Figure 24. Analytical results for density.

8. Conclusion

In this paper, we have presented a Markov chain model developed to describe the behavior of mobility and query arrival patterns of mobile nodes in home agent, quorum based, and grid location service update schemes. We have used distance based triggering strategy to update location servers of a moving node. The average total cost is calculated for different threshold distances corresponding to sub areas in the network. The analytical results show that as the threshold distance increases, the average total cost decreases.

We have also compared the analytical results of home agent, quorum based and grid location service models for density approach. The Home agent location update scheme outperforms quorum based and grid location service update schemes.

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