

A Scalable Quorum Based Location Service in Ad Hoc and Sensor Networks

Dandan Liu¹, Ivan Stojmenović² and Xiaohua Jia³

¹Computer School, Wuhan University, Wuhan, China liudd2004@hotmail.com.

²SITE, University of Ottawa, Ottawa, Ontario K1N 6N5, Canada Ivan@site.uottawa.ca

³Dept. Comp. Sci., City Univ. Hong Kong, Kowloon, csjia@cityu.edu.hk.

Abstract—Location service provides position of mobile destination to source node to enable geo-routing. Previous location service protocols suffer from partial flooding overhead, and/or location failures in group movement scenarios. To overcome those deficiencies, we propose a quorum-based location service. The basic idea is that destination node registers its location along a ‘column’ to form an update quorum. Source node makes a query along a ‘row’ to form a search quorum. The destination location is found at the intersection between the update and search quorums. Four strategies are proposed to adjust the quorum system. To guarantee the success of location retrieval, both search and update quorums are extended by face routing which traverses outer network boundary.

I. INTRODUCTION

TRADITIONAL location service protocols (surveyed in [1]) deal with this service using flooding-based methods, which involves all nodes, located inside a region, in data accessing. The location of destination can be retrieved locally, but the communication complexity of a location update by each node scales with $O(n)$. Large amount of interchanges among n nodes will consume considerable energy and even cause many collision problems at MAC layer. The main goal of this paper is to describe a scalable localized location update scheme, by controlling the overhead of each routing task to $O(\sqrt{n})$. Another goal is to present a method that does not require nodes to remain in a fixed region, which is the case with other known methods. That is, the proposed method is applicable when all nodes move in more or less same direction (e.g. rescue team or soldiers). This feature is lacking in another scalable, home-agent and hashing based schemes (see [1] for references).

In this paper, we propose a scalable quorum-based location service based on a localized approach. It relies on multiple location servers replicated on several geographical positions to form a quorum. Nodes report their new positions to their neighbors whenever a link is broken or created. After certain number of such link changes, nodes forward their new position to all nodes located in its ‘column’, that is, to the north and south of their current location with

certain ‘thickness’ of reporting. The destination search then begins with two tickets being sent in the east and west direction, with certain ‘thickness’, looking for the most up to date information of destination’s position. When the tickets reach each end of current ‘row’, the search is continued toward best reported destination position, with corrections along the path as better information becomes available closer to destination. We also propose four strategies for the quorum construction to increase the success rate, and improve the energy efficiency. The intersection of ‘row’ and ‘column’ can be guaranteed by adding outer face of the ad hoc network to both of them. We describe a strategy based on face routing along perimeter of outer boundary of the network.

Literature review and performance evaluation sections are deleted because of space limitations, and can be found in the full version of this article at www.site.uottawa.ca/~ivan. We specify the location update and destination search in sections 2 and 3.

The preliminary version of this article appeared as technical report [2] in 1999. A summary of it was also given in [1]. In the meanwhile, the quorum based method [2] was cited in about two dozens articles, and applied to solve other problems. Other researchers also experimentally evaluated variants of it. Due to space limitations, details are given in the full version of this article. We also mention two independent rediscoveries of basic horizontal-vertical greedy quorum based method (without face routing part for guaranteed service) in 2002 [3] and in 2004 [4] in the context of efficient content location in location-aware ad hoc networks.

II. LOCATION UPDATE

We adopt the quorum-based idea to enable efficient routing in mobile ad hoc and sensor networks. The basic update procedure is performed by each moving node whenever it observes that, due to its movement, an existing edge will be broken (that is, the distance between two nodes becomes $>R$). Similarly, the same action may be taken in response to a message arriving from a new neighbor. The availability of geographic

position information enables nodes to estimate the connection time with other nodes [5]. It is defined as the estimated duration of a connection between two neighboring nodes. Neighboring nodes frequently update their location to each other, and this information may be used to estimate the direction and speed of their movements. Let A and B be the two neighboring nodes which move at speeds a and b , respectively. Here, A and B are position vectors while a and b are directional vectors. At time t , they move to new positions $A' = A + at$ and $B' = B + bt$. They lose their connection when the distance between them becomes $>R$, where R is the radius of corresponding unit graph. The time t when the connection will be lost can be estimated by solving quadratic equation $|A'B'| = |B - A + (b - a)t| = R$ [5]. Note that this adopted criterion allows nodes to move with same speed and

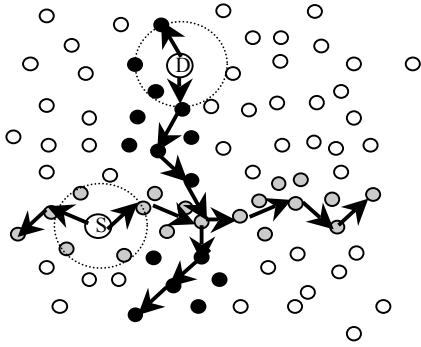


Fig. 1. Quorum construction.

in the same direction (e.g. a road) without generating any location update message.

In response to detected broken link, each node A will broadcast a message containing its new location information to all neighbors. Neighboring nodes will reply to newly detected neighbor. Note that nodes do not transmit their location in response to location update received from already existing neighbors.

The main location update method is to forward the new location information (and node's identifier) within a 'column' in the network, in the following way. Each node uses a counter to count the number of previously made changes in edge existence (the number of created or broken edges). When the counter reaches a fixed threshold value e , location information is forwarded along the 'column', and e is reset to 0. Node A that reaches threshold value will initiate location update within column as follows. A transmits update information to all its neighbors (within transmission radius R). The same message also includes location or ID of the northernmost neighbor B of A (and similarly southernmost neighbor C). The selected neighbor B retransmits the message

in the same fashion (but in the north direction only). This search continues until a node B has no neighbor that is more to the north than B . The initiator of location update A sends the update in both directions, while other nodes follow only one of directions. The main location update route, in north-south direction, is created in the process (Fig.1). It consists of all nodes on the route and all of their neighbors. This is referred to as the column with thickness $p=1$. Neighboring nodes may retransmit to enlarge the thickness to $p=2$. The process may continue until arbitrarily selected thickness p is reached.

The frequent problem is that the northernmost node as determined by the northward update may be only locally northernmost. A 'horizontal' destination search can miss such a node, which can remain 'below' it. To overcome this problem, each locally northernmost node may switch to *FACE* mode [6] until another node, more northern, is found on a face. Such nodes may return back to regular upward move. This switch can be repeated few times. The final result will be that all nodes at the outer face of the network will receive location update. This method guarantees that 'horizontal' destination search and 'vertical' location update will intersect at one of nodes on the outer face. The drawback is that these nodes will have more traffic demands.

Each node receiving new location information for A , by means of any of transmissions, will record it, together with date of update. Moreover, each node transmitting any kind of message will include its own location with the message, thus providing an update on its own position to its neighbors.

III. DESTINATION SEARCH

Destination search is performed in the following way. The source S broadcasts search request to neighbors that are located at most q hops away. If destination is $q+1$ hops away, it will be located. If there is no reply, the search continues in east-west direction, in similar way as for the location update. The search message includes time of last available information, and other nodes are requested to replace it with more up to date information, if they have.

When easternmost and westernmost nodes are reached, the search strategy changes. The message search is then oriented toward the destination, using latest available information for each search message. There are three searches initiated. The first one originates at sender node S , using the best information collected within neighbors at most q hops away. This search does not need to wait for the result

of searches in the east and west directions. Easternmost and westernmost nodes in a given ‘row’ initiate the other two searches. Each of three search tasks follows a path toward destination, using *greedy* strategy [7, 8], or *GFG* [6, 9] (to guaranty process continuation). That is, at each step, the neighbor closest to destination is selected to forward the message. Since all nodes within radius R can hear any of messages between two nodes, if any of them has better information about destination, it may respond, and the new information will take precedence over the former one in forwarding decision. Note that the location of source node is updated at each node that hears destination search or path creation messages.

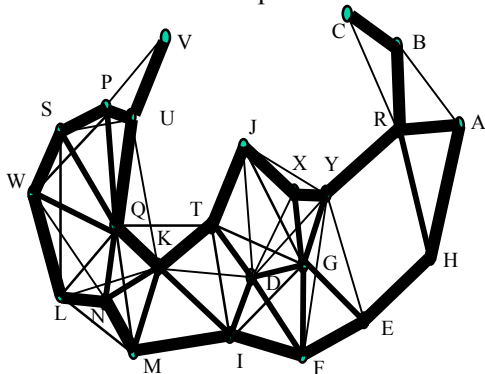


Fig. 2. ‘Row’ $SUV-SW$ and ‘column’ $DJ-DF$, and outer boundary in ‘heavy’ bold lines

We now illustrate the extension that guarantees the intersection of ‘row’ and ‘column’ in Fig. 2. The ‘Row’ $SUV-SW$ constructed by destination search from S , and ‘column’ $DJ-DF$, constructed by location update by D , do not intersect. They are constructed by applying the described greedy mode in east/west and north/south directions. This means that the constructed quorums are of insufficient size and do not meet general criteria for guarantying the intersection. However, the row/column end nodes V , W , J and F may switch to the boundary mode, and extend their search and update following GFG algorithm [6] with destinations set at infinity nodes in east, west, north, south directions. Node V applies face routing $VUQKT$ until reaching node T that is located east of V , meaning that the recovery was achieved and construction may continue in greedy mode. Note that recovery can be also called earlier, at node Q , since it has neighbor T that is to the east of V . From T , greedy routing continues eastward $TGEHA$ until reaching another local maximum in the east direction. Node A is not aware of its global east position until face routing along outer boundary, initiated at A , returns back to A . This means that nodes on the outer boundary (indicated by ‘heavy’

bold lines) are part of any quorum. Face routing uses edges of planar Gabriel graph, indicated by ‘normal’ bold lines. The plane is divided into faces. All but one of them is closed, and the only open face can be used as the resource for sharing the information.

Since F could be a local maximum, the location update should continue from it. Suppose that the outer boundary is followed in clockwise direction. Node F switches to the boundary node, and finds neighbor I (among all GG neighbors I , D , G , and E) with the smallest clockwise angle with respect to the south direction. The receiving node I similarly finds the neighbor with the smallest clockwise angle $\angle FIM$, with respect to incoming packet direction FI . Node M then forwards to neighbor N having the closest clockwise direction with respect to direction MI among GG neighbors of M (thus L is ignored). Finally, when packets arrive at node F again, the update operation terminates. This is because the following edge FI is the first edge of the outer face that will be reached twice. Therefore, the boundary follows $LWSPUVUQKTJXYRBCBRAHEF$ in Fig. 2.

The elegance of the proposed method is that it is adaptable to ‘surprises’ along the route. Consider, for example, the node J as the one switching to boundary mode. It forwards the packet to neighbor X with the closest direction with respect to the north direction. It is then forwarded to Y and R . Node R , however, is north of node J , and may switch back from the boundary mode to the greedy mode, then forward packet to C (all neighbors considered) etc. To enable recovery along the route, messages include the north/south/east/west-ernmost node ‘visited’ along the location update (and similarly destination search), and stop following outer boundary upon return to the same node. This then confirms that outer boundary was indeed followed. Note that the same method can be used to determining whether destination is disconnected from source. If they were disconnected then they would have distinct outer boundaries.

Both quorum constructions, one towards the east and one towards west, will continue traversing outer boundary. This implies almost doubling the communication overhead with respect to a version that will only follow quorum construction in the east direction. While searching for the easternmost node, the westernmost, northernmost and southernmost nodes may also be discovered.

The nodes on the outer boundary may be interpreted as a kind of location servers for the network. In fact, it suffices that only these nodes memorize the locations of all nodes from the

network. In order to identify the location server nodes, one more pass around outer boundary, upon visiting the northernmost node, is needed (between first and second encounter of the northernmost node, message will visit all boundary nodes). The overhead can be reduced if only one of destination search or location update follows the outer boundary, while the other stops when it reaches the first such node. In a reactive algorithm, location update messages should stop at the first recognized outer boundary node, without following the whole boundary.

Since nodes on the boundary may move and thus change their status, a mechanism is needed to transfer the location database to one of remaining outer boundary nodes. This can be achieved by transmitting location database upon moving out of boundary, with information being picked up by all neighboring nodes. The thickness of the boundary may also be increased to increase reliability.

Finally, the protocol needs also to handle node mobility between two location updates. The destination search will reach the area where node was located when it last initiated 'column' location update. Therefore moving node needs to maintain 'connection' with nodes remaining in that area. The best method may depend on the size e of 'breakage' counter. Reactive protocols being preferred, we suggest that the node closest to reported destination position initiates geocasting up to distance of e hops.

IV. VARIANTS OF QUORUM BASED LOCATION SERVICE

We consider here several variants of quorum based location service, for both greedy only and greedy-face-greedy quorum construction methods.

1) *Column for location update, row for destination search*: Node updates its current location along the column in north-south direction, using greedy routing. When other node searches the destination, it sends retrieve packet along the row in east-west direction by greedy routing.

2) *Both columns and rows are used for location updates and destination searches*: To increase the member of quorums, location update and destination search can be performed on both column and row, that is, in both north-south and east-west directions. There may be two sets of rendezvous between update and search quorums generally, increasing the probability of finding quorum intersections since greedy only routing is applied in their construction. We compare this variant with others in the experiments. Another option is to perform location update and search in two arbitrary but mutually

orthogonal directions. Moreover, they can be executed in four different lines, such as row, column, and two lines at angles $\pi/4$ between them, in order to produce more rendezvous between quorums.

3) *By applying GFG method, update and search packets are transmitted along north-south and east-west directions, respectively*: Quorums can be extended to reach the extreme points of network when GFG [6, 9] is triggered when packet forwarding stops at the local maximum. Face routing will increase communication overhead, because all the nodes located in the perimeter have to be involved. However such overhead is inevitable if we need to guarantee success in quorum based protocol.

4) *By applying GFG method, update and search packets are transmitted along north only and east only directions, respectively*: Since Face routing guarantees packets to traverse the outer perimeter of the network, we can further reduce communication overhead by performing update and search in only one direction. Specifically, location updates are going along north only direction and search packets are going along east only direction. Both are forwarded by GFG. The searches and updates are guaranteed to meet on the common outer boundary.

REFERENCES

- [1] I. Stojmenovic, "Location updates for efficient routing in wireless networks," in: *Handbook on Wireless Networks and Mobile Computing*, Wiley, 2002, 451-471.
- [2] I. Stojmenovic, "A scalable quorum based location update scheme for routing in ad hoc wireless networks," SITE, Univ. Ottawa, TR-99-09, September 1999.
- [3] I. Aydin, C.C. Shen, "Facilitating match making service in ad hoc and sensor networks using pseudo quorum," *IEEE ICCCN*, 2002.
- [4] J. B. Tchakarov and N.H. Vaidya, "Efficient content location in mobile ad hoc networks," *IEEE Int. Conf. on Mobile Data Management MDM*, 2004.
- [5] I. Stojmenovic, M. Russell, and B. Vukojevic, "Depth first search and location based localized routing and QoS routing in wireless networks," *IEEE Int. Conf. Parallel Proc.*, Aug. 2000, 173-180.
- [6] P. Bose, P. Morin, I. Stojmenovic and J. Urrutia, "Routing with guaranteed delivery in ad hoc wireless networks," *ACM DIALM 1999*, 48-55; *ACM/Kluwer Wireless Networks*, 7, 6, 2001, 609-616.
- [7] G.G. Finn, "Routing and addressing problems in large metropolitan-scale internetworks," ISI Research Report ISU/RR-87-180, March 1987.
- [8] I. Stojmenovic and X. Lin, "Loop-free hybrid single-path/flooding routing algorithms with guaranteed delivery for wireless networks," *IEEE Trans. Parallel Distrib. Systems*, 12, 10, 2001, 1023-1032.
- [9] H. Frey, I. Stojmenovic, "On guaranteed delivery of face and combined greedy and face routing in ad hoc and sensor networks," *ACM Mobicom* 2006.