RESEARCH PAPER

International Journal of Recent Trends in Engineering, Issue. 1, Vol. 1, May 2009

Source routing in Mobile Ad hoc NETworks (MANETs)

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***Abstract*— Mobile ad hoc network is a reconfigurable network of mobile nodes connected by multi-hop wireless links and capable of operating without any fixed infrastructure support. In order to facilitate communication within such self-creating, self-organizing and self-administrating network, a dynamic routing protocol is needed. The primary goal of such an ad hoc network routing protocol is to discover and establish a correct and efficient route between a pair of nodes so that messages may be delivered in a timely manner. Route construction should be done with a minimum of overhead and bandwidth consumption. This paper examines two routing protocols, both on-demand source routing, for mobile ad hoc networks– the Dynamic Source Routing (DSR), an flat architecture based and the Cluster Based Routing Protocol (CBRP), a cluster architecture based and evaluates both routing protocols in terms of packet delivery fraction, normalized routing load, average end to end delay, throughput by varying number of nodes per sq. km, traffic sources and mobility. Simulation results show that in high mobility (pause time 0s) scenarios, CBRP outperforms DSR. CBRP scales well with increasing number of nodes.**

***Index Terms*—MANET, CBRP, DSR, routing, performance**

I. INTRODUCTION

Mobile ad hoc networks are formed by autonomous system of mobile nodes that utilize multi-hop radio relaying and connected by wireless links without any preexisting communication infrastructure or centralized administration. Such networks are also known as infrastructureless or multi-hop wireless networks. Communication is directly between nodes or through intermediate nodes acting as routers. Such network requires each mobile host to be more intelligent so that it can perform both functions of transmitting and receiving of data as a host and of forwarding packets for other mobile host as a router. The advantages of such a network are rapid deployment, robustness, flexibility and inherent support for mobility. Ad hoc networks, due to their quick and economically less demanding deployment, find applications in military operations, collaborative and distributed computing, emergency operations, wireless mesh networks, wireless sensor networks and hybrid networks.

Due to dynamic topology, lack of fixed infrastructure and frequent link failure the traditional routing for wired networks cannot be directly applied to mobile ad hoc networks because wired routing methods assume the network to be stable and routing overhead to be almost negligible. They either lack the ability to adapt to the dynamic topology change of mobile ad hoc networks or may cause large overhead that degrades network performance. Therefore, routing is the most studied problem in mobile ad hoc networks and a number of routing protocols have been proposed [1-13], derived from either *distance-vector* [14] or *link-state* [15] based on classical routing algorithms.

Routing protocols for Mobile ad hoc networks can be classified into two main categories: Proactive or table driven routing protocols and Reactive or on-demand routing protocols. In proactive protocols, every node maintains the network topology information in the form of routing tables by periodically exchanging routing information. They include the Destination Sequenced Distance Vector (DSDV) [2], the Wireless Routing Protocol (WRP) [3], Source-Tree Adaptive Routing (STAR) [5] and Cluster-head Gateway Switch Routing protocol (CGSR) [4]. On the other hand, reactive protocols obtain routes only on demand, which include the Dynamic Source Routing (DSR) protocol [6], the Ad hoc On-demand Distance Vector (AODV) protocol [7], the Temporally Ordered Routing Algorithm (TORA) [8], and the Associativity Based Routing (ABR) protocol [10].

On-Demand routing protocols can be classified into two categories: source routing and hop-by-hop routing. In Source routed on-demand protocols each data packets carry the complete path from source to destination. Therefore, each intermediate node forwards these packets according to the information in the header of each packet. The major drawback with source routing protocols is that in large networks they do not perform well. This is due to two main reasons; firstly as the number of intermediate nodes in each route grows, then so does the probability of route failure. Secondly, as the number of intermediate nodes in each route grows, then the amount of overhead carried in each header of each data packet will grow as well.

In hop-by-hop routing each data packet only carries the destination address and the next hop address. Therefore, each intermediate node in the path to the destination uses its routing table to forward each data packet towards the destination. The advantage of this strategy is that routes are adaptable to the dynamically changing environment of MANETs, since each node can update its routing table when they receiver fresher topology information and hence forward the data packets over fresher and better routes. Using fresher routes also means that fewer route recalculations are required during data transmission. The disadvantage of this strategy is that each intermediate node must store and maintain routing information for each active route and each node may require being aware of their surrounding neighbors through the use of beaconing messages.

A crucial issue for mobile ad hoc networks is the handling of a large number of nodes. As more nodes join a mobile ad hoc network, contention is more likely and the open nature of a mobile ad hoc network makes it important that a network continues to operate even if there are more nodes involved Several researchers have done the qualitative and quantitative analysis of Ad Hoc Routing Protocols in terms of different performance metrics under different scenarios and is summarized in brief in the following table 1.

TABLE 1
RELATED WORKS

Author [ ]	**Parameters**					**Performance parameter**
	Protocol	***Area***	***No. of Node***	***Connections***	***Packet rate***	
J.Broch [16]	DSDV, DSR, TORA, AODV	1500 m x 300 m	50	10-30	1,4,8 per sec	Pause time
S. Das [17,18]	DSR, AODV	1500 m x 300 m	50	10,20,30, 40	4/ sec 3/sec	Pause time
		2200 m x 600m	100	10, 20, 40	4/sec 2/sec	Pause time, Network load
A. Boukerche [19 - 21]	AODV, CBRP, DSR	1500 m x 300 m	50	10,20,30, 40	4/ sec 3/sec	Pause time
		2200 m x 600m	100	10, 20, 30 40	4/sec 2/sec	Pause time
A. Boukerche [22]	AODV, CBRP, DSR, PAODV, DSDV	1500 m x 300 m	50	10,20,30, 40	4/ sec 3/sec	Pause time
		2200 m x 600m	100	10, 20, 30 40	4/sec 2/sec	Pause time

Similar simulations were also carried out in [23-26] and all of them have used pause time as a performance parameter. Most of the above work is limited on performing simulations for ad hoc networks with a limited number of nodes (either 50 or 100 nodes) deployed in fixed geographical area maintaining node density constant. But none of these works consider the scalability issue and carry out the simulations with number of nodes as a performance parameter. Nowadays, the ad hoc network technology becomes more and more popular and, as a result, large-scale ad hoc networks may be deployed in battlefields, regions of disaster and large towns. In fact, this was the motivation of this paper: to make observations about the behavior of these protocols in large-scale environment, to show which protocol scales well in large scale mobile ad hoc network and to decide which topology either flat or cluster is best suited in low and high mobility.

The rest of the paper is organized as follows: Section II provides an overview and general comparison of the routing protocols used in the study. The simulation environment and performance metrics are described in Section III and then the results are presented in Section IV. Finally Section V concludes the paper.

II. OVERVIEW OF DSR AND CBRP

As each protocol has its own merits and demerits, none of them can be claimed as absolutely better than others. Two mobile ad hoc routing protocols – the Dynamic Source Routing (DSR), the flat architecture based On-Demand source routing protocol and the Cluster Based Routing Protocol (CBRP), the cluster architecture based On-Demand source routing protocol are selected for study. The reasons behind comparing of CBRP with DSR are as follows:

Among flat architecture AODV and DSR protocols are very much popular. AODV makes an assumption that there are only bi-directional links (and ignores any links that are not bi-directional) and that they all incur the same cost to use. The assumption can decrease the overall performance of the network if a large number of the links do not meet the assumption. Also, whenever an established route is broken the source must be notified and this way the source gets interrupted whereas DSR protocol can successfully discover and forward packets over paths that contain unidirectional links. The DSR protocol operates entirely on demand. It does not use any periodic routing advertisement, link status sensing, or neighbor detection packets; nor does it rely on these functions from any underlying protocols in the network.

In hierarchical approach Cluster Based Routing Protocol is suggested in [28] which seem to give answer to the scalability issue and further DSR and CBRP both use source routing. The key advantage of a source routing design is that intermediate hops do not need to maintain fresh routing information in order to route packets they receive, since the packets themselves already contain all the routing decisions. This advantage eliminates the need for the periodic route advertisement and neighbor detection packets present in other protocols. So in this study performance of two routing protocols DSR and CBRP is analyzed and compared. .

A. *Dynamic Source Routing protocol (DSR)*

The Dynamic Source Routing Protocol [6,27] is an on-demand routing protocol designed to restrict the bandwidth consumed by control packets by eliminating the periodic table-update messages required in the table-driven approach. It is beacon-less and hence does not require periodic hello packet transmissions, which are used by a node to inform its neighbors of its presence. DSR is in a different class than most other routing protocols for multi-hop ad hoc networks in that it uses source routes supplied by a packet's originator to determine the packet's path through the network, rather than using independent hop-by-hop routing decisions made by each node that receives the packet. In a source routing design, each packet to be routed through the network carries in its header the complete, ordered list of nodes through which the packet must pass.

The key distinguishing feature of DSR is the use of source routing. That is, the sender knows the complete hop-by-hop route to the destination. These routes are stored in a route cache. The data packets carry the source route in the packet header. The basic operations of the DSR protocol are divided into two mechanisms: Route Discovery and Route Maintenance.

Route Discovery is the mechanism by which a node which has a data packet to send to a destination obtains a source route to the desired destination. The route discovery process is carried out by flooding the route request throughout the network in controlled manner as follows.

Node having a data packet to send to some desired destination it

```
Checks the route cache
        If (there exists a fresh enough path for desired destination)
                {Use it}
        Otherwise
                {Broadcast a route request (RREQ) packet}
Intermediate or destination node receiving the RREQ checks
        If (Itself is a destination)
                {Send a route reply (RREP)}
        Otherwise
        {
            If (there exists a fresh enough path for desired destination)
                {Send RREP}
            Otherwise
                {Broadcast a route request (RREQ) packet)    }
        }
```

The RREQ builds up the path traversed across the network. The RREP routes back to the source by traversing this path backward. The route carried back by the RREP packet is cached at the source for future use.

Route Maintenance is the mechanism by which a sending node is able to detect if the network topology has changed such that it can no longer use its route to the desired destination. For example, a route becomes broken if two nodes listed as neighbors on the route have moved out of range of each other. If any link on a source route is broken, the source node is notified using a route error (RERR) packet. The source removes any route using this link from its cache. A new route discovery process must be initiated by the source if this route is still needed. DSR makes very aggressive use of source routing and route caching. No special mechanism to detect routing loops is needed. Also, any forwarding node caches the source route in a packet it forwards for possible future use.

B. Cluster Based Routing Protocol (CBRP)

In CBRP the nodes of a wireless network are divided into clusters. The diameter of a cluster is only two hops and clusters can be disjoint or overlapping. Each cluster elects one node as the clusterhead that is unique to each cluster, for maintaining information about its members and is responsible for the routing process. Flooding traffic during route discovery gets minimized and route discovery process speeds up due to grouping of nodes into clusters.

The head of a cluster knows the addresses of its members and each member has a bi-directional link to it. Clusterheads communicate with each other through gateway nodes. A gateway is a node that has two or more clusterheads as its neighbors when the clusters are overlapping or at least one clusterhead and another gateway node when the clusters are disjoint.

The CBRP is characterized by its fully distributed operation involving less flooding traffic during the dynamic route discovery process with additional local repair and route shortening mechanism that explicitly utilize uni-directional links which would otherwise be unutilized.

The operation of CBRP can be divided in three phases: Cluster formation, routing process and Cluster maintenance

(a) Cluster Formation: At any time, a node is in one of the three states: a cluster member (CM), a cluster head (CH), or undecided (UNDECIDED) (meaning still searching for its host cluster). Every node broadcast a hello message to its neighbors periodically. When a node comes up, it enters the undecided state and broadcasts a Hello message. When a cluster-head gets this hello message it responds with a triggered hello message immediately. When the undecided node gets this message it sets its state to member. If the undecided node times out, then it makes itself the cluster-head if it has bi-directional link to some neighbor otherwise it remains in undecided state and repeats the procedure again.

(b) Routing process: The routing process works in two steps. First, it discovers a route from a source node S to a destination node D, afterwards it routes the packets. When a source has to send data to destination, it floods route request packets (but only to the neighboring cluster-heads). On receiving the request a clusterhead checks to see if the destination is in its cluster. If yes, then it sends the request directly to the destination else it sends it to all its adjacent cluster-heads. The cluster-heads address is recorded in the packet so a cluster-head discards a request packet that it has already seen. When the destination receives the request packet, it replies back with the route that had been recorded in the request packet. If the source does not receive a reply within a time period, it backs off exponentially before trying to send route request again. In CBRP, routing is done using source routing. It also uses route shortening that is on receiving a source route packet, the node tries to find the farthest node in the route that is its neighbor and sends the packet to that node thus reducing the route. While forwarding the packet if a node detects a broken link it sends back an error message to the source and then uses local repair mechanism. In local repair mechanism, when a node finds the next hop is unreachable, it checks to see if the next hop can be reached through any of its neighbor or if hop after next hop can be reached through any other neighbor. If any of the two works, the packet can be sent out over the repaired path.

(c) Cluster maintenance: Clusterheads are elected by the individual clusters. It is expected that the clusterheads will not change frequently. For avoiding frequent change of clusterheads, a non-clusterhead never challenges the status of the existing clusterhead even though it satisfies the preliminary requirements of becoming a clusterhead and the clusterhead change takes place only when two clusterheads move next to each other in which case one of them leaves the role of clusterhead depending on certain rules for node removal, node addition and cluster head contention.

C. Comparison of DSR and CBRP

The routing protocols used in this study are compared with respect to different routing parameters are compared below in table 2

TABLE 2
COMPARISON OF DSR AND CBRP ROUTING PROTOCOLS

Parameter	DSR	CBRP
Routing structure	Flat	Cluster
Hello messages	No	Yes
Multiple routes	Yes	No
Critical nodes	No	Yes
Route maintained	Route Cache	Route table at cluster-Head
Routing metric	Shortest path or next available in route cache	First available route
Time complexity (route discovery)	O (2D)	O (2D)
Time complexity (route maintenance)	O (2D)	O (2d)
Communication complexity (route discovery)	O (2N)	O (2C)
Communication complexity (route maintenance)	O (2N)	O (2n)
Advantages	Multiple routes, beacon less	cluster heads exchange routing information
Disadvantages	Scalability problem, large delays	Cluster maintenance
Abbreviations: D = Diameter of the network N = Number of nodes in the Network d = Diameter of affected area C = Number of Clusters n = Number of affected nodes		

III. SIMULATION PARAMETERS AND PERFORMANCE METRIC

A. Simulation model

Network Simulator2 (NS-2) [29] a object-oriented, discrete event driven network simulator developed at UC Berkely written in C++ and OTcl, particularly popular in the ad hoc networking research community is use for the simulations. The traffic sources are CBR (continuous bit – rate). The source-destination pairs are spread randomly over the network. The node movement generator of ns-2 is used to generate node movement scenarios. The movement generator takes the number of nodes, pause time, maximum speed, field configuration and simulation time as input parameters. The parameter, which is of primary importance, is pause time. Pause time basically determines the mobility rate of the model, as pause time increases the mobility rate decreases. At the start of the simulations nodes are assigned some random position within the specified field configuration, for pause time seconds nodes stay at that position and after that they make a random movement to some other position. The propagation model is the Two way ground model [30]. Each data point in the following figures is the average of 5 runs each lasting for 500s of the simulated time with the same scenario configuration but different random seeds. Simulation parameters are listed in table 3.

TABLE 3
SIMULATION PARAMETERS

Parameter	Value
Simulator	ns-2
Protocols simulated	DSR and CBRP
Number of nodes	50,100,150,200,250
Traffic type	CBR (UDP)
Traffic sources	30% of nodes 70% of nodes
Simulation time	100 seconds
Simulation area	2000 m x 500 m
Transmission range	250 m
Node movement model	Random waypoint
Propagation model	Two way ground
Data payload	512 bytes/packet
Packet rate	4 packets/sec
Node pause time	0s highest mobility 100 s lowest mobility
Speed	20 m/s
Bandwidth	2 Mb/s

B. Performance metrics

The following performance metrics are considered for evaluation:

Packet Delivery Fraction: The ratio of the data packets delivered to the destinations to those generated by the sources.

Average end-to-end delay: This includes all possible delays caused by buffering during route discovery latency, queuing at the interface queue, retransmission delays at the MAC, and propagation and transfer times.

Normalized routing load: The number of routing packets transmitted per data packet delivered at the destination.

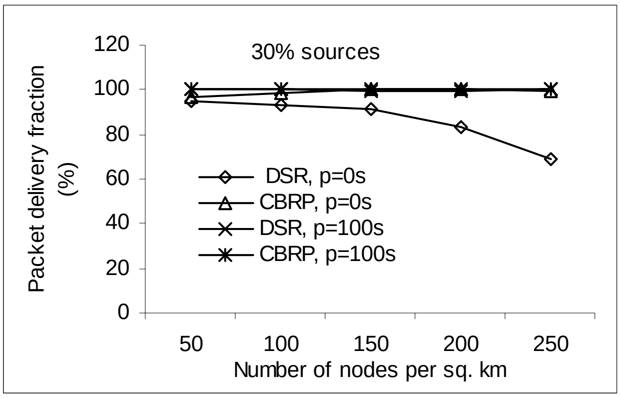
Throughput: The amount of data transmitted by the network divided by time period.

IV. RESULTS AND DISCUSSION

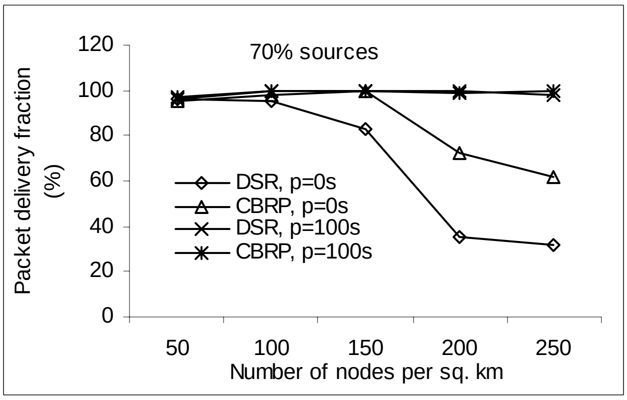
The simulation results are shown in the following section in the form of line graphs. Graphs show comparison between the two protocols on the basis of the above-mentioned metrics as a function of node density in high mobility (pause time = 0s) and stationary (pause time = 100s) scenarios with 30%, 70% traffic sources.

A. *Packet delivery fraction*

Figure 1 shows the packet delivery fraction as a function of both nodes density and different number of traffic sources. Each graph shows the PDF of both the protocols, DSR and CBRP, in a high mobility (pause time = 0s) and stationary (pause time = 100s) scenarios.



(a) 30% sources



(b) 70% sources

Figure1 Packet delivery fraction as a function of 50, 100, 150, 200, 250 nodes per sq. km and 30%, 70% traffic sources

In static scenarios (p = 100s) with 30% CBR sources, PDF is nearly 100% for both the protocols. For DSR, PDF remains 100% upto number of nodes, N, = 100 per sq. km after that PDF slowly degrades to 99.80% at N = 250 with an overall decrease of 0.2% from N = 50 to N = 250, whereas for CBRP the PDF remains 100% upto N = 200 and degrades to 99.96% from N = 200 to N = 250 with an decrease of just 0.04%. In high mobility (p = 0s) scenarios, the packet delivery fraction of DSR degrades from 95.32% at N = 50 to 69.14% at N = 250 with an overall decrease of 26.18% as the density of nodes increases, whereas in CBRP packet delivery improves from 96.98% at N = 50 to 100% at N = 200 after that PDF degrades as the density increases.

However in stationary (p = 100s) scenarios with 70% CBR sources, the PDF of DSR increases from 96.56% at N = 50 to 99.77% at N = 150 after that it degrades to 97.75% at N = 250, whereas for CBRP the PDF increases from 96.82% at N = 50 to 100% at N = 150 after that PDF degrades to 98.97% at N = 250. Both the protocols scale well with increasing number of nodes per sq. km. However this is not true for high mobility (p = 0s) scenarios. For DSR the PDF degrades from 95.79% at N = 50 to 31.73% at N = 250, whereas for CBRP the PDF first increases from 95.62% at N = 50 to 99.98% at N = 150 then degrades to 61.88% at N = 250. Both the protocols have nearly comparable PDF (DSR 95.79% and CBRP 95.62%) at N = 50 but as the number of nodes per sq. km increase, CBRP performs better than DSR and with N = 200 or more CBRP clearly outperforms DSR at a factor of ~ 2.

DSR has a lower PDF than CBRP in high mobility (0s pause time) scenarios and more or less same PDF in stationary (100s pause time) scenarios. In high mobility scenarios, the PDF due to 30% traffic sources is better (with 200 or more nodes PDF is two times more) than that due to 70% traffic sources. The performance degradation in PDF is due to packet drops by the routing algorithm after being failed to transfer data in the active routes. The packet drops are due to network partitioning, link break, collision and congestion in the ad hoc network.

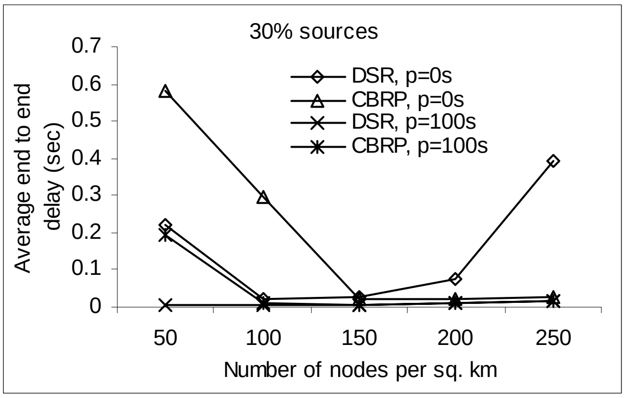
B. *Average end to end delay*

Figure 2 shows average end to end delay of both the protocols, DSR and CBRP, as a function of both nodes density- 50, 100, 150, 200 and 250 nodes per sq. km and different number of traffic sources- 30% and 70% CBR sources. Each chart shows throughput of both the protocols in a high mobility (p = 0s) and a stationary (p = 100s) scenarios.

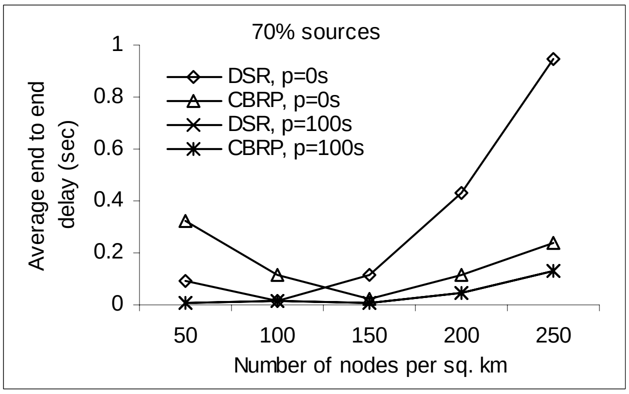
In high mobility (p = 0s) scenarios with 30% CBR traffic sources, average end to end delay for DSR decreases 10 times from 0.2221s at N = 50 to 0.0207s at N = 100 after that it increases gradually till N = 200 where it increases 5 times from 0.0768s to 0.3924s at N = 250, whereas for CBRP average delay decreases up to N = 200 after that it increase slightly. For low density (up to 100 nodes per sq. km) DSR performs better than CBRP whereas CBRP performs better for large density (more than 100 nodes per sq. km). For stationary (p = 100s) scenarios, both the protocols show comparable average end to end delay except at N = 50 where DSR (0.0059s) performs better than CBRP (0.1955s).

In high mobility (p = 0s) scenarios with 70% traffic sources, the average end to end delay for DSR is below 0.1s with 50 and 100 nodes per sq. km. As the number of nodes increases, delay grows quickly and at 250 nodes per sq. km delay is about 0.9s, whereas in case of CBRP the average delay decreases from 0.3211s at N = 50 to 0.0202s at N = 150 and with increasing number of nodes the delay grows slowly (with 250 nodes this delay is 4 times less than that of DSR). In stationary (p = 100s) scenarios both protocols show more or less same average delay as the number of nodes increases.

With number of nodes less than 150, DSR has lower or same average end to end delay in high mobility (p = 0s) and static (p = 100s) scenarios with both traffic sources. With increasing number of nodes beyond 150, DSR has higher average delay than CBRP with both traffic sources and in high mobility scenarios. Since an increasing number of nodes means an increase in path length, longer routes takes longer time to discover and to travel along them. They also have a higher chance of breaking than shorter ones; as a result more route repairs are needed, which in turn result in a higher delay of the data packets, whereas for CBRP this behavior is due to their cluster based structure. Low density may form large number of small loosely connected clusters and may cause network to be frequently disconnected by movement of any node, which introduce delay in route setup, results in higher average end to end delay of data packets.



(a) 30% sources



(b) 70% sources

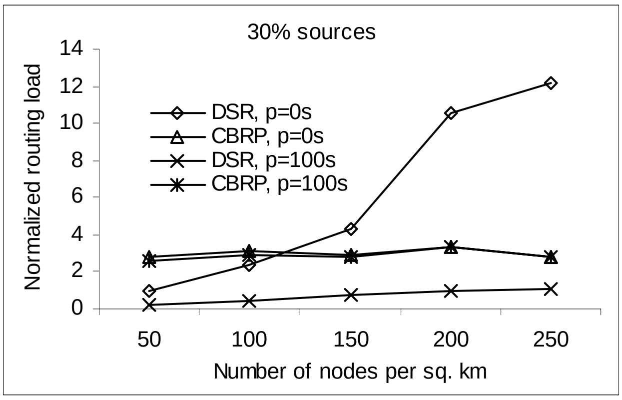
Figure2 Average end to end delay as a function of 50, 100, 150, 200, 250 nodes per sq. km and 30%, 70% traffic sources.

C. *Normalized routing load*

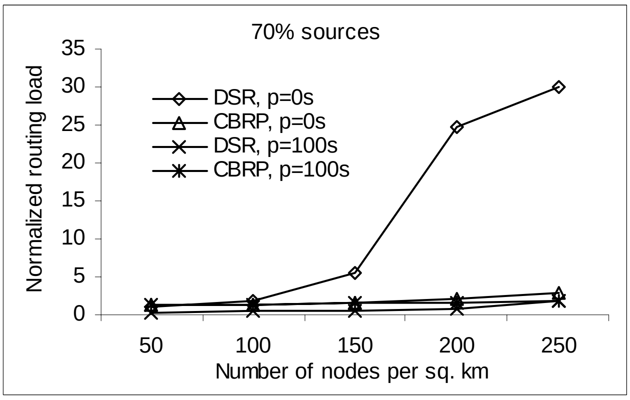
Figure 3 shows the normalized routing load as a function of both nodes density and different number of traffic sources. Each graph shows the PDF of both the protocols, DSR and CBRP, in a high mobility (pause time = 0s) and stationary (pause time = 100s) scenarios.

In high mobility (p = 0s) with 30% traffic sources, DSR exhibits NRL below 1 with 50 nodes per sq. km but as the number of nodes increases, NRL grows and with 250 nodes NRL is about 12, whereas NRL is well below 4 (lies between 2.8 and 3.3) for CBRP. In static (p = 500s) scenarios, NRL for DSR grows with number of nodes but is well below 1 except at N = 250 where it is just above 1 (1.06). NRL for CBRP is more or less similar to NRL in high mobility (p = 0s) scenarios. In stationary scenarios DSR performs better than CBRP.

In high mobility (p = 0s) with 70% traffic sources, NRL for DSR is just above 1 (1.08) with 50 nodes per sq. km but as the number of nodes increases, NRL grows and with 250 nodes NRL is of the order of 30, whereas NRL is well below 3 (lies between 1.25 and 2.97) for CBRP. In static (p = 100s) scenarios, NRL for DSR grows with number of nodes but is well below 1 except at N = 250 where it is more than 1 (1.84), whereas NRL for CBRP is always more than 1 (lies between 1.21 and 1.75) as the number of node increases.



(a) 30% sources



(b) 70% sources

Figure3 Normalized routing load as a function of 50, 100, 150, 200, 250 nodes per sq. km and 30%, 70% traffic sources.

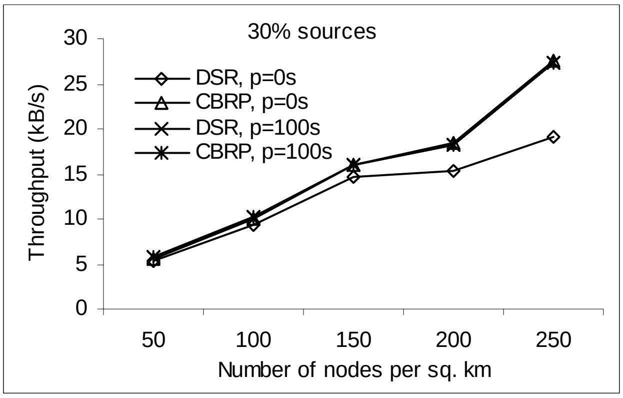
In high mobility (p = 0s) with 70% traffic sources, NRL for DSR is just above 1 (1.08) with 50 nodes per sq. km but as the number of nodes increases, NRL grows and with 250 nodes NRL is of the order of 30, whereas NRL is well below 3 (lies between 1.25 and 2.97) for CBRP. In static (p = 100s) scenarios, NRL for DSR grows with number of nodes but is well below 1 except at N = 250 where it is more than 1 (1.84), whereas NRL for CBRP is always more than 1 (lies between 1.21 and 1.75) as the number of node increases.

CBRP has lower NRL than DSR in high mobility (0s pause time) and a higher NRL in case of stationary (100s pause time) scenarios. This is because CBRP only broadcasts route requests to cluster heads. Gateway nodes receive the route requests as well but they forward them to the next cluster-heads. This largely reduces the route discovery packets which in turn reduces NRL.

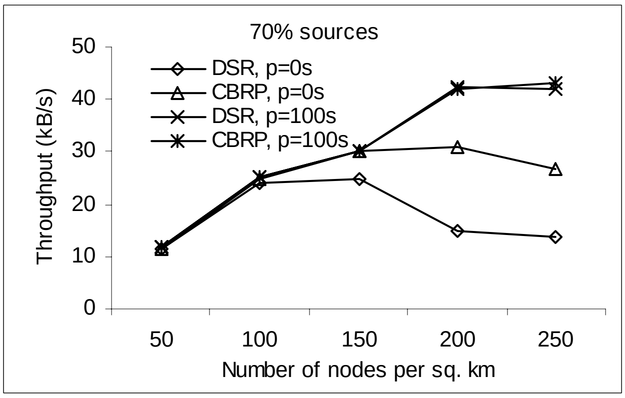
D. *Throughput*

Figure 4 shows throughput of both the protocols, DSR and CBRP, as a function of both nodes density- 50, 100, 150, 200 and 250 nodes per sq. km and different number of traffic sources- 30% and 70% CBR sources. Each chart shows throughput of both the protocols in a high mobility (p = 0s) and a stationary (p = 100s) scenarios.

In high mobility (p = 0s) and zero mobility (p = 100s) scenarios with 30% CBR sources the throughput of both the protocols improve with increasing nodes density. In high mobility (p = 0s) both the protocols depicts nearly comparable throughput (DSR 5.42kB/s, CBRP 5.54kB/s at N = 50 and DSR 9.44kB/s, CBRP 9.92kB/s at N = 100) up to 100 nodes per sq. km. After that CBRP outperforms DSR and at N = 250 this difference is quit significant (DSR 19.06kB/s and CBRP 27.55kB/s). In static (p = 100s) scenario both the protocols show no significant difference in throughput and scales well with increasing nodes density. Chart (a) depicts that DSR at p=100s and CBRP at p=0s, p=100s shows similar behavior with increasing number of nodes per sq. km.



(a) 30% sources



(b) 70% sources

Figure 4 Throughput in kB/s as a function of 50, 100, 150, 200, 250 nodes per sq. km and 30%, 70% traffic sources.

In high mobility (p = 0s) and with 70% CBR traffic sources the throughput of both the protocols increase up to N = 150 for DSR and N = 200 for CBRP, after that the throughput degrades. Both have nearly same throughput up to N = 100 and with increasing nodes density CBRP performs better than DSR and with N = 200 or more CBRP clearly outperforms DSR at a factor of ~ 2. In stationary (p = 100s), throughput of CBRP improves with increasing number of nodes per sq. km, whereas for DSR throughput improves up to N = 200 after it degrades.

CBRP has a better throughput than DSR in high mobility and stationary scenarios with both traffic sources. This better throughput comes from its cluster based structure which largely reduces network traffic.

V. CONCLUSION

This paper compared the performance of DSR and CBRP, two on-demand source routing protocols for mobile ad hoc networks. DSR and CBRP both use on-demand route discovery, but with different flooding behavior. In particular, DSR use network-wide flooding for route discovery and does not depend on any periodic *hello* message or timer-based activities. CBRP, on the other hand, only broadcasts route requests to cluster heads, largely reducing the network traffic. *Hello* messages are the integral part of CBRP and the size of a hello message may be large as it contains the neighbor table and cluster adjacency table of the sender. As a result, while CBRP uses hello messages to establish clusters and in turn reduce the flood in route discovery, the hello message itself is another kind of overhead. The general observation from the simulation is that in static (pause time 100s) scenarios, due to similar performance any, either DSR or CBRP, can be used in large scale mobile ad hoc networks but in high mobility (pause time 0s) scenarios, CBRP outperforms DSR. CBRP scales well with increasing number of nodes per sq. km.

Further when compared results of this work with earlier reported similar works [16, 19-22, 25,26] it clearly show that the previous results for 50 and 100 nodes closely matches with the result of this work for number of nodes up to 100. However earlier works did not consider number of nodes above 100. Hence results of this work are inline with previously reported results and can be considered as statistically confident for those scenarios.

We are currently analyzing more precisely the effect of mobility and network load on the performance of routing protocols (DSR and CBRP) in large scale mobile ad hoc networks. CBRP broadcasts periodic hello messages to establish and maintain clusters, clusters reduce network traffic but at a cost of extra overhead in the form of hello messages. We believe that there are some ways to reduce this overhead. We plan to investigate and study on how to improve the performance of CBRP by reducing clustering overhead.

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