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A Location-Aware Routing Protocol for the Bluetooth Scatternet

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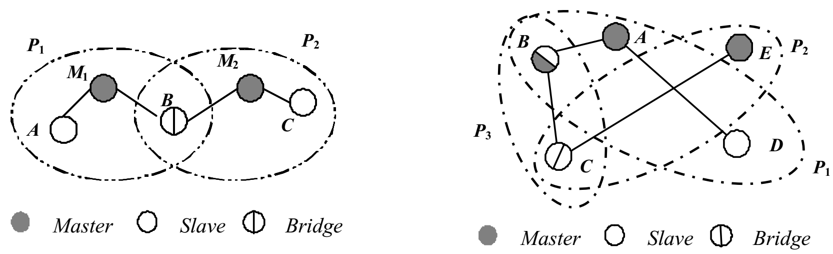
Abstract. Bluetooth is a most promising technology for the wireless personal area networks and its specification describes how to build a piconet. Though the construction of scatternet from the piconets is left out in the specification, some of the existing solutions discuss the scatternet formation issues and routing schemes. Routing in a scatternet, that has more number of hops and relay nodes increases the difficulties of scheduling and consumes the bandwidth and power resources and thereby impacts on the performance of the entire network. In this paper, a novel routing protocol (LARP) for the Bluetooth scatternet is proposed, which reduces the hop counts between the source and the destination and reconstructs the routes dynamically using the location information of the Bluetooth devices. Besides, a hybrid location-aware routing protocol (HLARP) is proposed to construct the shortest routes among the devices with or without having the location information and degenerate the routing schemes without having any location information. Experimental results show that our protocols are efficient enough to construct the shortest routing paths and to minimize the transmission delay, bandwidth and power consumption as compared to the other protocols that we have considered.

Keywords: Bluetooth, routing, scatternet

1. Introduction

Bluetooth [1] is a low-cost, low-power; short-range communication technology for the battery-operated portable radio devices like personal digital assistant, headsets and notebooks. It operates in the unlicensed 2.4 GHz ISM band and supports both connection-oriented and connectionless links to communicate both voice and data among the devices typically located in the range of 10 m. It is developed to replace the inter-connection cables, and provides a cost effective environment for the personal area communications. As per the specification, a piconet consists of at most eight active devices, including one master and maximum up to seven active slaves. Both the master and the slaves hop over 79 channels with a speed of 1600/sec, and the time-division duplex is employed for the sequential medium access. The master monitors the scheduling of the data transmission with its slaves and each piconet utilizes the frequency hopping spread spectrum (FHSS) techniques. Different piconets employ different frequency hopping code-division multiple-access (FH-CDMA) channels to prevent mutual interferences. So, multiple piconets can co-exist in a common area and each piconet can also be interconnected via some relay nodes to form a bigger ad-hoc network known as the scatternet. The relay node which is also referred to as bridge node can be a master in one piconet and slave in another or bridge between two or more piconets as shown in Figure 1. In Figure 1(a), nodes A and C are pure slaves, and M_1 and M_2 are masters in P_1 and P_2 respectively. Node B plays the role of slave/slave bridge node for both the piconets. Figure 1(b) illustrates another example in which



(a) Scatternet with pure slaves and bridge nodes.

(b) Scatternet with master/slave and slave/slave bridge nodes.

Figure 1. Various configurations of master, slave and bridge nodes in Bluetooth scatternet.

node A is the master and node D is slave in P_1. Node B is a master/slave bridge and node C is a slave/slave bridge. Node C is slave for both the piconets P_2 and P_3 whereas node E is the master for the piconet P_2.

The performance of the connected scatternet is highly relied on the number of bridge nodes. For example, scatternet that contains a large number of bridge nodes will be benefited from the advantages, including low probability of disconnection, short routing path and fast flooding, but will suffer from the drawbacks including consumption of active member address, creating a large amount of packets in flooding and difficulties of synchronization among the piconets. Besides, a higher degree of relay enables to switch frequently among the participated piconets, increasing difficulties of scheduling and the packet loss probability. Since Bluetooth scatternet is considered as a special type of ad-hoc network, the routing protocols for Bluetooth can be categorized into two types, such as: table driven and on-demand routing protocols. In the table driven routing protocols [3], each node actively maintains a routing table irrespective of message to send or not. The main disadvantage of such protocol is the maintenance overhead of the routing table at each node of the scatternet. Also the table driven protocol may require more memory, as the size of the routing table is proportional to the size of the network. In case of the on-demand routing protocols [4–6], a node first floods a query message to learn the route to the destination before it can send a message. Some drawbacks in on-demand routing protocols are due to the delay incurred by the query phase and flooding of the query signals. A blue-tree scatternet formation algorithm [7] is proposed to build a self routing scatternet to minimize the routing overhead. But it does not mention how to construct the scatternet if nodes are not within the proximity of each other. Moreover, the number of hops between the source and the destination of blue-tree based scatternet are more, which incur more delay time to dispatch the packets.

The link formation time of current Bluetooth specification is too long for mobile devices. So a dynamic source routing scheme [8] in Bluetooth scatternet is proposed. In this scheme, source device delivers page request packet to find the destination and the destination node appoints each node either as a master or as slaves and sends the page reply packets through these nodes on receiving the request packet. Other than this routing scheme, the location-aware mobile network is an important research issue in Bluetooth technology. 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 [9–12]. Such location aware protocol [13] 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 its indoor applications are more than the outdoor one. The typical example is the m-commerce scenario [14, 15], 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 and also receive store coupons and advertisements. As described in [16], the Bluetooth Location Networks (BLN) transmits location information to the service servers without user participation and its base technology is supported by the existing commercial handhelds [17]. However, the shortest routing length, shortest transmission delay, low bandwidth and power consumption are important issues for such small sized devices. So, in this paper we propose a location aware routing protocol [LARP] that minimizes the number of hop counts, thereby minimizes the wastage of bandwidth and power consumption, and improves the end-to-end packet delivery delay.

The rest of the paper is organized as follows. Section 2 discusses the overview of the related work. The location aware routing protocol (LARP) including the network model of the protocol is described in Section 3. An extended form of LARP, i.e. the hybrid location aware protocol (HLARP) is given in Section 4. Performance analyses of both protocols and their comparison with some standard routing methods are discussed in Section 5. Concluding remarks is drawn in Section 6 of the paper.

2. Overview of Related Works

In this section, we discuss some related works that motivate us to propose some new ideas for the routing. Though several works have been proposed on Bluetooth routing protocols, we consider here only the routing vector method (RVM) [4] and the relay reduction and route construction (LORP) protocol [2] for our discussion as they have special relation to our work.

2.1. Routing Vector Method (RVM)

The RVM proposes a routing scheme for encoding source routing paths in the scatternet. The paper proposes protocols for discovering the new routes and the packets forwarding methods. According to RVM routing algorithm, the source initiates a broadcast of SEARCH packets which accumulate the list of nodes that represent the route from the source to the destination. Ultimately, several broadcast packets reach at the destination, and the destination device considers the first SEARCH packet during the search process and returns a unicast REPLY packet to the source, along the same path. An example of Routing Vector Method is shown in Figure 2.

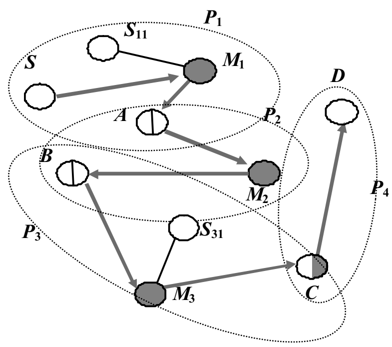


Figure 2. Transmission of control packet and routing path in RVM Protocol.

As shown in Figure 2, let M_1, M_2, and M_3 are the master nodes for the piconets P_1, P_2, and P_3 respectively. Node C is the master for the piconet P_4 as well as a bridge between P_3 and P_4. Node A is the bridge node between piconets P_1 and P_2; B is the bridge node between P_2 and P_3. Suppose 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 $S \to M_1 \to A \to M_2 \to B \to M_3 \to C \to D$, 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.

2.2. 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, reduction of hop counts are based on the physical distance among the nodes located in different piconets. In RVM, as shown in Figure 2, $S \to M_1 \to A \to M_2 \to B \to M_3 \to C \to D$ is the routing path between the source and the destination. Though the nodes S and B are within the communication range (typically 10 m), the source S, still routes the packets through M_1, A, M_2 and finally to B, in which number of hops between S and B are 4. According to LORP, since S and B are within the communication range of each other, the packet can be routed through S, B, C and D, by which number of hops can be reduced to 3 as compared to 7 hops in RVM. The short explanation of LORP is described through Figure 3 and the improvements in LORP over the RVM can be summarized as follows: (i). it provides a route reduction protocol. (ii). it maintains the bridge record information in the route reply packet. (iii). source device pages the farthest bridge of the scatternet that is within its communication range and constructs the piconet. But we still find some drawbacks in LORP, such as routing length is still not shortest and the bridge information stored in route reply packet may not be possible to pass to other nodes, if they are out of the communication range. So it may be just an overhead to the route reply packet thereby consuming more bandwidth.

In this paper, we propose a route reduction protocol, which requires the location information of the nodes, and still reduces the number of hops as compared to RVM, and LORP. As shown in the Figure 4, the numbers of hops are reduced to 2 instead of 3 as in LORP and 7 as in RVM. The details of our protocols are described as follows.

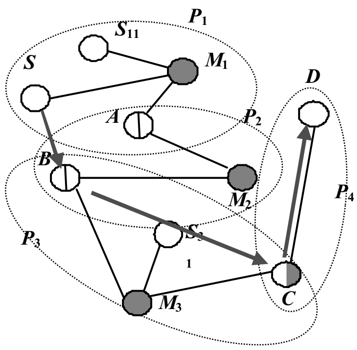


Figure 3. Transmission of control packet and routing path in LORP.

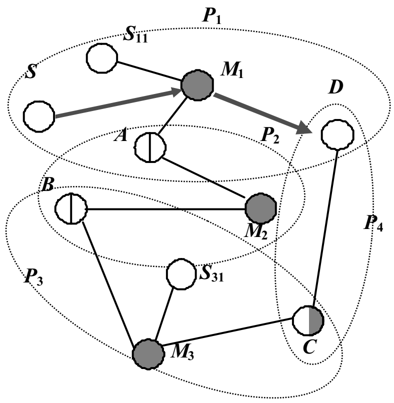


Figure 4. Final routing path constructed in LARP.

3. The Location-Aware Routing Protocol (LARP)

Before proceeding to our location aware routing protocol, we describe first the network model of our protocol, which provides few definitions and rules those are frequently used in our protocol.

3.1. Network Model

Consider a connected scatternet comprising *N* number of nodes distributed in different piconets over the 2-D plane having low mobility. We assume that each device of the scatternet knows its location information from the service servers, which gets location information from the Bluetooth Location Networks [16]. Each node in the scatternet is identified by its 48-bit Bluetooth device address (BD_ADDR) and it is known as the ID of the node. The source node of one piconet intends to communicate with the destination node of another one of the scatternet, whose ID is known and location is unknown. It is assumed that each master has knowledge about its slave's ID, clock offset and location information, during the connection phase of the piconet. Subsequently, the intermediate nodes get location information of its neighbors, when a control packet is routed from the source to the destination.

3.1.1. *Definition 1: Location (LOC (A))*

Location of any Bluetooth device *A* is its position in the scatternet which is expressed in Cartesian co-ordinate *A(x, y)*. We assume that Bluetooth Location Networks (BLN) [16] transmit location information to the service servers without user's participation by which nodes can get location information.

3.1.2. *Definition 2: 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* in the scatternet, either in the same or in different piconets, the distance between *A* and *B* is the Euclidean distance of *AB*, which is denoted as *d*(*A,B*) and defined as

$$\overline{AB} = d = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad \text{for } i \neq j.$$

Table 1. Intra nodes communication range table for the nodes present in the piconet P_3 of Figure 2

	B	M_3	S_{31}	C
B	Null	1	1	0
M_3	1	Null	1	1
S_{31}	1	1	Null	1
C	0	1	1	Null

Table 2. Slave Information table for the scatternet given in Figure 2

Master	Slaves list
M_1	A, S, S_{11}
M_2	A, B
M_3	B, C, S_{31}
C	D

3.1.3. *Definition 3: Possible Forwarding Node set (PFN)*

The set of intermediate nodes between the source and the destination, through which a control packet is forwarded during the route search phase as described in Section 3.2.1, is called possible forwarding node set (PFN).

3.1.4. *Definition 4: Determined Forwarding Node set (DFN)*

The set of intermediate nodes between the source and the destination, through which a control packet is forwarded during the route reply phase as described in Section 3.2.2, is called determined forwarding node set (DFN).

3.1.5. *Definition 5: Intra Node Communication Range Table (CRT)*

The intra node communication range table (CRT), indicates whether a node in the piconet is within the communication range of another node of the same piconet or not. If a node is within the communication range of another one, the entry in the Table 1, else the entry is 0, where as the entry is Null, if both nodes are identical.

In our protocol, we assume that master of the piconet maintains this table from their location information, in the construction phase of the piconet. The entries of this table is updated time to time, if, any node is dead due to scarcity of battery energy or due to addition of a new node to the piconet.

3.1.6. *Definition 6: Slave Information Table (SIT)*

Each master maintains a table with the list of connected slaves of its piconet, which is known as Slave Information Table (SIT).

As shown in Table 2, each master maintains its slave's list and updates time to time for any new addition or deletion of slaves to the piconet. Whenever a node is connected to the master of any piconet, it supplies its location information, ID and its clock offset in the FHS packet during the connection phase so that, the master gets knowledge about its slave's ID as well as location information (LOC).

3.1.7. *Definition 7: Equation of Ideal Path (EIP)*
If $S(x_1, y_1)$ and $D(x_2, y_2)$ are the locations of the source and the destination nodes respectively, the equation of the straight line joining these two points is denoted as equation of ideal path (EIP) and defined as:

$$(y - y_1) = \left(\frac{y_2 - y_1}{x_2 - x_1}\right)(x - x_1)$$

3.1.8. *Definition 8: Deviation from Ideal Path (DIP)*
The shortest distance between the locations of a node from the EIP is called the Deviation from 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, then deviation of the node from the ideal path (L) is denoted as DIP(A,L) and defined as:

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

3.2. The Protocol

In this section of the paper, the location aware routing protocol (LARP) is proposed taking ID and location information of the nodes. The protocol comprises three different phases like Route Search, Reply and the Connection Phase, details of which are described as follows.

3.2.1. *Route Search Phase*
In this phase, a source node searches the route to transmit a packet to the destination node, whose ID is known but location is unknown. Initially, it forwards a Route Search Packet (RSP) to its master with its own ID and location in the PFN field of the packet. The format of the RSP is shown in Figure 5, which is similar to the Bluetooth baseband packet, where its payload field initially contains the location (LOC), and ID of the source, and only ID of the destination. The LOC and ID of all intermediate nodes between the source and the destination are appended to the PFN field of the packet, when it is forwarded from one node to other. The time to live (TTL) field in PFN indicates the life of the RSP, and the packet is invalid beyond that duration. Each packet contains a sequence number in the SEQN field of the RSP to maintain the packet uniqueness. The route search phase is based on two different sub phases.

3.2.1.1. *Flooding.* On receiving an RSP from the source node, the master of a piconet forwards the same packet to all of its bridge nodes, by appending its own ID and location information to the respective PFN field of the packet. Then each bridge node forwards the packet to their master by appending their own ID and location to the PFN field of the RSP. Ultimately several RSP are flooded at the destination, through different routes from the source node.

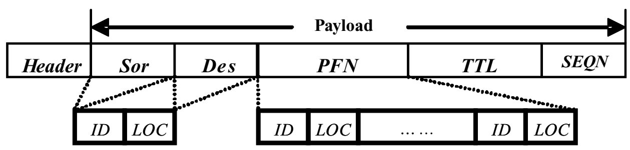


Figure 5. Format of the Route Search Packet.

3.2.1.2. *Appending and Replacement.* This rule describes when to append and replace node's information to the PFN field of the RSP, while it hops from one node to other. At the beginning of the route search phase, the ID of both source and the destination and LOC of only source are put in the route search packet and the RSP is forwarded to the master of the source node and later to its bridge nodes. From the location information given in the PFN field of the packet, each bridge node estimates their communication range d with the nodes present in the PFN field and itself. If $d > 10$ (which is generally the maximum transmission range for Bluetooth devices), the bridge node simply appends its own ID and LOC, else the ID and LOC of all the previous intermediate nodes are replaced by its own ID and LOC to the PFN field of the RSP, which is then forwarded to its master. This replacement is done, so that the new device may construct the one-hop link with the node, present in the PFN field. This process continues until the RSP is reached at the destination. Various steps of the route search phase is given in Algorithm 1 and diagrammatically represented in Figure 6. As shown in Figure 6, when node B receives the RSP from master M_2, it checks the location information of other nodes recorded in the PFN field of the RSP and finds that it can directly construct a link with source node. Therefore, the ID and location information of nodes M_2 and A are replaced by the ID and location information of node B. The format of RSP by different senders of Figure 6, during route search phase is shown in Figure 7.

Algorithm.1: Appending and reduction RSP (Source, Destination)

Source: Appends ID and LOC to RSP and forwards the RSP
On receiving the RSP packet:
Do
{Master/Relay/Slave:Scans the RSP and verifies if any node presents between the source and itself
if (any node present)
  Master/Relay/Slave: Calculates its distance (*d*) from the source node. if ($d > 10$)
  {Master/Relay/Slave ← Appends its own ID and LOC and forwards the RSP}
  else
{Master/Relay/Slave ← Deletes the ID and LOC of all the previous nodes and forwards the RSP}
}
else
  {Master/Relay/Slave: Appends its own ID and LOC, broadcasts the RSP}
} **while (Master/Relay/Slave ! = Destination);**

3.2.2. *Route Reply Phase*

On receiving the RSP through several routes, this phase is initiated by the destination node. From the RSP, destination node gets the location information of the source and all intermediate nodes between the source and itself. So the destination node forwards the Route Reply Packet (RRP) to the next hop master/bridge node, format of which is shown in Figure 8. The RRP has six different sub-fields in the payload field of the packet such as the source and destination ID, Determined Forwarding Node Set (DFN), equation of ideal path (EIP), time to live (TTL), and sequence (SEQN) field.

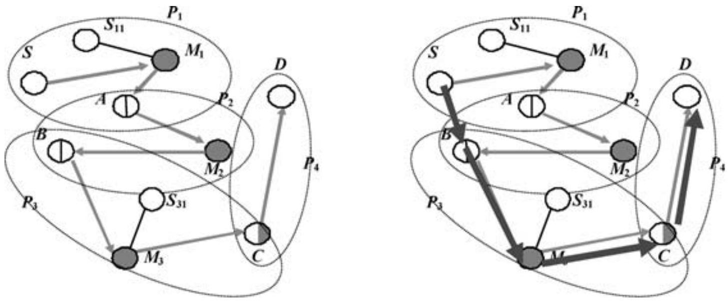


Figure 6. *(a)* Path along which RSP is forwarded. (b) Path due to appending and reduction rule.

Sender	Corresponding RSP									
S	*S.ID*	*S.LOC*	*D.ID*	*DLOC* (Null)						
M_1	*S.ID*	*S.LOC*	M_1*.ID*	M_1*.LOC*	*D.ID*	*D.LOC* (Null)				
A	*S.ID*	*S.LOC*	*A.ID*	*A.LOC*	*D.ID*	*D.LOC* (Null)				
M_2	*S.ID*	*S.LOC*	*A.ID*	*A.LOC*	M_2*.ID*	M_2*.LOC*	*D.ID*	*D.LOC* (Null)		
B	*S.ID*	*S.LOC*	*B.ID*	*B.LOC*	*D.ID*	*D.LOC* (Null)				
M_3	*S.ID*	*S.LOC*	*B.ID*	*B.LOC*	M_3*.ID*	M_3*.LOC*	*D.ID*	*D.LOC* (Null)		
C	*S.ID*	*S.LOC*	*B.ID*	*B.LOC*	M_3*.ID*	M_3*.LOC*	*C.ID*	*C.LOC*	*D.ID*	*D.LOC* (Null)
D	Receives the RSP									

Figure 7. Format of the route search packet sent by different nodes present in the scatternet.

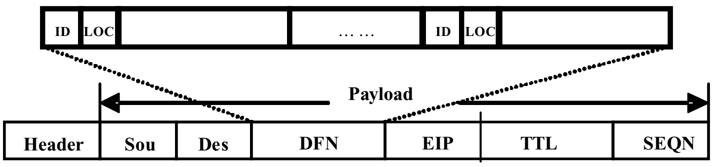
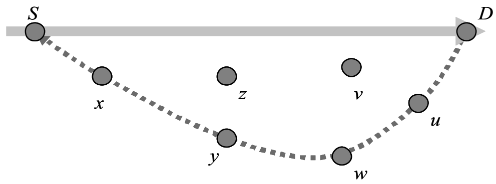


Figure 8. Format of the route reply packet.

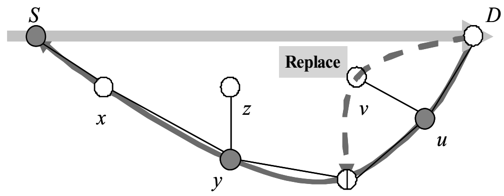
It is to be noted that as soon as the destination node receives the RSP, it considers the only packet with least hop counts from the ID of the nodes present in the RSP. Then it copies and reverses the order of ID and LOC pairs in PFN field of the RSP to the corresponding DFN field of the RRP. In this phase, destination node becomes the source and source as the destination and the RRP is routed along the same path as created during the route search phase. The final shortest path between the source and the destination is obtained from the reduction and replacement rule as described below.

3.2.2.1. *Reduction and Replacement Rule.* It is to be noted that each master knows its slave's location and ID. In this rule we assume that the route search path as described in Section 3.2.1.1 has already been created and this rule is used to reduce the route search path by replacing some new nodes, which is described by the following few steps.

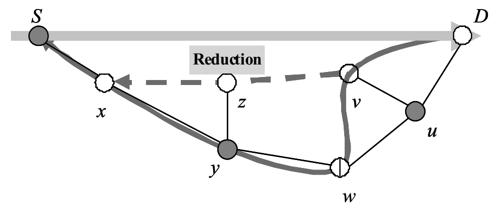
- Destination node calculates the distance between the source and the destination, appends the EIP in the RRP and forwards it to the next hop which ultimately reaches to the source.



(a) The expected route reply path along *D-u-w-y-x-S*.



(b) Applying the replacement rule in route reply phase by replacing the node *u* with *v*.



(c) Applying the reduction rule in route reply phase.

Figure 9. Example of applying reduction and replacement rule in route reply phase.

- On receiving the RRP, the bridge node, simply forwards it to the next master node along the routing path. The master node checks the following rules:
  (a) *Replacement Rule*: The master node calculates the DIP for each of its slaves, using the formula given in definition 8 of Section 3.1. If it finds that any of its slaves has minimum DIP value, master checks the CRT table to verify if that slave is within communication range of its previous bridge node from which it has received the packet and also with the next hop bridge node to which it has to forward the RRP. If so, the master stores LOC and ID information of that slave in DFN field of RRP, in stead of its own information and forwards the RRP packet to the next hop.

  Figure 9(b) illustrates the Replacement rule applied on the expected path: *D-u-w-y-x-S* as shown in Figure 9(a). As master *u* receives RRP, it estimates that neighbor *v* has the least DIP and confirms from its CRT that node *v* is within the communication range of nodes w and D. Therefore, node u stores the LOC and ID information of v in the DFN field, rather than its own information, and then forwards the RRP to the next hop.

  (b) *Reduction Rule*: The master node checks the path connectivity to reduce the number of hops. If the master or any of its node say *N*, has least DIP, then it verifies if that node *N* can communicate with any two nodes, say d_i and d_j in DFN $= \{d_1 \ldots, d_i, \ldots, d_j, \ldots, d_m\}$ or the destination node where d_i is the nodes in DFN field, and $j > i+2$. If it finds that any of its neighbor qualifies the above condition, then those nodes with index from d_i to d_j in the DFN are replaced by node *N* and RRP is forwarded to the next hop with DFN $= \{d_1, \ldots, d_{i-1}, N, d_{j+1}, \ldots, d_m\}$.

Figure 9(c) illustrates the Reduction rule further applied on the route shown in Figure 9(b). As master *y* receives RRP, it finds neighbor *z* can communicate with nodes *x* and v recorded

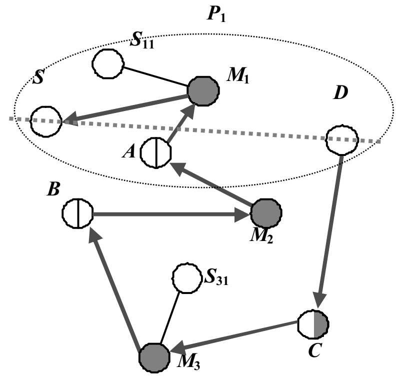


Figure 10. Route reply phase based on reduction and replacement rule.

in DFN field and the distance between nodes *x* and *v* are three hops. Therefore, node *y* deletes information of nodes *y* and *w* from DFN field, and instead, put LOC and ID information of node *z* in DFN field. Then node *y* forwards the RRP to the next hop.

- Continue this process until the source node receives the RRP. On receiving the RRP, source node gets the final shortest connecting path between the destination and itself in a reduced form. An example of this rule is shown in Figure 9.

3.2.2.2. *Construction and Connectivity of Path.* As shown in Figure 10, the destination node *D*, forwards the RRP to the master/bridge master node *C*. Since *C* is far away from the ideal path joining the source and the destination, it simply changes its role to a bridge and forwards the RRP to M_3. As master M_3 has its slave's location information, it scans the EIP from the RRP and then calculates the DIP for each of its slaves S_{31} and bridge nodes *B*, *C* and itself. Though, node *B* has the minimum DIP as compared to its slaves and itself, master M_3, finds from its CRT that node *B* is not connected with node *C*. Then it verifies the node having the next minimum DIP and considers node $S_{31,}$ as it satisfies the connectivity. Finally it appends node S_{31}'s information to replace M_3 in the DFN 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. Now master M_2 estimates the DIP of its own with its slave nodes *A* and *B*. Though, node *A* has the minimum DIP, it is neither connected to S_{31} nor to the destination node. So master M_2 appends its own information to replace S_{31} and *C* in the DFN field, as it is the node having next minimum DIP and satisfies the connectivity. Bridge node *A* simply forwards it to M_1 and then M_1 estimates the DIP of its slaves *A*, S_{11} and *S*. and itself. Though node *A* has the minimum DIP, it is not connected to the destination node *D*, where as $M_{1,}$ having the next minimum DIP, can be connected to *D*. So, it appends its own information to the DFN field and deletes the information of other nodes between itself and the destination. Finally master M_1 forwards the RRP to the source node *S*. As soon as, source receives the RRP, it goes to page state and tries to synchronize with the node in the PFN field of the RRP. Thus the numbers of hops are reduced and new node M_1 is replaced and a new scatternet is constructed as described in the next phase. For different senders of Figure 10, the corresponding RRP formats are shown in Figure 11.

Sender	Corresponding RRP									
D	*D.ID*	*D.LOC*	*C.ID*	*C.LOC*	M_3*.ID*	M_3*.LOC*	*B.ID*	*B.LOC*	*S.ID*	*S.LOC*
C	*D.ID*	*D.LOC*	*C.ID*	*C.LOC*	M_3*.ID*	M_3*.LOC*	*B.ID*	*B.LOC*	*S.ID*	*S.LOC*
M_3	*D.ID*	*D.LOC*	*C.ID*	*C.LOC*	S_{31}*.ID*	S_{31}*.LOC*	*B.ID*	*B.LOC*	*S.ID*	*S.LOC*
B	*D.ID*	*D.LOC*	*C.ID*	*C.LOC*	S_{31}*.ID*	S_{31}*.LOC*	*B.ID*	*B.LOC*	*S.ID*	*S.LOC*
M_2	*D.ID*	*D.LOC*	M_2*.ID*	M_2*.LOC*	*B.ID*	*B.LOC*	*S.ID*	*S.LOC*		
A	*D.ID*	*D.LOC*	M_2*.ID*	M_2*.LOC*	*B.ID*	*B.LOC*	*S.ID*	*S.LOC*		
M_1	*D.ID*	*D.LOC*	M_1*.ID*	M_1*.LOC*	*S.ID*	*S.LOC*				
S	**Receives the RRP**									

Figure 11. The DFN field in RRP sent by different nodes present in the route replay phase.

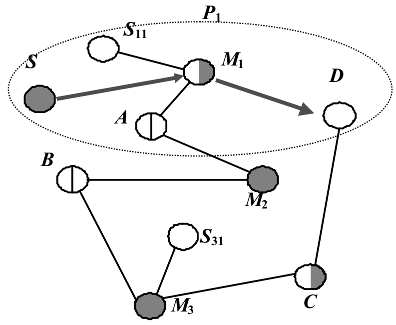


Figure 12. Final route construction phase in LARP.

3.2.3. *Route Connection Phase*

On receiving the route reply packet, the source node *S* tries to select the shortest path to connect to the destination. First it goes to the page state and requests node *A* to go to the page scan state. Once node *A* goes to page scan state, it becomes the slave for the source node *S*. Similarly, node *A* again goes to page state and node *D* goes to page scan state. Finally, *A* becomes the master to both nodes *D* and *S*. Thus a new connected scatternet is formed taking the nodes *S*, *D* and *A* with *A* as a master/slave bridge node. Connection of the path between *S*, *A*, and *D* is shown in Figure 11. It is to be noted that the numbers of hops between the source and the destination are reduced to 2, as shown in Figure 12, which are least as compared to LORP [2] and RVM [4]. Though we have explained our protocol taking a specific example, however it is obvious that it'll work in any type of scatternet configurations.

4. Hybrid Location Aware Routing Protocol

As discussed in Section 2.2, the dynamic relay reduction protocol (LORP) [2], does not require location information of the nodes to construct the routing path. Contrary to the LORP, the location aware routing protocol (LARP), as discussed in Section 3 needs location information of each node to construct the routing path and requires least number of hops to transmit packets. In this section, both LORP and LARP are combined to present a hybrid location aware routing protocol (HLARP), in which some nodes in the scatternet may not have location information. As described below, the protocol is divided into three phases such as route search, route reply and route construction phases.

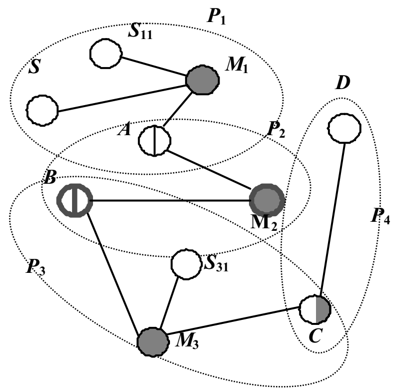


Figure 13. Construction of route in HLARP.

4.1. Route Search Phase

In this phase, a route search packet (RSP) is used to find the shortest route between the source and the destination. Format of this packet is same as the RSP of the LARP, which is shown in Figure 5. Figure 13 depicts an example, in which all nodes, except M_2 and B have location information. When the RSP is transmitted through nodes M_1 and A, they attach their location information and device ID to the PFN fields of the RSP and forward it to the master M_2. Since, master M_2 has no location information; it appends its ID only, to the PFN field and forwards the packet to the bridge node B. Similarly the bridge node appends its ID only, as it has no location information. Thus the RSP packet is forwarded to the destination node D, through the intermediate nodes M_3 and C. It is to be noted that, since source node A and S are within the communication range of each other and both nodes have their location information, node M_1 is replaced by node A in the PFN field of the packet. However, node M_2 and B are not deleted from PFN field, though node B is within the communication range of the source node S. So, during route search phase, the final path between the source and destination will be: $S \to A \to M_2 \to B \to M_3 \to C \to D$.

4.2. Route Reply Phase

As similar to the route reply phase of LARP, the RRP packet is forwarded to node C by the destination node D and the RRP packet format is also same as shown in Figure 8. Applying the reduction and replacement rules as given in Section 4, node C is replaced to the DFN field of the RRP, and the packet is then forwarded to the next node, M_3. Since its slave S_{31} is closure to the ideal path, S_{31} is replaced to the PFN field of the RRP. However, node B and M_2 can not estimate their distance from the ideal path as they have no location information and their ID still remain in the DFN field. Later, master M_2 forwards the packet to the bridge node A which is ultimately reached at the master node M_1. M_1 estimates the DIP for each of its slaves and the bridge nodes A and B. Since node A is closure to the ideal path, M_1 verifies intra communication range between A and D using the communication range table (CRT). As shown in the figure, node A and D are not within the communication range of each other, so M_1 deletes information of all nodes from the DFN field except nodes M_1 and D and forwards the packet to the source node S. On receiving the packet, S goes to the route construction phase as described below.

4.3. Route Construction Phase

This phase is meant to reconstruct the scatternet, taking the nodes with minimum hops and within the communication range. On receiving the RRP, the source node goes to page state and tries to communicate with the nodes present in the DFN field of the packet. As per our example, source node S is within the communication range of M_1 and M_1 is within communication range of D. So node M_1 changes its role and becomes a master for the slave D and the scatternet is formed taking S, M_1 and D.

5. Simulation Results and Comparison

Based on power and bandwidth consumption, end to end packet delay in the scatternet, the performance analysis of our protocols is described in this section. Different number of devices, scatternet size and different routing paths are considered as the simulation metrics. Based on the transmission of control packets of our protocols presented in Section 3 and 4, various routing paths are chosen for the simulation. To compare our results with some routing protocols like RVM [4] and LORP [2], it is assumed that, initially a connected scatternet is formed. Fixed numbers of 100 nodes are distributed randomly in the scatternet of variable size that ranges from $100\,\mathrm{m}^2 \sim 2500\,\mathrm{m}^2$. The control packets are forwarded from one node to other along all possible successful paths between the source and the destination. Besides, the average route construction time and routing length are calculated for different scatternet size.

Figure 14 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 the Figure 15, it is observed that the route construction time of our protocol is less than that of the LORP. Also, our Hybrid LARP gives better improvement to the route construction timing over LORP. However we find that the route construction time of RVM is better than our protocols. It may be case in our protocol, as we explore all possible ways to find a route in order to minimize the number of hops. In Figure 16, we have compared the routing 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 our protocol outperforms both RVM and LORP, even if, our Hybrid LARP protocol gives better performance than the RVM and LORP. In

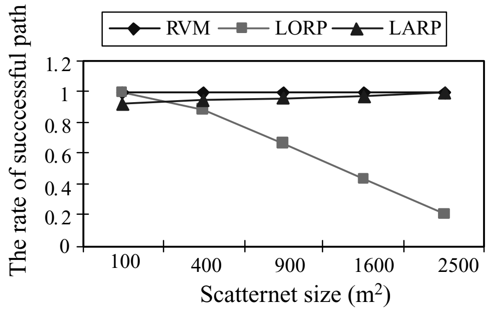


Figure 14. The rate of finding successful path for different scatternet sizes.

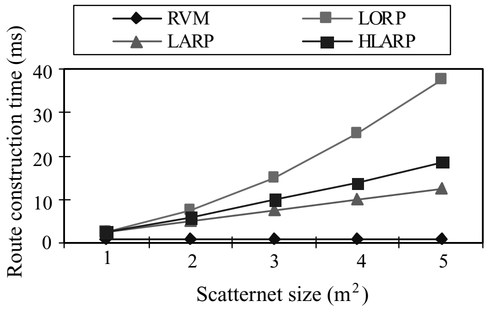


Figure 15. The route construction time for various scatternet sizes.

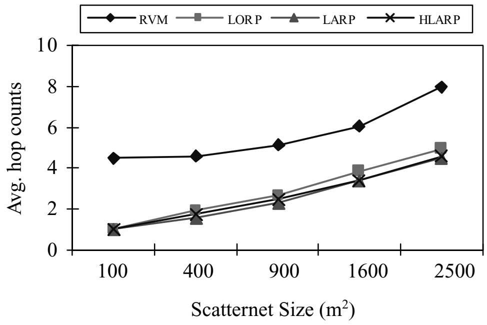


Figure 16. Average number of hop counts in different protocols for various scatternet sizes.

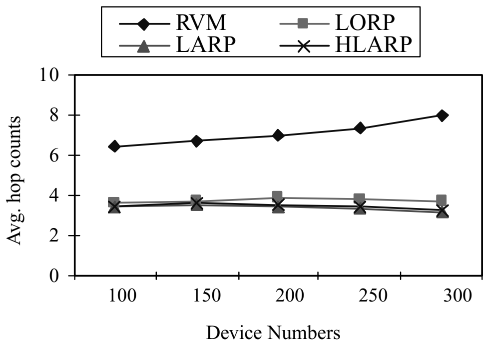


Figure 17. Average number of hop counts in different protocols for different device numbers.

LARP or HLARP, the packet transmission will be very quick as average routing length is shorter. Though, the route construction time of our protocol is not better than the RVM, but it is observed that once the route is constructed, our protocol shows very good result for quick packet delivery, thereby increasing end to end packet delivery throughput. In Figure 17, it is observed that the average routing length is even better than the other routing protocols for different number of nodes. So our protocol (both LARP and HLARP) outperforms the LORP and RVM either for different scatternet size or for different node numbers present in the scatternet.

In our simulation, we have 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

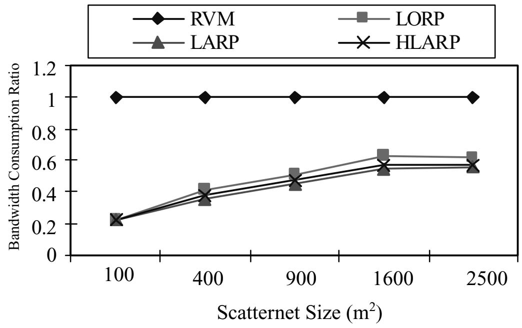


Figure 18. Bandwidth consumption in different protocols for various scatternet sizes.

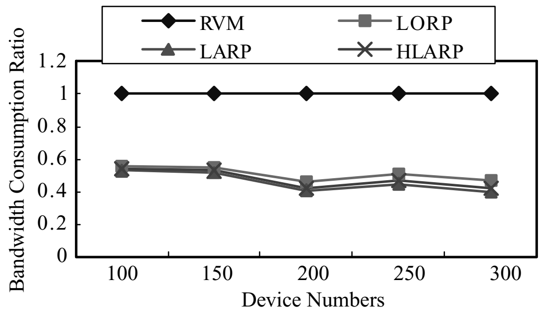


Figure 19. Bandwidth consumption in different protocols for different device numbers.

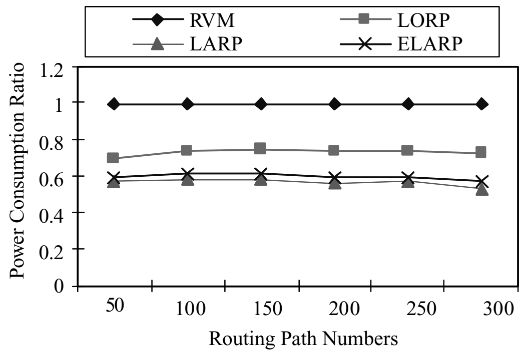


Figure 20. Ratio of power consumption in different protocols for different number of routing paths.

scatternet size. The simulation result as represented in Figure 18 indicates that LARP, and HLARP consumes less bandwidth in comparison to the RVM and LORP. Also it is found that; highest amount of bandwidth is consumed in RVM, as compared to other protocols. Similar results of bandwidth consumption for different number of nodes are presented in Figure 19. Considering the bandwidth consumption, our protocol outperforms RVM and LORP for different number of devices. Finally, in Figure 20, we have analyzed the power consumption of our protocol with RVM and LORP for different number of routing paths. It shows that both of our protocols LARP or HLARP consume 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 the power.

6. Conclusion

In this paper, we propose a location aware routing protocol to reduce the number of hops of a constructed Bluetooth scatternet and reconstruct it after reducing the hops. Besides, we extend our protocol to the Hybrid LARP by considering a mixed number of nodes with or without location information. For both LARP and HLARP, our algorithms contribute the shortest routing path and thereby least transmission delay; low bandwidth consumption and low power consumption as compared to the RVM and LORP. Since number of hops in our protocols is least, they are the best of its kind and can be applied to the low mobility Bluetooth devices in certain environments such as 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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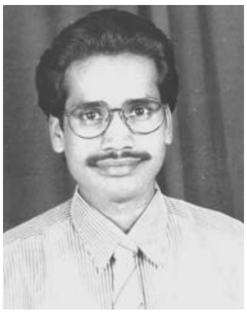

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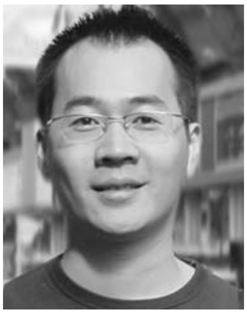

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