LARP: A Novel Routing Protocol for the Bluetooth Scatternet

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***Abstract*— In this paper we design an efficient location aware routing protocol (LARP) for the Bluetooth scartternet. Taking advantages of the location information of all nodes, LARP reconstructs the routing path dynamically and minimizes the number of hops between the source and the destination of the scatternet. Besides, the paper also presents a hybrid routing protocol (HLARP), which minimizes the routing path for the scatternet, taking location information of some nodes. Experimental results show that both of our protocols are efficient enough to construct the shortest routing paths over a multi-hop scatternet and bandwidth and power consumption are least as compared to other routing protocols that we have considered.**

Key words: Bluetooth, scatternet, routing protocols, location-aware.

I. Introduction

Bluetooth [1] is a promising short-range, low-cost and low-power wireless technology to provide communication between the battery-operated portable radio devices like personal digital assistant, headsets and notebooks. As per the specification [1], a piconet consists of at most eight active devices, including one master and maximum up to seven active slaves. Each piconet utilizes the frequency hopping spread spectrum (FHSS) and its master monitors the scheduling of the data transmission with its slaves. Besides, several piconets can co-exist in a common area, and can be interconnected via some bridge nodes to form a bigger ad-hoc network known as the scatternet, in which each bridge employs different frequency hopping code-division multiple-access (FH-CDMA) channels to prevent mutual interferences. Many users-positioning solutions have been proposed in many contexts, but they are based on the specialized devices that are not supported by commercially available data terminals. Such location aware protocol [4], proposes how to establish a cooperative location network among the Bluetooth devices and intends to cover the two-dimensional target areas.

Since Bluetooth is a short-range communication technology, we feel that it is more applicable for indoor applications than the outdoor one. The typical example is the m-commerce scenario [5], in which customers walk around a large commercial area or shopping mall carrying wireless PDA and Bluetooth enabled wireless devices. In such scenarios, a customer is supposed to purchase items, request information, receive store coupons, and advertisements, in which shortest routing path and transmission delay are certain important issues for such mobile indoor applications. In order to minimize the number of hops between the source and the destination, we propose here a routing protocol that requires the location information of the devices. As described in [6], the Bluetooth Location Networks (BLN) transmit location information to the service servers without user participation and its basic technology is supported by the existing commercial handhold devices [7].

The main contributions of our work are summarized as follows:

- The paper proposes a routing protocol (LARP) to reduces the number of hops between the source and the destination.
- Describes a reduction and replacement rule that further tries to reduce the routing path.
- Proposes a hybrid routing protocol (HLARP) that generalizes LARP to reduce the hop counts.

The rest of the paper is organized as follows. Section II discusses the overview of the related works. The location aware routing protocol (LARP) is described in Section III and the hybrid location aware routing protocol (HLARP) is given in Section IV of the paper. Performance analysis of the protocol and its comparison with some standard routing methods are discussed in Section V. Finally conclusion is drawn in Section VI of the paper.

II. Overview of Related Works.

In our work, we consider here the routing vector method (RVM)[3] and the relay reduction and route construction protocol (LORP)[2], as they have special relation and implication to our proposed work.

A. Routing Vector Method (RVM)

In RVM, the source initiates the broadcasting of SEARCH packets to its neighbors that ultimately reaches to the destination. During the route search procedure, SEARCH packet accumulates the list of nodes along the route between the source and the destination. On receiving several SEARCH packets, destination device considers the first one and returns

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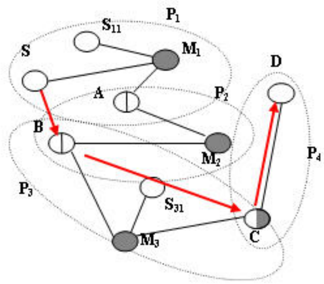

Fig. 1. Transmission of control packets and construction of routing paths.

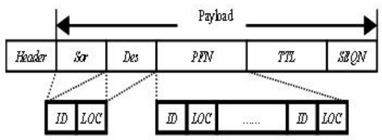

Fig. 2. Format of the Route Search Packet (RSP).

a unicast REPLY packet to the source, along the same path traversed during the searching process. An example of RVM is shown in Figure 1.

In Figure 1, let M_1, M_2, and M_3 are the masters for the piconets P_1, P_2, and P_3 respectively, whereas C is the master for the piconet P_4 and the bridge node for both the piconets P_3 and P_4. For piconets P_1 and P_2, node A and for piconets P_2 and P_3, node B are the bridge nodes respectively. If a packet is sent from the source S of piconet P_1 to the destination node D of the piconet P_4, according to RVM protocol, the final routing path is S$\longrightarrow M_1\longrightarrow$A$\longrightarrow M_2\longrightarrow$B$\longrightarrow M_3\longrightarrow$ C$\longrightarrow$D, which requires 7 hops to route the packet from the source to the destination. But, we feel that the routing path in RVM is longer due to more number of hops, thereby increasing the delay time and hence consume more power and network bandwidth.

B. Relay Reduction Routing Protocol (LORP)

An efficient protocol for the relay reduction and disjoint routes construction in Bluetooth scatternet [LORP] is proposed to improve the drawbacks in RVM. As per the LORP, the network topology can be adjusted dynamically by reducing the unnecessary relay nodes. In LORP, the routing path and hop counts are reduced considering the physical distance among the nodes and the disjoint routes for any pair of source and destination nodes, located in different piconets.

If RVM is applied to Figure 1, it is found that though nodes S and B are within each others communication range (10 meters), source S, routes the packets through M_1, A, M_2 and finally to B, by which number of hops between S and B are 4. As per LORP, the routing path should be S$\longrightarrow$B$\longrightarrow$C$\longrightarrow$D, so that the number of hops can be reduced to 3 instead of 7 hops as in RVM.

However in LORP, we still find some drawbacks such as the routing path from the source to destination is still not shortest and the bridge information stored in the route reply packet may not be possible to forward to other nodes, if they are out of the communication range. So it'll just be an overhead to the route reply packet thereby consuming more bandwidth.

III. LARP: The Location-Aware Routing Protocol

In this section, we consider a connected scatternet comprising N number of nodes, having very low mobility and are distributed in different piconets. We assume that each device knows its location information which is transmitted by the Bluetooth Location Networks (BLN) [6] to the service servers without user's participation. The source of one piconet that intends to communicate to a node of another piconet of the scatternet, must have knowledge about its ID but not its location information. We assume that each master has knowledge about its slaves ID, clock offset and location information which are obtained during the connection phase of the piconet. The 48-bit Bluetooth device address (BDADDR) is assigned as a node's ID in the scatternet. We introduce here some definitions and rules that have been frequently used in our protocols.

- Distance d(A, B): If A $(x_i,\ y_i)$ and B$(x_j,\ y_j)$ are the location of two different nodes A and B, either in the same or in different piconets, the distance between A and B is the Euclidean distance which is denoted as d(A, B) and defined as:

$$\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{1}$$

- Ideal Path (IP): If S $(x_1,\ y_1)$ and D $(x_2,\ y_2)$ are the locations of the source and the destination nodes respectively, equation of the straight line joining these two points is called the Ideal Path (IP) and is estimated as follows:

$$(y - y_1) = \frac{(y_2 - y_1)}{(x_2 - x_1)}(x - x_1) \tag{2}$$

- Deviation from Ideal Path (DIP): The distance of any node from the Ideal Path is called the deviation from the ideal path (DIP). If ax+by+c = 0, is the equation of the straight line connecting the source and the destination and A$(x_0,\ y_0)$ is the location of any node in the scatternet, deviation of the node from the ideal path is denoted as DIP(A,IP) and defined as:

$$DIP(A, IP) = \frac{|ax_0 + by_0 + c|}{\sqrt{a^2 + b^2}} \tag{3}$$

Our location aware routing protocol (LARP), comprises three different phases i.e. Route Search, Route Reply and Route Connection Phases, details of which are described as follows.

A. Route Search Phase

We describe here the different sub-phases of the route search phase.

- **A-1**. *Flooding:* To search the route between the source and the destination, a source node, first broadcasts the route search packet (RSP), format of which is shown in Figure 2. On receiving an RSP from the neighboring nodes, each node in the scatternet rebroadcasts the same

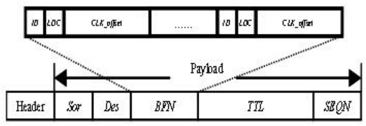

Fig. 3. Format of the Route Reply Packet (RRP).

packet and ultimately several RSP are flooded to the destination.

- **A-2**. *Appending:* The source node appends its ID and location information (LOC) to the payload field of the RSP. Also, the ID of the destination node is added to the respective field of the RSP and then forwarded to the master of the corresponding piconet. The master appends its LOC and ID to the possible forwarding node (PFN) field of the packet and forwards it to the relay node. From the location information given in the PFN field of the packet, the relay node estimates the communication ranges d (d=10 meters for the Bluetooth technology) between each node and itself. If d $>$ 10, it simply appends its own ID and LOC to the PFN field of the RSP and rebroadcasts the packet, else it removes the ID and LOC from the PFN field of all intermediate nodes that are falling within 10 meters, and then add its own ID and LOC to it and rebroadcasts the RSP. This process continues until the RSP is reached at the destination.

B. Route Reply Phase

On receiving several RSP packets, destination node gets the location information of the source and the intermediate nodes between the source and itself. Then the destination node calculates the equation of Ideal Path (IP) using equation 2 and starts broadcasting the route reply packet (RRP) to the next hop. The RRP has 4 different fields in the payload of the packet such as the source and the destination ID, PFN, IP, and the time to live (TTL) field and format of RRP is shown in Figure 3.

When a master node receives the RRP, it estimates the deviation of ideal path (DIP) from each of its slaves, using equation 3 and also verifies if a slave is within the communication range of its next hop bridge node. If so, it appends that slave's location information and clock offset to the PFN field of the RRP and forwards it to the bridge node. Else, it appends its own location information and clock offset to the PFN field and forwards the packet to the bridge. The bridge node simply forwards the RRP to the master of another piconet without any estimation. This process continues until the source node receives the RRP. On receiving the RRP, the source selects the shortest path between the destination and itself. The shortest path between the source and the destination is obtained from the reduction and replacement rule as described below.

1) Reduction by Replacement: As per this rule, the destination node first estimates the distance between the source and itself using equation 1, appends equation of IP in the control packet and then unicasts it to the next hop. On receiving

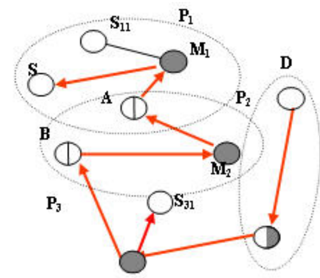

Fig. 4. Route Reply Phase based on reduction and replacement rule.

the control packet, the node simply forwards it to the next hop along the same path of the route search phase, if it is a bridge node. If the node is a master, it estimates the DIP for each of its slaves. If it finds that any of its slave has least DIP value, it replaces that slave node's LOC, ID and clock offset to the control packet and forwards it to the next hop. This process continues until the source node receives it. On receiving the control packet, source node selects the final shortest connecting path between the destination and itself. For example, in Figure 4, D is the destination node and it forwards the RRP packet to the master/slave bridge node C. Then C simply adds its own location and clock offset to the PFN field of the packet and forwards it to M_3. Master M_3 knows its slave's location information and scans the equation of IP from the RRP and then estimates the DIP value for its slave S_{31}, backward bridge node C and next hop bridge node B that is along the packet forwarding direction. As shown in Figure 4, since node B has the least DIP value as compared to other nodes such as S_{31}, C, and master M_3, master M_3 deletes node C's information and appends node B's location and clock offset to the PFN field of the RRP and forwards it to the bridge node B. Bridge node B simply forwards that RRP to the next master M_2 as it is a relay node. Now master M_2 estimates the DIP value for its slave nodes A and B and its own. Since node A is having the least DIP value (as evident from Figure 4), master M_2 appends A's location and clock offset in place of B and forwards the RRP to the bridge node A. Then bridge node A simply forwards the RRP to the master M_1. Finally master M_1 estimates the DIP value of its slave A, S_{11} and S. Since S is the source node, it is excluded from the estimation and M_1 confirms that A is the closest node to the equation of IP. So, in the RRP, it forwards its location and clock offset to the source node S. As soon as, source node receives the RRP, it goes to page state and tries to synchronize with M_1. As shown in Figure 5, the numbers of hops such as D$\longrightarrow$C, C$\longrightarrow M_3$, $M_3\longrightarrow$B, B$\longrightarrow M_2$, $M_2\longrightarrow$A, A$\longrightarrow M_1$, $M_1\longrightarrow$S are reduced to S$\longrightarrow M_1$ and $M_1\longrightarrow$D, where only one node M_1 is replaced instead of several intermediate nodes. Based on our protocol, construction of final routing path is described in the next phase.

C. Route Connection Phase

In this phase, the source node selects the most suitable connected path between the source and the destination. The

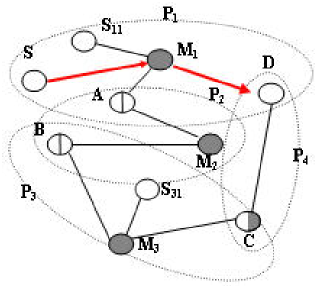

Fig. 5. Construction of route in LARP.

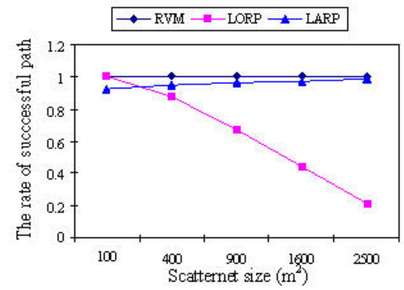

Fig. 6. Rate of finding successful paths for different scatternet sizes.

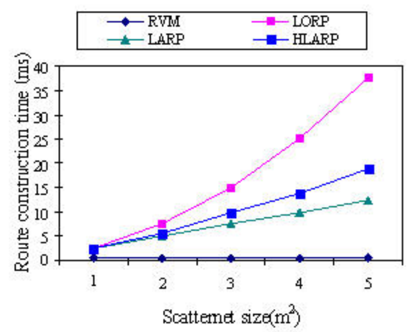

Fig. 7. Route construction time for different scatternet sizes

source node S goes to page state and node M_1 changes to page scan state and becomes the slave of node S. Latter, M_1 goes to page state and node D goes to page scan state. So M_1 becomes the master for node D and slave for node S. Thus a new connected scatternet is formed taking nodes S, D and the master/slave bridge node M_1, where the number of hops are reduced to 2 as shown in Figure 5. It is to be noted that, our protocol can be explained in any type of scatternet configurations and we demand that the number of hops in our protocol is least as compared to LORP [2] and RVM [3].

IV. HLARP: Hybrid Location Aware Routing Protocol

The dynamic relay reduction protocol (LORP) [2], does not require location information of any node to construct the routing path. We combine here both LORP and LARP, and present the hybrid location aware routing protocol (HLARP), in which some nodes of the scatternet mayn't have location information. Similar to LARP, this protocol is divided into three phases such as route search, route reply and route construction phases as in LARP and the procedures in each phase are also same in HLARP. However, in route search phase, the nodes without having location information simply append their ID and forwards the RSP to the next hop without estimating anything. Finally, the source node estimates the distance between the nodes having the location information as given in the PFN field of the route reply packet. It ignores the nodes without having location information and construct the final route with the destination as described in the construction phase of the LARP. In HLARP, it is proposed that for any scatternet, least number of hops can be achieved between the source and the destination, even if some devices don't have any location information. To save space, the figure and detail description of the protocol is not described here.

V. Simulation Results and Comparison

In this section, we present the simulation model that is used for the performance evaluation of our protocol and to compare our results with similar protocols like RVM [3] and LORP [2]. In our model, a connected scatternet is formed with different scatternet size that randomly ranges from 100 m^2 to 2500 m^2 with fixed number of 100 nodes present in it. The control packets are sent from one node of the scatternet to other irrespective of its location in any piconet and all possible successful paths between the source and the destination are considered in the simulation.

Figure 6 shows the rate of finding successful path between the source and the destination for various sizes of the scatternet. It is observed that our protocol gives similar result with the RVM for larger scatternet size where as it outperforms the LORP. From Figure 7, it is observed that the route construction time of our protocol is less than that of the LORP. Also, our Hybrid LARP shows better improvements to the route construction timing over LORP. In Figure 8, we have compared the routing path length for different protocols which is defined here as the distance from the source to the destination. We have simulated it for different scatternet size. It is found that both of our protocols, LARP and HLARP outperforms both

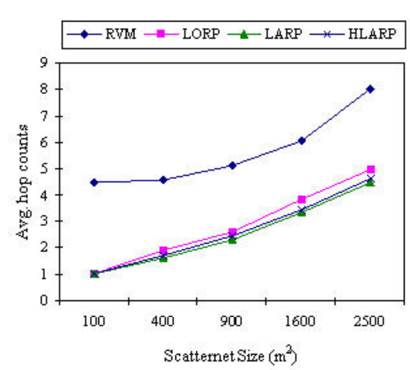

Fig. 8. Average number of hop counts for different scatternet sizes

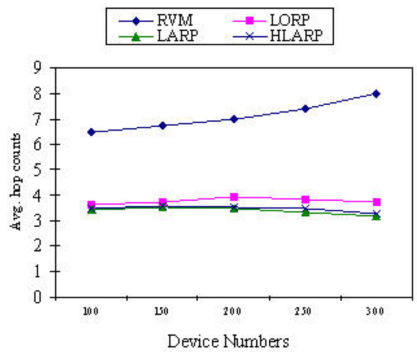

Fig. 9. Average number of hop counts for different number of devices

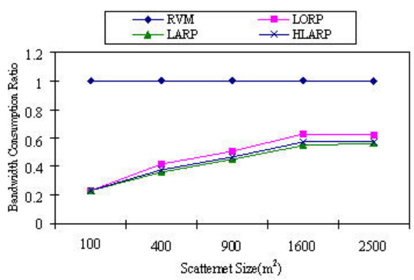

Fig. 10. Bandwidth consumption for different scatternet sizes.

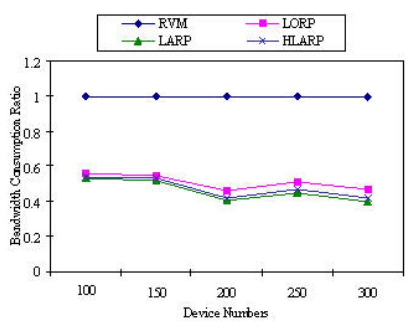

Fig. 11. Bandwidth consumption for different number of devices.

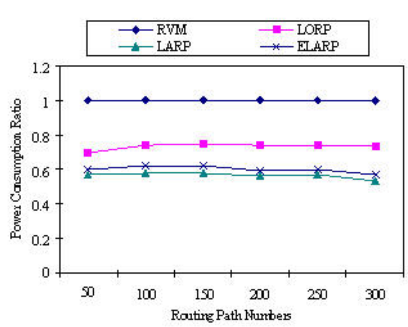

Fig. 12. Ratio of power consumption for different number of routing paths.

RVM and LORP. In LARP or HLARP, the packet transmission is quicker as average routing length is very less. Once the route is constructed, our protocol shows very good result for speed packet delivery, thereby increasing the end-to-end packet delivery throughput. As shown in Figure 9, it is observed that the average routing length of our protopol is better than the LORP and RVM for different number of nodes, either for different scatternet size or for different node numbers. In our simulation, it is also analyzed to know and compare the required number of control packets that are used to construct the routing in RVM, LORP, LARP and HLARP. Accordingly, we have simulated the ratio of the bandwidth consumption in the above protocols for different scatternet size. The simulation result as represented in Figure 10, indicates that LARP, and HLARP consumes less bandwidth in comparison to the RVM and LORP. Similar results of bandwidth consumption for different number of nodes are presented in Figure 11. The bandwidth consumption of our protocols is better than RVM and LORP irrespective of quantity of devices. Finally, in Figure 12, we have analyzed the power consumption of our protocol with RVM and LORP for different number of routing paths. The results show that both of our protocols consumes least power as compared to LORP and RVM. Since, power consumption is an important issue for the Bluetooth devices, our protocol is the best among other routing schemes in saving power.

VI. Conclusion

In this paper, we propose a location aware routing protocol to reduce the number of hops of a connected scatternet and reconstruct it to facilitate the hop reduction. Besides, we extend our protocol to Hybrid LARP by considering a mixed number of nodes with or without location information. Our algorithms for both LARP and HLARP contribute the shortest routing path as compared to the RVM and LORP. So our protocols are the best of its kind and are applicable to the low mobility Bluetooth devices used in big shopping malls, supermarkets and specifically in mobile e-commerce scenarios where people walk with the handhold wireless devices and frequently access information.

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