Ad hoc and Opportunistic Routing in Static Scatternet Environment

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Abstract

Peer-to-peer connectivity between mobile phones using technologies such as Bluetooth has given a new dimension to the mobile communication. Peers through the help of various underlying protocols can form piconets and scatternets to transparently communicate the content across the network. There however are issues like reliability in communication, delay and the cost of communication that need to be considered before resorting to this form of communication. This paper presents a study where opportunistic concept such as Bubble Rap is tested in Bluetooth ad hoc networking environment. The notion behind this research is to study the properties of these two networking environments, since opportunistic networks are derived from ad hoc networks. Thus, study of these two different environments yet related to each other may help us find new ways of message forwarding in Bluetooth communication environment. This paper is aimed at investigating the behaviour of nodes present in Bluetooth static scatternet environment by *1)* studying message transfer from a source to destination using traditional ad hoc communication protocols such as AODV and *2)* message transfer using opportunistic algorithms such as Bubble Rap on top of traditional ad hoc communication. This paper also proposes a concept of ranking to transfer messages to the node that has higher social centrality ranking compared to the current node. Nodes with varying social ranking are allowed to join piconets and forward messages based on Bubble Rap concept in scatternet environment. In BR algorithm, nodes forward messages to only those encountering nodes which are more popular than the current node.

Keywords: Ad hoc networks, opportunistic routing, piconets, scatternets.

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1. Introduction

Bluetooth based ad hoc network has special constraints compare to other wireless networks. For instance, Bluetooth technology by default works on master/slave principle known as piconet. A piconet consists of a master and maximum of up to seven slaves. Master node is the central entity in the network that is responsible for the communication of that piconet. If more than 8 nodes are present in the network then multiple piconet can be formed that can communicate each other by sharing slaves, this formation is known as scatternet. The work presented by Miklos et al [1] and Zurbes et al [2] show that if scatternet contains more piconets the rate of packet collision increases. Therefore, the performance of Bluetooth ad hoc network is greatly depends upon the efficiency of the formation of scatternet.

In Bluetooth communication environment a node may come across a single node or set of multiple nodes within 10m range. Therefore, this chapter presents a proof of concept study where opportunistic concept such as Bubble Rap (BR) [3] is tested in Bluetooth ad hoc networking environment. The notion behind this effort is to study the properties of these two networking environments, since opportunistic networks (one-to-one communication, where nodes do not have prior knowledge of destination nodes) are derived from ad hoc networks (one-to-many, where nodes have full or partial view of network). Thus, study of these two different environments yet related to each other may help us to find new ways of message forwarding in Bluetooth communication environment.

In this paper, the purpose of these experiments is to learn and investigate the behaviour of nodes present in Bluetooth static and dynamic scatternet environment. In these experiments, two types of message transfer were performed 1) the traditional ad hoc communication from source to destination using AODV 2) opportunistic algorithm such as BR concept on top of traditional ad hoc communication. In Bubble Rap, the concept of global and local ranking is proposed to transfer messages to that node which has higher social centrality ranking compare to the current node. Nodes with varying social ranking are allowed to join piconets and forward messages based on BR concept in scatternet environment. In BR algorithm, nodes forward messages to only those encountering nodes which are more popular than current node.

2. Literature review

A multi-hop scatternet is where two nodes are far from each other's communication range and a bridge node or nodes are used to make communication possible. The issues normally discussed in multi-hop scatternets algorithms are similar to those of single-hop scatternets algorithms, with the exception of large scale network.

A centralized approach is discussed in [4] for fixed Bluetooth sensor networks used in civil infrastructure such as highways and bridges. The idea presented in this approach is to consider network traffic generated by the sensor nodes and also take node's storage capacity as well as link strength into account while forming the network topology. This algorithm makes no assumptions with regards to deployment and location of nodes. The network formed through this approach is tree like in structure. The tree originates from the central point known as data logger. The data logger collects information from all the nodes present in the network, based on collected data it then can take decisions. The traffic send on link use the balance approach to avoid congestion.

An optimized concept is proposed in [5], where the idea is to minimize the network traffic load which is caused due to the changing network topology of scatternets. A problem of min-max creates bottlenecks in the network due to the congestion on a particular node. This problem can be dealt with if the network topology is built on the prior knowledge of traffic patterns and routes by using distributed approach.

An on-demand routing protocol is proposed in [6] for the formation of scatternets, thus reducing the extra links and network maintenance traffic. In a typical Bluetooth network topology, all neighbours need to be discovered prior to sending the paging signal and route request. First the piconet is created and the role of master/salve is assigned before the route request packet is released. The neighbour nodes continue to search for the destination node. In proposed alternative topology formation methodology, the first alternative is to first create the full piconet and then release the route request. The second is to immediately release route request to each neighbour after paging, no need to wait for full establishment of piconet. The authors introduce another concept, an extended connectionless broadcast mechanism, where nodes in a same piconet use the same channel for communication. An inquiry message is broadcast on the channel by the master node and slaves keep listening on the same channels to grab the message. Such a process can minimize the route discovery delay considerably. The authors also suggest that if piconets in the network are synchronized this can remove the switching overhead and hence better utilization of channels. The method proposed is very good for real time traffic and in order to handle large packets in wireless networks.

A BlueStar formation for multi-hop scatternet is proposed in [7 and 8]. The BlueStar formation is based on clustering scheme described in [9]. In BlueStar master node is selected on the basis of node weight rather than on node IDs. The master nodes are selected on the basis of weight and are called as Clusterheads. Each Clusterhead node becomes the master of its piconet and all other nodes present in that piconet become its slaves. The slave nodes present in Clusterhead's piconet may act as master nodes for other nodes thus forming their own piconets in tree like fashion. A major drawback in formation givne in [7] is the degraded network performance that is due to the presence of more than seven slaves in a piconet. There is a traffic overhead and delay due to parked and un-parked process of slaves in order to communicate with their masters. Before clustering, a topology discovery process takes place for about eight seconds to gather the information about all neighbouring nodes.

In [10], a comparison of scatternet formation in Bluetooth networks using NS2 simulation is presented. The comparison is made on the formation techniques presented in [11, 12, 13]. They conclude that the most time consuming process in Bluetooth network is device discovery, irrespective of any protocol used. The results also showed that Bluestar is the fastest protocol due to its simplicity for the formation of scatternets. One drawback in Bluestar is the presence of many slaves (more than seven) in a single piconet that can affect operations due to parking and un-parking of nodes.

A greedy centralized algorithm is proposed in [14], where a node keeps the information of others nodes that are at most 2-hops away. The 2-hops concept can be feasible in Bluetooth networks since neighbour nodes are known during the device discovery process. Each node is responsible to exchange the neighbourhood information so that they have a partial view of the network. In this algorithm, a piconet cannot have more than seven nodes. A node that has higher degree is elected as master node and can have seven slaves selected on the basis of least degree connections.

In [15, 16], a technique known as BlueMesh is used for the formation of scatternets. The proposed scheme assures network connectivity with limited number of slaves in each piconet. A two phase discovery process is used to gather the information about the neighbouring nodes at most 2-hops away. A modified clustering is used, where if a piconet has more than seven nodes, the master node will select seven slaves and allows its slaves to form relationships with the remaining nodes present in that piconet. In this way the master node can have access to the remaining nodes. The same concept is proved in [17] with five slaves. The scatternet formation is based on the repetition process. At the start no node has been assigned the task of either master or slave. The selection of master node (could be more than one) is based on the largest weighted node among nodes present in the area. In the next repetition the original masters do not participate in the selection process because they have already made piconets with their salves, however slave nodes and remaining undecided nodes again participate and the same process goes on until all nodes become part of their respective piconets. Simulation results showed that although this algorithm may show some weaknesses on some other metrics, but where position information is not used, it is the best algorithm available.

3. Network Modelling

This section gives an overview of the simulator module used for the purpose of the research. It also discusses the simulation scenario and simulation parameter used in the experiments pertained to this paper.

3.1. Simulator Module

A UCBT-Bluetooth (stands for University of Cincinnati – BlueTooth) extension for NS-2 simulator [20] is used for simulation. UCBT-Bluetooth is NS-2 based Bluetooth network module which works on principle of Bluetooth protocol specification version 1.1 and partially version 2. UCBT can simulate most of the specification at Baseband and above like link management protocol (LMP), logical link control and adaption protocol (L2CAP), Bluetooth network encapsulation protocol (BNEP). UCBT can also perform device discovery, connection set up, frequency hopping, Hold, Sniff and Park modes management. UCBT also allows nodes to form piconets and there is provision in this simulator to establish communication between two multiple piconets with the help of slave nodes known as "bridge nodes".

3.2. Static Scatternet in Multi-piconet Scenario

For these experiments, up to five different connections are considered from one simultaneous connection to five simultaneous connections in scatternet where source nodes are in piconet '1' and destination nodes are in piconet '4'. In order to specifically understand the BR concept two source nodes are considered from piconet '2', which are destined for the highest ranked nodes in the network. Total 32 nodes are considered in these experiments, the network topology is depicted in Fig. 1. In order to simplify the experiments, nodes are allowed to join maximum of up to 2 piconets. Under these experiments different behaviour such as data rate, delay, delivery ratio and energy consumption is studied on different nodes. For BR experiments each node has assigned a social ranking value, which defines its social status (popularity) in the community. Table 1 shows the list of parameters considered for these experiments.

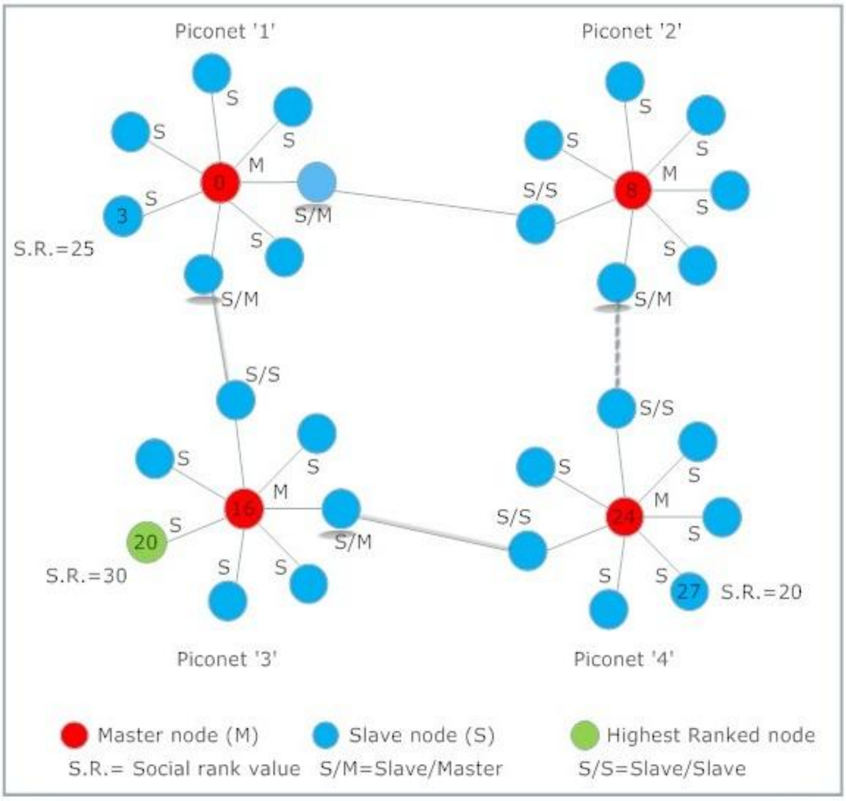


Fig. 1. Network Topology for 32-Nodes Scatternet

Table 1. Simulation Parameters for Scatternet

No.	Parameters	Value	No.	Parameters	Value
1	No. of nodes	32	9	Packet Size	1400
2	Area (range)	10 m	10	Interval	0.015
3	Max. allowable slaves (per piconet)	07	11	Bluetooth Baseband packet type	DH3
4	Routing Protocol	AODV	12	Battery Life (initial)	10 J

5	Scheduling (or Polling) algorithm	PRR	13	Avg. energy consumption rate	2.5e-3 J
6	Bridge Algorithm	TDRP	14	Min. Energy	0.1 J
7	Traffic Sources	07	15	Node Rank (social popularity level)	Default = 01, Node(20)=30 Node(27)=20, Node(3)=25,
8	Packet Type	UDP	16	No. of times each experiment run	20

4. Discussion on Results

This section provides a discussion on experimental results pertaining to static scatternet in multi-piconet environment. Results in Fig. 2(a) and Fig. 2(b) show the data rate response in bits per second for the same destination in scatternet environment as the number of simultaneous connections increases from one simultaneous connection up to five simultaneous connections. Two different set of experiments are performed in order to check the data rate response for the same destination in presence of one and two routes, as depicted in Fig. 2(a) and Fig. 2(b) respectively. The simulation parameters considered for both types of experiments are exactly the same. It is clearly shown in the figures that when there is only one connection present between source piconet '1' and destination piconet '4' the data rate response is maximum and it starts to decrease as number of simultaneous connections increase in scatternet. Both the figures show that behaviour of normal and BR-based scatternet is almost similar in the presence of single and double paths, this is due to the fact that BR performs in a similar fashion as normal scatternet perform as long as destination node is present in the scatternet, if destination node is not present in the scatternet than BR-based scatternet will perform differently, which is discussed in upcoming graphs. It is important to note that in single piconet environment (out of scope of this research), one master node is present in the network and there is no bridge node, therefore time scheduling is very simple, less delays as a result higher data rates. Fig. 2(a) pertains to the scatternet where more than one piconet and also bridge nodes are present in the network, therefore the time scheduling in scatternet is complex which results in higher delays, higher error delivery ratio and low data rates. When results in Fig. 2(a) are compared with the results in Fig. 2(b), it is quite evident that if more than one path is available from source node to destination node in scatternet the data rates received at the destination is higher. Therefore it is proved from the experiments that if number of bridge nodes increase in the network there will be more chances of having multiple routes from source node to the destination node which will increase the data rates in Bluetooth nodes in static scatternet environment.

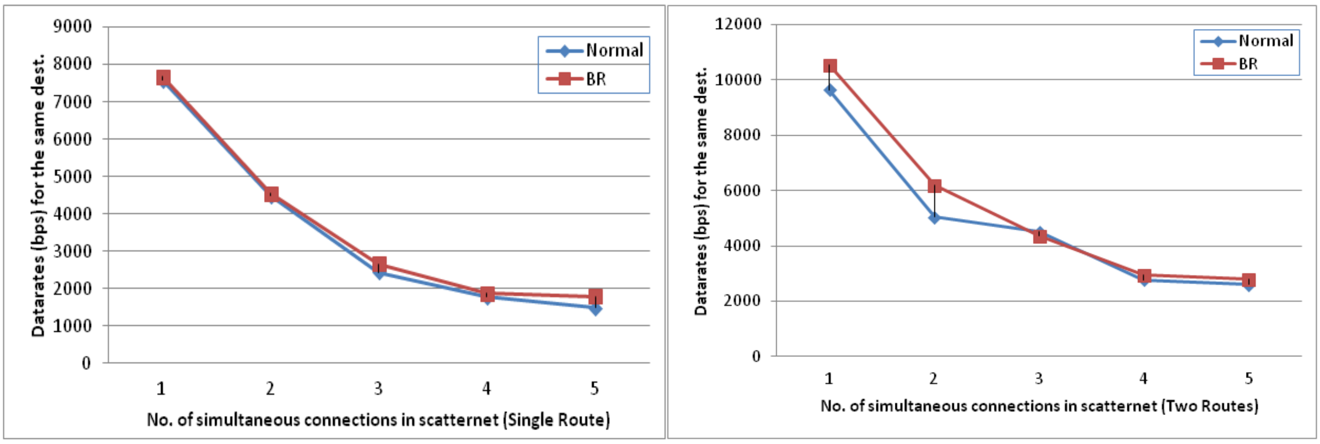


Fig. 2(a) Data rates for the same destination in scatternet with single route, Fig. 2(b) Data rates for the same destination in scatternet with two routes

Results in Fig. 3(a) and Fig. 3(b) show the delay response of the same destination with the increasing number of simultaneous connections in scatternet using single and two routes respectively. When there is only one connection active between piconet '1' and piconet '4' the minimum delay is observed at the destination. As number of simultaneous connections increase in the network more delay is observed at the destination. As it is also evident in the figures that there is variation in graph this is due to the fact that time scheduling is not only happen in piconets but also bridge nodes are involved in the network so each piconet has its own time offset based on the scheduled algorithm used in the piconet along with the bridge algorithm for the salve node participating in two piconets, so each node can only transmit in its own schedule time and same is true for the bridge node that it can only communicate in its dedicated time slot, thus causes varying delays. The BR-based scatternet response is similar to the normal scatternet, since destination node is present in the network. If we compare results in Fig. 3(a) with results in Fig. 3(b), it is quite clear that when there is more than one route for the destination is present in the scatternet; the information can be reached to the destination with minimum delays.

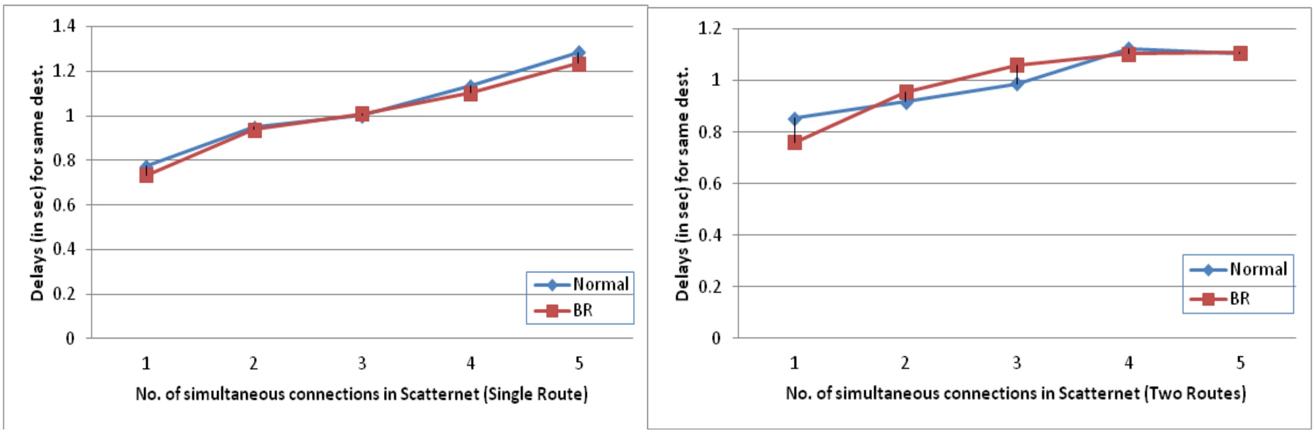


Fig. 3(a) Delay response for same destination with single route, Fig. 3(b) Delay response for same destination with two routes

Results in Fig. 4(a) and Fig. 4(b) show the packet error delivery ratio for the same destination in scatternet in the presence of one and two routes respectively. Fig. 4(a) indicates that when there is only one connection the error is low, as the number of simultaneous connections increases in the scatternet the error starting to increase with variation. The reason behind this trend is that when there is only one connection in scatternet the maximum time is allocated to only one node as a result the node can transfer data at higher rates thus probability of error is low due to large amount of data can be transmitted. As number of simultaneous connection increases in the scatternet, master nodes of participating scatternet have to use the polling algorithm to equally distribute the time slots among its slaves as well as bridge nodes as a result each node will get a limited amount of time slots for data transmission, since nodes are now sending data with lower rates thus error delivery ratio is high. The BR-based scatternet shows almost the similar trends as shown by the normal scatternet with variation due to complex scheduling process in scatternet. Results in Fig. 4(b) shows a better trend compared to Fig. 4(a) which is due to the fact that there are now two routes for the destination so less congestion in the network as a result better delivery ratio is achieved but still varying due to complex time scheduling in scatternet.

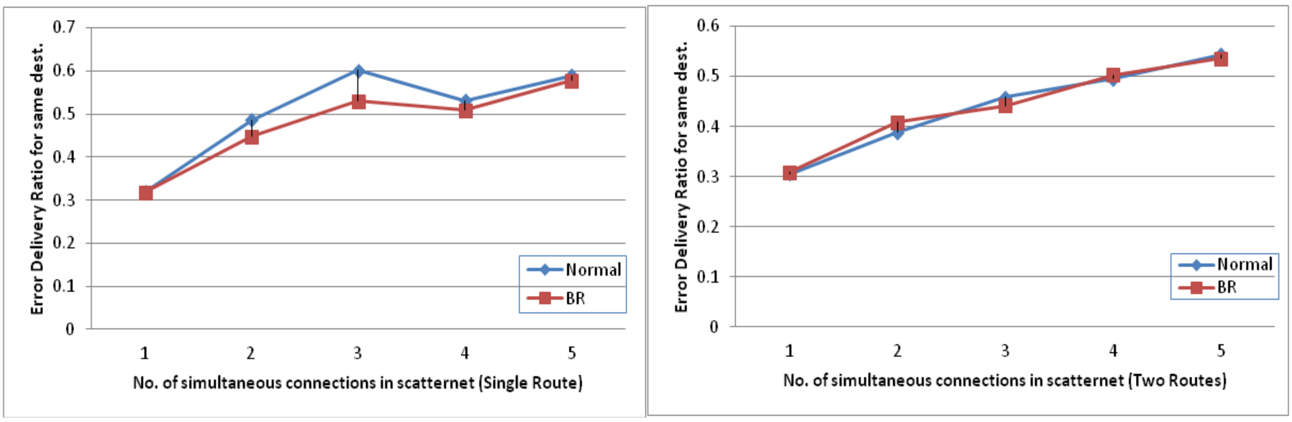
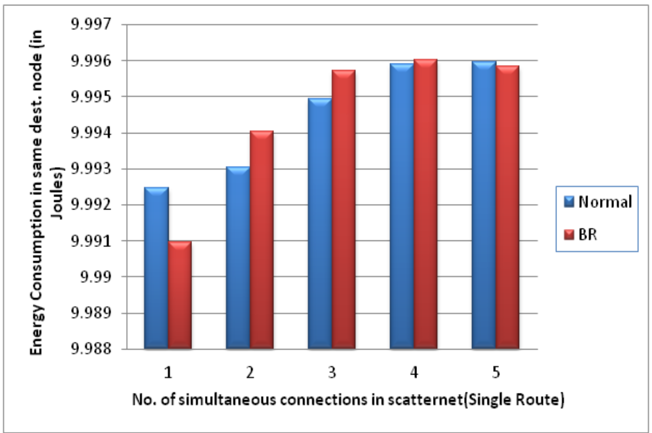


Fig. 4(a) Packet error delivery ratio for the same destination with single route, Fig. 4(b) Packet delivery ratio for the same destination with two routes

Results in Fig. 5(a) and Fig. 5(b) show the typical energy consumption of same destination in presence of single and two routes respectively, with the increasing number of simultaneous connections from same source piconet to the same destination piconet. When there is only one active connection present between source piconet and destination piconet the energy consumption at destination node is highest due to high data rates. However when number of simultaneous connections starts to increase, the master node of destination piconet has to schedule the time slots for the equal share between other slave nodes in that piconet as a result the destination node gets the reduced chunk of time slot for transmission and reception of data, thus energy consumption is lower. The behaviour of BR-based scatternet is almost similar to the normal scatternet because the destination node is present in the scatternet. By comparing results in Fig. 5(a) and Fig. 5(b) it is quite evident that the energy consumption at destination node is much higher in the presence of two routes compare to the one route. This is because when there are two routes present between source and destination piconets, there will be less congestion in the scatternet as a result large amount of data can be transferred from the source to the destination as shown in Fig. 2(a) and Fig. 2(b), since destination node can now receive large amount of data this means that energy consumption at destination node will also be higher.



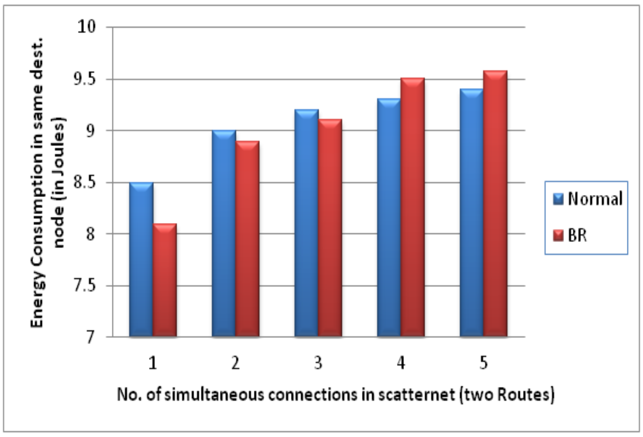


Fig. 5(a) Energy consumption in scatternet with single route, Fig. 5(b) Energy consumption in scatternet with two routes

So far the experiments have shown that the BR-based scatternet acts almost similarly as normal scatternet as long as destination is present in the scatternet. In this experiment the aim is to check the behavior of BR algorithm, for this purpose the nodes selected as a destinations are not present in the scatternet. For BR-based scatternet, three different nodes such as node 20 in piconet '3', node 3 in piconet '1' and node 27 in piconet '4' have assigned social (popularity) ranks of 30, 25 and 20 respectively, whereas, all other nodes have given the default rank i.e. 1, as shown in Fig. 1. When the source nodes attempts to send the data and not able to find the destination then BR-algorithm comes into play and data will be sent to the node which is more popular than the current node, since routing protocol is AODV as a result each node in static scatternet knows that which node is the most popular node, therefore source node will target the highest (popular) ranked node. In order to check that nodes are indeed targeting the most popular node, after 50s of simulation the current highest node is removed from the network, as soon as node '20' is removed from scatternet the nodes automatically start to target the second highest popular node i.e. node '3' which is now become most popular node in the scatternet.

Results in Fig. 6(a) show the typical behaviour of BR-based scatternet in terms of data rates received at highest rank (HS.R) nodes and their respective master (M) nodes in the presence of one and two routes in scatternet. It is clearly shown in the figure that in order to reach at highest ranked nodes, if more than one route is present in scatternet; the data rates received are high. Fig. 6(a) shows that data rates received at node '3' and its respective master node is much higher compare to the node '20' and its respective master node. The reason behind this behaviour is due to the fact that for this experiment the sources considered are present in piconet '2', initially nodes are targeting the highest ranked node i.e. node '20', that present in piconet '3' which is far from piconet '2'. Whereas, node '3' is present in piconet '1', which is near to piconet '2' (compared to the piconet '3') and also piconet '1' has other nodes which are transmitting data to piconet '4', due to these extra transmissions in piconet '2' master node (node 0) in that piconet shows the highest data rate response, whereas node '3' is receiving messages for those nodes who are not present in the network when node '20' is removed from the scatternet. Results in Fig. 6(b) show the delay response of the node '20' and node '3', that are 1st and 2nd highest (popular) ranked nodes respectively. When 1st highest ranked node i.e. '20' is removed from the scatternet , the unresolved queries for the destination nodes (not present in the network) is automatically send to the 2nd highest ranked node i.e. '3' (which is now become the highest popular node). Fig. 6(b) clearly shows that when more than one path is present in the network, the overall delay received at highest ranked nodes is starting to decrease.

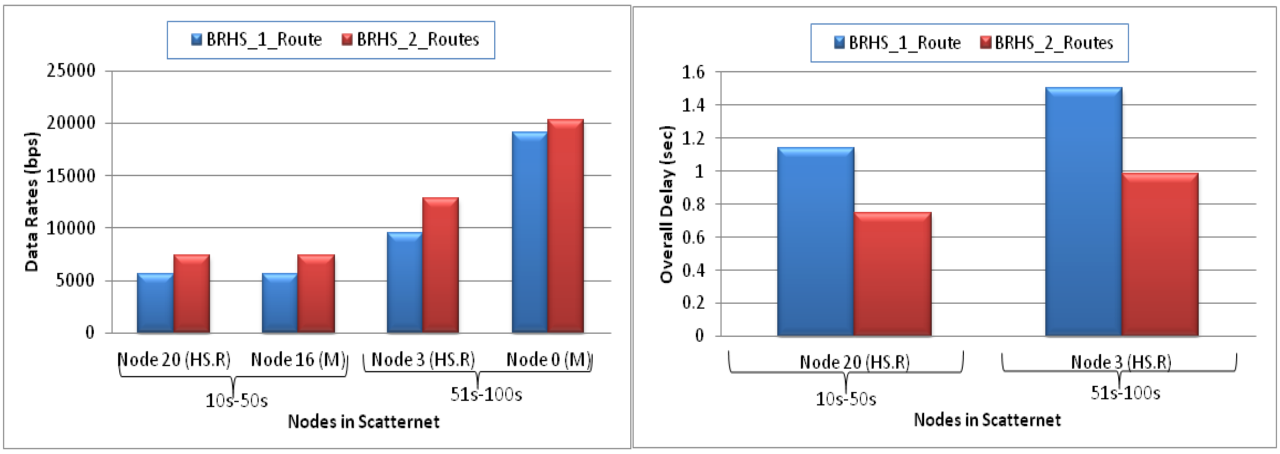


Fig. 6(a) Data rates received at highest ranked node and master node in BR-based scatternet, Fig. 6(b) Delay response of highest ranked nodes in BR-based scatternet

Results in Fig. 7(a) show the packet error delivery ratio for highest (popular) ranked nodes. In both cases of node '20' and node '3', which are 1st and 2nd highest popular node in the scatternet respectively, the overall delivery ratio is improved in the presence of one and two paths for the highest ranked nodes. This again validates our findings that if more paths are available in the scatternet for the destination, better will be the overall packet delivery ratio. Results in Fig. 7(b) show the energy consumption in 1st and 2nd highest ranked nodes and their respective master nodes, respectively. As found in our previous findings the master nodes will consumed more energy because it is responsible for its piconet, so here in this particular case not only the master node is handling the highest popular nodes but also the other nodes present in that piconet. This figure again proves that when more than one path is available in order to reach to the highest ranked nodes, the congestion in the scatternet becomes less as a result more data can be transmitted to these nodes, which will ultimately increase the energy utilization in participating nodes.

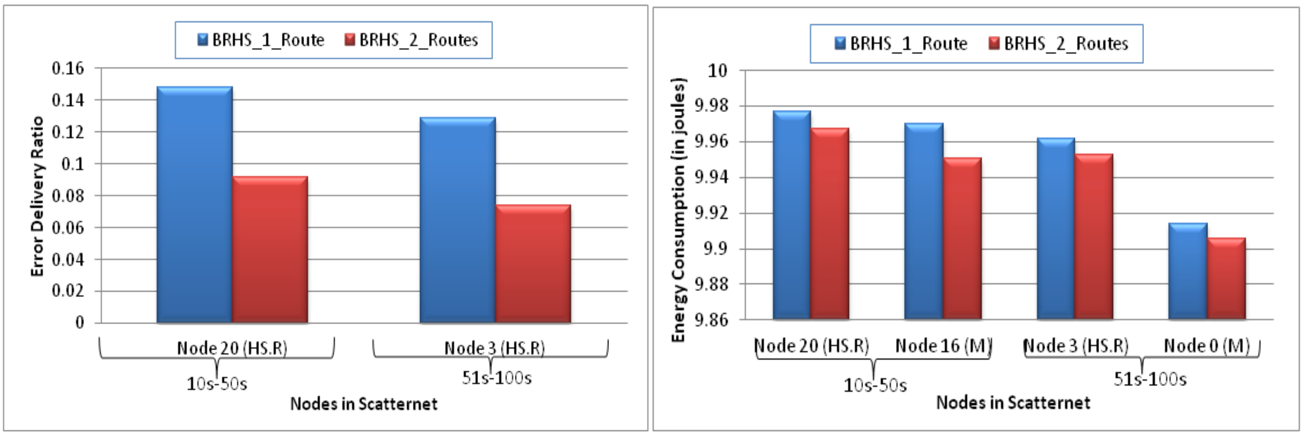


Fig. 7(a) Error delivery ratio of highest ranked nodes in BR-based scatternet, Fig. 7(a) Energy consumption at highest ranked nodes and master nodes in BR-based Scatternet

5. Conclusion

This paper investigates the behaviour of nodes present in Bluetooth static scatternet environment by *1)* studying message transfer from a source to destination using traditional ad hoc communication protocols such as AODV and *2)* message transfer using opportunistic algorithms such as Bubble Rap on top of traditional ad hoc communication. This research has provided an insight into a novel concept of opportunistic forwarding (Bubble Rap) over ad hoc routing algorithm (AODV). The results have demonstrated that although opportunistic forwarding and ad hoc routing are entirely different concept, both do effectively complement each other. Experimental results demonstrate that by allowing opportunistic forwarding on top of a traditional ad hoc network, source nodes are no more required to wait for direct encounters with potential forwarder or destination. Moreover, potential forwarders can be reached by using traditional ad hoc routing such as AODV even if they are multiple hops away in the scatternet.

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