Performance evaluation of Multipoint Relays: Collision and Energy efficiency issues

Technical Report

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1. Abstract

Mobile Ad Hoc Network (MANET) is an infrastructure-less wireless communication network, in which the mobile nodes communicate directly with other nodes that are within their transmission range and forward packets for other nodes that are not within the transmission range of each other. Various routing protocols for such environment have been suggested at the Internet Engineering Task Force's (IETF) working group for MANET [13], like Ad Hoc On-demand Distance Vector Routing (AODV), Optimised Link State Routing (OLSR), Topology Broadcast Based on Reverse-Path Forwarding (TBRPF) etc.

Since the nodes in MANET are mobile, they are usually power constrained due to the limited battery resources. Various algorithms have been proposed to control the power for transmission of packets in order to minimise the total energy consumption of the nodes.

Multipoint Relays (MPR) are a subset of immediate neighbours of a node such that these MPR nodes reach every two-hop nodes of that node. MPR nodes have been used to reduce the number of transmissions for broadcast and unicast routing in various algorithms. Since the number of transmissions and receptions are drastically reduced when using MPRs for transmissions, this method is a very efficient way of reducing total power consumption of the network nodes, especially during flooding of a packet. This report compares the performance of five new algorithms for MPR selection to the original MPR selection scheme as included in the OLSR protocol. The new algorithms have been designed with the aim of reducing the total number of MPR nodes in the network and the total number of transmissions and/or receptions, so that it will finally reduce the power consumption of the nodes.

A simulator was designed for the comparison of these algorithms, and this report discusses the results of the simulations performed. Overall, though these new algorithms theoretically reduce the number of transmissions and receptions, they were found to perform similarly to the original algorithm, thus proving that the MPR selection algorithm, commonly used in various protocols is a very robust and efficient algorithm.

2. Introduction

Mobile Ad Hoc Network is a network formed by a set of mobile nodes, which are capable of communicating with each other without an existing infrastructure and in a wireless environment. Nodes in MANET dynamically form a distributed, autonomous network, with each node capable of acting not only as a source or sink for single-hop messages (node to access point and vice versa) like in traditional wireless environment, but also as a router for multi-hop messages. When not within wireless transmission range, some of the nodes in the network can forward a packet for other nodes, thus creating multi-hop paths in the network. Each node supports an ad hoc routing protocol that enables it to find multi-hop paths to all the other nodes in the network. Presence of mobility and wireless medium, however, requires that the protocols must be directly adaptive to them.

Currently, two main types of protocol exist: proactive protocols, in which topology information is exchanged and updated periodically to maintain routes to all possible destinations, and reactive protocols, in which routes are discovered on demand. The main issue with proactive routing is the large amount of control message generation, while reactive protocols must cope with the delay in route generation, without creating a lot of control traffic.

Routing protocols like OLSR relies on Multipoint Relay nodes to optimise the number of packets that are flooded into the network while diffusing network information. The MPR nodes are used to calculate the route to all destinations in the network, and each such route is found to be a shortest-path route.

This report discusses about an existing MPR selection scheme, and some suggested improvements to it. The new MPR selection heuristics have been proposed to minimise the number of transmissions and receptions, so that the energy of the nodes, which is spent in transmissions and receptions, is reduced. A simulator has been developed and the schemes have been tested. The design of the simulator, the experiments performed, and the results obtained are then described.

3. OLSR (Optimised Link State Routing)

3.1. Description of OLSR

OLSR [1, 6, 8] exists as a Request for Comments (RFC) in the IETF MANET charter. It is a link state protocol, in which all the nodes distribute information about the neighbourhood regularly. Consistent and up-to-date information about the status of the network is thus always maintained, which allows for the calculation of routing information for all the nodes in the network. There is no latency for route discovery as information is available immediately whenever a new route is required.

In this protocol, the nodes send neighbourhood link state information to their immediate neighbours through periodic “Hello” messages, and information about topology or link state is disseminated to the whole network for route calculation purposes with the help of “Topology Control” messages. From these two types of information exchanged, shortest routes are calculated and are immediately available when needed. However, it includes an optimization, where only a subset of the nodes, called MPR nodes, are used to broadcast packets in the network.

The MPR nodes provide an efficient mechanism of controlling the traffic flooding in the network while broadcasting network information. Only messages received from MPR selectors are forwarded, thus reducing the number of re-transmissions. Also, the nodes only have to declare the link state information about their MPR selectors instead of all the links, thus reducing the size of control packets. The protocol is distributed since the selection of MPR is done independently and locally by each node, and according to the information collected from all the neighbours, routing decisions are made hop-by-hop at each node, using the information about MPR nodes, and a shortest path algorithm.

Proactive protocols like OLSR offer low latency for path finding, but a large overhead may be needed in the exchange of up-to-date information about even some unnecessary routes. They might waste resources while updating the information about the network topology even when there is no change in the network. It however does not generate extra traffic when there are link removals or additions. Such protocols is well-suited for network where the topology information changes rapidly due to high mobility, since in reactive protocols, rapid changes usually leads to delay in active transmissions due to route recalculations. Also, due to its multipoint relaying technique, OLSR is proved to be highly efficient in dense networks [5].

3.2. MPR

Each node chooses as its MPRs, a subset of its immediate neighbours, such that all its two hop neighbours are reachable through these MPRs. For example, in figure 1, for the black node (source) in the centre, all the 2-hop neighbours (all the nodes in the outer dotted circle) are reached by at least one of the grey nodes, which are a subset of its immediate neighbours (all the nodes in the inner dotted circle). MPR selection however requires that only those nodes that have bi-directional links with the selecting node be considered as its immediate neighbourhood. The nodes that have bi-directional links with these neighbour nodes but not with the selecting node are taken as the two-hop neighbourhood of that node.

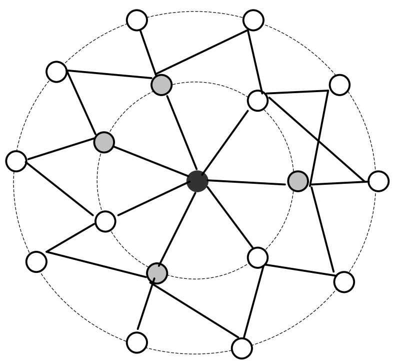


Figure 1: Example of possible MPR set (grey nodes) for the central (black) node

Upon receipt, a node forwards a broadcast message if and only if the message was received for the first time and the sender of the message has selected this node as its MPR. The other nodes only receive and process the packets, but do not forward. Hence, a significant reduction in total messages spread through the network occurs. Also, the link state information disseminated through the network can only contain the information about a node's MPR selectors, i.e. nodes that have selected the node as their MPR, thus the volume of information exchanged is also reduced – another optimisation offered by this protocol.

The MPR set is recalculated whenever a change in one or two hop neighbourhood is detected. Also, Topology Control messages are sent at a shorter interval after a change in this information.

OLSR uses MPR nodes only as the intermediate relays in its route calculations. By decreasing the number of MPRs in a network, the routing protocol can be made more efficient by producing shorter routes. MPR nodes are also being used in other routing protocols like Multipoint Relay Flooding for Manets (MPRF) [12], and reactive protocols like Multipoint Relay Distance Vector protocol (MPRDV) [9].

4. MPR Selection Algorithms

This section report discusses some MPR selection algorithms as described in [1, 2, 4]. Each node selects MPR nodes independently of other nodes. A node chooses as its MPRs, a subset of its immediate neighbours, such that all its two hop neighbours are reachable through these MPRs. Lesser the number of MPRs selected, the more efficient is the final routing calculations in reducing the number of hops in a path. OLSR suggests an efficient MPR selection algorithm, which is described below. After that, some suggested improvements algorithms are described, which are aimed at reducing duplicate retransmissions during broadcast flooding. By reducing the number of retransmissions and receptions, the total energy expenditure in the network due to a single broadcast can be reduced, thus increasing the battery life of the nodes in the network.

4.1 Notations

For each node i,

N(i) =the set of immediate neighbouring nodes with bi-directional links to i;

$N_2(i)$ = the set of strict 2-hop neighbours of i, i.e., the set of nodes that are immediate neighbours of nodes in N(i), but does not contain i, or any nodes in N(i);

MPR(i) = set of MPR nodes for node i, which is a subset of N(i);

D(j) = degree of the set of strict 2-hop neighbourhood of i, which are covered by node j, where j belongs to N(i), i.e., $D(j) = |\{u \in N(j) \mid u \in N_2(i) \text{ and } j \in N(i)\}|$;

$d_u(j)$ = the number of two-hop nodes that j can cover which are yet uncovered by other nodes;

$d_c(j)$ = the number of two-hop neighbours that neighbour j can cover but are already covered by another selected MPR;

Thus, $D(j) = d_u(j) + d_c(j)$ at all times;

Din(k) = in-degree of two-hop neighbours of i, or, number of neighbours of a node k in $N_2(i)$, such that the neighbours are also immediate neighbours of i, i.e., $Din(k) = |\{j \in N(i) \mid j \in N(k) \text{ and } k \in N_2(i)\}|$;

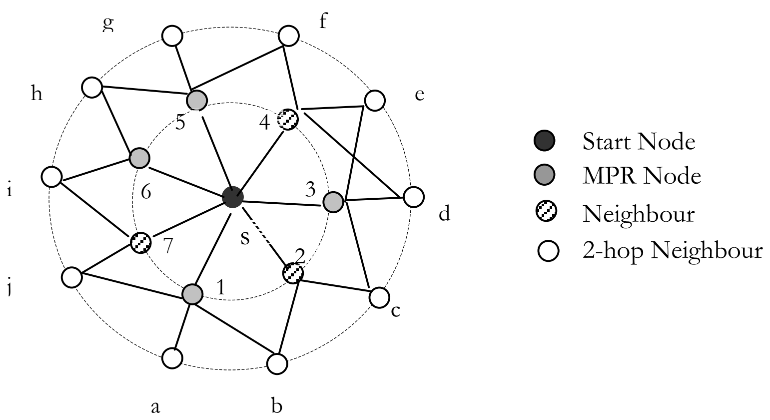


Figure 2: Example of MPR selection

For figure 2 above, for node s,

N(s) = {1, 2,3,4,5,6,7},

$N_2(s)$ = {a, b, c, d, e, f, g, h, i, j},

MPR(s) = {1, 3, 4, 6} (one possible solution)

D(1) = |{a, b, j}| = 3,

Din(b) = |{1, 2}| = 2,

4.2 Original Algorithm

The following is the algorithm presented in the RFC for OLSR protocol for the selection of MPR set of a node i:

1. Start with an empty MPR set (MPR(i) = ∅).
2. Calculate D(j) for each node in the network.
3. Find any node in N_2(i), which is covered by only one node j in N(i). Add j to MPR(i). Remove all the nodes in N_2(i) covered by j from N_2(i), and remove j from N(i).
4. While $N_2(i) \neq \emptyset$
    a. Calculate d_u(j) for each remaining nodes j in N(i), i.e., calculate the number of strict 2-hop nodes reachable by j.
    b. Add to MPR set, node j' with maximum d_u(j), i.e., the node that covers the maximum number of remaining two hop nodes. In case of multiple choices, chose a node with **maximum** D(j).
    c. Remove all nodes covered by j' from N_2(i) and remove j' from N(i).

An optimisation step consists of checking if removal of any node in the MPR covers all the nodes in N2(i), and removing such a redundant node.

Step 2 in this algorithm selects nodes that will eventually be added to the MPR node set, since at least one of the nodes covered by such nodes are not covered by any other neighbours. For example, in figure 2, the step selects and adds to MPR set nodes like 5 which is the only node that covers node g. Similarly, 1 is added because of node a.

Theoretical Performance: the approximation ratio of this algorithm is $1+\ln|N_2(i)|$ for source node i, or $1+\ln|\Delta(i)|$ when Δ(i) (the maximum number of two hop nodes that each one-hop neighbours of i may cover) is bounded by a constant independent of the size of the network [2].

4.3 Alternate Algorithms

4.3.1 In-Degree Greedy Set Cover

The algorithm introduced in [2] considers the in-degree (Din(k)) of the neighbouring nodes of the selector node i. The in-degree gives the number of nodes that are neighbours of nodes in strict two-hop neighbourhood of node i, such that the neighbours are also neighbours of i. The goal of this strategy is to exploit the fact that this maximum value of in-degree of the two-hop nodes is likely to be smaller than the maximum uncovered node degree (d(j)) as used in the original algorithm.

1. Start with an empty MPR set (MPR(i) = ∅).
2. Find any node in N_2(i), which is covered by only one node j in N(i). i.e., find any node for which Din(k) = 1. Add j to MPR(i). Remove all the nodes in N_2(i) covered by j from N_2(i), and remove j from N(i)
3. While $N_2(i) \neq \emptyset$
    3.1. Calculate D(j) for each remaining nodes j in N(i), i.e., calculate the number of strict 2-hop nodes reachable by j
    3.2. Pick any two-hop node k.
    3.3. From all the nodes in N(i) that covers k, find the node j' with minimum D(j')
    3.4. Add j' to MPR set, remove all nodes covered by j' from N_2(i) and remove j' from N(i)

An optimisation step consists of checking if removal of any node in the MPR covers all the nodes in N2(i), and removing such a redundant node.

Theoretical Performance: let $\Delta^+(i)$ be the maximum number of two hop nodes that each one-hop neighbours of i may cover, and $\Delta^-(i)$ be the maximum value of in-degree (Din(k)) of the two-hop nodes. The approximation ratio of this algorithm is $1+\ln|N_2(i)|$ for general case and min($\Delta^-(i)$,

$1+\ln|\Delta^+(i)|$ when $\Delta^-(i)$ and $\Delta^+(i)$ are bounded by a constant independent of the size of the network [2].

4.3.2 Minimum Overlap Selection

This algorithm also introduced in [2] aims at exploiting the mimimum overlap between the two-hop nodes covered by the selected MPR set, such that the sets of two-hop nodes covered by the MPRs are as disjoint as possible. Since only MPR nodes are used for routing and broadcasting, such a selection will reduce collisions due to possible hidden terminal problem.

Let $d_c(j)$ be the number of two-hop neighbours that neighbour j can cover but are also already covered by another selected MPR, and $d_u(j)$ be the number of two-hop nodes that j can cover which are yet uncovered by other nodes.

1. Start with an empty MPR set ($MPR(i) = \emptyset$). Initially, $d_u(j) = D(j)$ and $d_c(j) = 0$.
2. Find any nodes in $N_2(i)$, which is covered by only one node j in N(i). i.e., find any node for which Din(k) = 1. Add j to MPR(i) and remove j from N(i). Remove each node k in $N_2(i)$ covered by j from $N_2(i)$, and for each neighbour j' which also covers k, increment covered count $d_c(j')$ by 1 and decrement uncovered count $d_u(j')$ by 1.
3. While $N_2(i) \neq \emptyset$
   3.1. Calculate ratio $d_c(j)/ d_u(j)$ for each node in N(i) with $d_u(j) > 0$ and pick node j with the minimum ratio. If ties exist, pick **randomly**.
   3.2. Add j to MPR(i) and remove j from N(i). Remove each node k in $N_2(i)$ covered by j from $N_2(i)$, and for each neighbour j' which also covers k, increment covered count $d_c(j')$ by 1 and decrement uncovered count $d_u(j')$.

An optimisation step consists of checking if removal of any nodes in the MPR covers all the nodes in N2(i), and removing such a redundant node.

Theoretical Performance: The approximation ratio of this algorithm is $1+\ln|N_2(i)|$ for source node i in general case and $1+\ln|\Delta(i)|$ when $\Delta(i)$ (the maximum number of two hop nodes that each one-hop neighbours of i may cover) is bounded by a constant independent of the size of the network [2].

4.3.3 Minimum Overlap with Highest Degree Selection

This algorithm is similar to the minimum overlap algorithm in section 4.3.2, except that in step 3.1, instead of picking a random node when ties exist, this algorithm selects the node that has **maximum** number of remaining uncovered nodes.

The theoretical performance of this modified algorithm remains the same as in the minimum overlap algorithm in section 4.3.2.

4.3.4 Prioritised MPR Selection

This algorithm is a combination of the original MPR selection algorithm described in section 4.3.1 and the minimum overlap algorithm described in 4.3.2 above. This algorithm chooses as the MPR, the node that covers maximum number of yet uncovered nodes like in original algorithm, but in case there is a tie among such nodes, the node that has minimum uncovered nodes is used to minimise the possible overlap between the nodes covered by the MPR nodes.

Thus the algorithm is the same as in case of the original MPR selection algorithm (section 4.2), except in step 4.b, **minimum** $d_u(j)$ is chosen instead of maximum D(j) when ties exist.

Theoretical Performance: The approximation ratio of this algorithm is $1+\ln|N_2(i)|$ for source node i in the general case and $1+\ln|\Delta(i)|$ when $\Delta(i)$ (the maximum number of two hop nodes that each one-hop neighbours of i may cover) is bounded by a constant independent of the size of the network [3].

4.3.5 OLSR Random High Degree Selection

This algorithm varies from the original MPR computation heuristic is that when there are multiple nodes that provide the same number of 2-hop nodes that they can cover, instead of adding the one with maximum D(j), the node selected is randomly chosen. The original algorithm uses the maximum D(j) in order to provide some redundancy, but such redundancy might lead to increased number of transmissions and receptions, which this algorithm tries to avoid.

Thus the algorithm is same as in case of the original MPR selection algorithm (section 4.2), except in step 4.b, instead of choosing the node with maximum D(j), a node is chosen **randomly** when ties exist.

Theoretical Performance: The approximation ratio of this algorithm is $1+\ln|N_2(i)|$ for the source node i in general case and $1+\ln|\Delta(i)|$ when $\Delta(i)$ (the maximum number of two hop nodes that each one-hop neighbours of i may cover) is bounded by a constant independent of the size of the network.

5. Simulator Design

A simulator provides an environment with advantages over real world tests, for example, repeatable scenarios making retesting after some small improvement possible, and isolation of parameters to check the effects of single parameter in detail.

A simplified simulator was designed to evaluate the performance of various algorithms proposed for MANETS. It has been used to evaluate the MPR selection algorithms described above. The next two sections describe the simulator design and the results of simulations.

5.1 Requirements

The simulator should represent the arbitrary and wireless nature of MANET network as close as possible. Possible collisions, collision avoidance mechanisms, queuing etc should also be modelled. The specification for the underlying MAC and PHY layer is assumed to be in accordance with 802.11b specifications.

In addition, our simulator also provides a visual interface that allows analysing of simulation results. Mobility model (for both node mobility and changes in propagation medium), which is a crucial part of MANET, is however not modelled in this version of the simulator.

5.2 Design

Network Structure: The simulator uses a simple topology model: the network is modelled by a unit-disk graph, which consists of N nodes randomly positioned according to the uniform distribution law in a network area of length L and width W. We recall that in a unit-disk graph, there exists a direct link between any two nodes in this network if and only if the distance between the two nodes is less than or equal to the radio range r. For the sake of simplicity, we assure that all the nodes transmit at the same power level. All the links between the nodes are considered to be bi-directional.

Currently, only flooding of packets is simulated. The messages are broadcast messages and do not require an acknowledgement of reception or retransmissions when error of reception occurs.

Each node in the network is capable of calculating and storing its MPR set according to a chosen algorithm. It also stores a list of its immediate neighbours, and a list of nodes that has selected it as an MPR (MPR selector). The packet forwarding can be done as a full flooding, where each node that receives a packet for the first time forwards it to all its immediate neighbours. MPR flooding is also possible, where in accordance with OLSR specifications, a node forwards a packet only if it received its packet for the first time from an MPR selector.

Only MPR selection and usage of MPRs as described in OLSR have been developed, specifics like exchange of Hello or Topology Control messages or construction of various tables are not simulated here.

Scheduler: In a dense network, a lot of packets may be lost due to interference and collisions. Also, there might be some propagation delays and other delays (jitter, backoffs, etc.) introduced due to collision avoidance mechanisms. In order to simulate these possible collisions, and delays in case of a broadcast, a simple scheduler was designed.

The number of slots s is initially declared, which correspond to time slots. Transmission of a single packet can take k slots, where k is constant for each experiment. For the results included in this paper, the packets are assumed to be only 1 slot size, i.e., k = 1. The node that starts a broadcast starts at slot 0. It sends the packets to all of its neighbours. Each of the receivers processes the packet, and if it needs to forward the packet (for example, if it received it for the first time, and from an MPR selector), it chooses a random slot number between 0 and s-1. This receiver is then added to that slot as a transmitter. The scheduler checks at each slot for a list of transmitters, and calculates the possible receptors for them. If a node appears more than once in the list of receptors, it is assumed that the node will receive packet from two nodes at the same time resulting in a collision and loss of packet. So, the node is removed from the list of receptors. The packet is transmitted to the remaining receptors, all of which again repeat the random slot number selection process. The process completes when all the slots are empty. As collisions occur, it is possible that not all nodes received the packet and the broadcast failed.

Visual interface:

The Graphical User Interface was designed using a multi-platform C++ GUI toolkit called Qt [14]. The GUI consists of two modes: normal and script mode. In the normal mode, a single network can be created according to the user specifications about number of nodes, network size, radio range, etc. The network is visually depicted and maybe further used to simulate flooding, MPR selections etc, where different coloured nodes are used to show the steps involved. This mode also allows saving, and opening networks from files and creates some simple output trace files. In script mode, a script file can be opened, which gives the specification about the random network to be built, and the algorithm to follow to find the MPR nodes, flooding mechanism to use, number of runs etc. When the script is run, the output of these runs is written to a trace file, which can be analysed.

Data Analysis:

The trace files that are created contain measurement of variables like number of MPR node, total number of packets transmitted, total number of packet received, number of collisions, etc. These trace files are analysed using Microsoft Excel. The results of the analysis will follow in the next section.

Extensions:

The simulator will be later extended to include other routing protocols, and other algorithms related to MANET networks. Network mobility model may be included in the future. Also, more features like manual network creation will be added.

6. Experimentations and Results

Various sized networks with different parameters were used to test the MPR algorithms described above and their performances were compared according to three main criteria as will be discussed in this section. The main goal was to see if it was possible to save network resources (battery, CPU) by reducing the number of packets that need to be circulated in the network, while keeping network collisions to minimum, and guaranteeing that all the nodes receive the packet that was broadcasted.

In all cases, as was expected, pure flooding took more time to complete and took more packets transmissions and receptions than the flooding using any of the MPR selection algorithms. Overall, the new suggested MPR selection algorithms did not show any improvements in terms of reduction in number of MPR nodes selected, number of retransmissions/receptions etc, thus proving that the original MPR selection algorithm is robust, and results in an efficient set of MPR nodes for a wireless network. Among the new algorithms, in-degree selection algorithm gave a poor performance, while OLSR random high degree selection algorithm and the prioritised algorithm gave a performance that was similar to that of original MPR selection algorithm, with the values measured slightly higher or the same as the OLSR algorithm.

6.1 Number of Receptions and Transmissions

The aim of a broadcast protocol is to minimise the network traffic (i.e., number of packets received and transmitted) while assuring that each of the nodes in the network receives the broadcasted packet. Some simulations were carried out to measure how MPR flooding compares to full flooding in terms of the network traffic generated, as well as if the new MPR selection algorithms help in reducing the traffic. The values that were measured were the average MPR count per node, average number of retransmissions, and receptions for each broadcast, and comparison of these values for the different algorithms.

Simulation Conditions:

- Nodes are randomly placed in a square field of 1000m * 1000m
- Radio range is 200 meters
- Number of nodes in the network was varied from 50 to 400 for the radio ranges
- In each simulation, every node in the random network will start transmission one after the other, and various values are measured for each such transmission. Ten such simulations are carried out, and an average of the results is finally computed.

Simulation Results:

As expected, it was observed that the number of MPR nodes that the new algorithms selected was either the same as in the case original MPR selection algorithm (curve OLSR in the figures below), or increased by a small number. The number of MPR nodes per node were found to be increased by around up to 1 or 2 in most cases, but on average was similar, despite the increase in density of the network. With the in-degree algorithm, the average MPR node count increased the most, thus increasing the other parameters like retransmissions and reception counts.

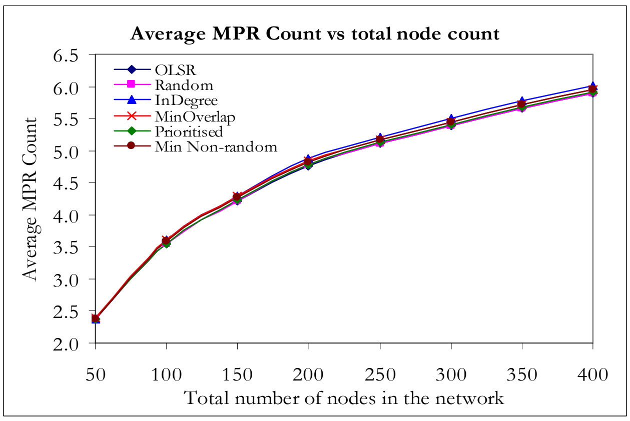


Figure 3: Average MPR nodes per node for network with radio range 200m

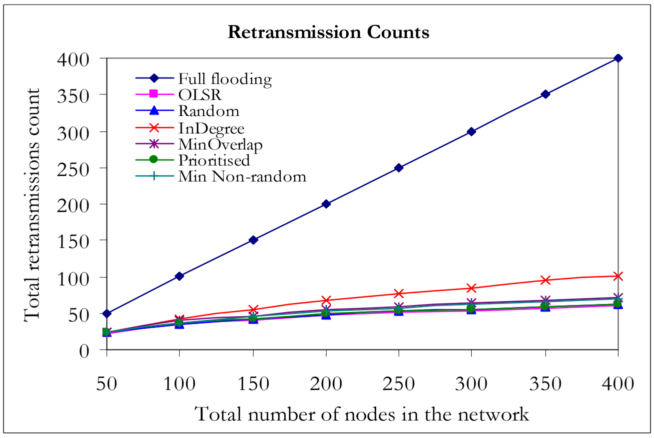


Figure 4: Total retransmissions for each broadcast for network with radio range 200m: comparison of MPR broadcast to full broadcast flooding

The number of retransmissions, which is the total number of packets sent and forwarded by the nodes in the network, reduced drastically for MPR flooding as compared to traditional full broadcast flooding as can be seen in figure 4. The number however mostly increased for the case of the new MPR selection algorithms as compared to the original MPR selection algorithm. Among the various MPR selection algorithms, the in-degree algorithm was found to perform poorly, increasing the retransmissions in average by 43.46% (see figure 5).

In case of minimum overlap algorithm (curve MinOverlap in figures), the number of retransmissions was found to increase by around 15.13% on average. The Minimum Overlap with Highest Degree Selection algorithm (Min Non-random in figures) gave a slightly better performance than the MinOverlap one with an increase of 11.47%. In case of prioritised algorithm, the number of retransmissions was mostly slightly higher than the original algorithm, with an average increase of about 3.2% than the original MPR selection algorithm. The OLSR random highest degree selection algorithm (curve Random in figure) gave a better performance with the retransmissions higher than the original OLSR algorithm by a small 2.48%.

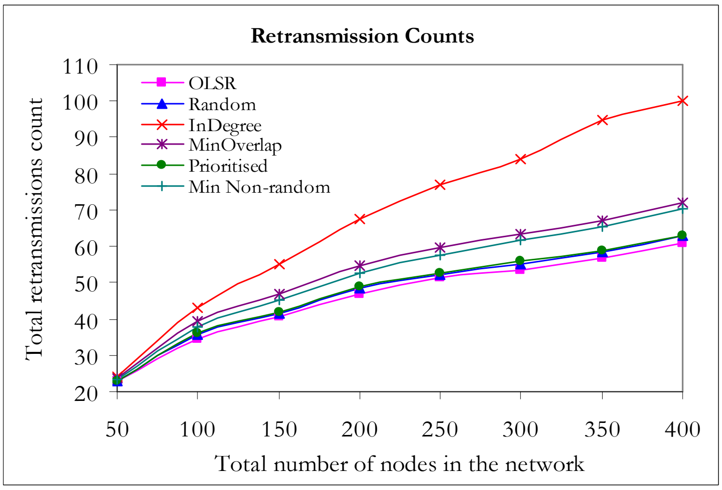


Figure 5: Total retransmissions for each broadcast for network with radio range 200m

The number of receptions that occurred (number of packets that were received, which includes those forwarded, and those discarded, for example if they were not received for the first time and not from the receptor's MPR selector) also increased by a large 40.35% for in-degree selection. The two overlap reduction algorithms MinOverlap and Min Non-random showed an increase of 9.71% and 6.79% respectively. A slight increase of 1.39% and 0.6% was observed in case of random and prioritised algorithm respectively.

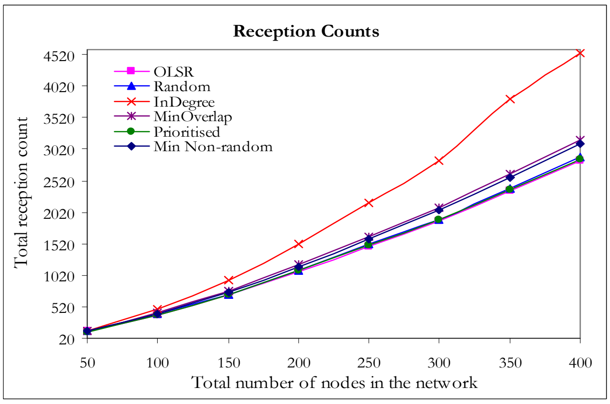


Figure 6: Total number of receptions for each broadcast

	OLSR	Random	In-Degree	Min-overlap	Prioritised	Min Non-random
Average MPR Count	4.97	4.97	5.07	5.03	4.98	5.02
Average Retransmission Ratio*	-	2.48	43.46	15.13	3.20	11.47
Average Reception Ratio**	-	1.39	40.35	9.71	0.60	6.79

* number of retransmission for each broadcast as compared to that of original (OLSR) MPR selection algorithm

** number of receptions for each broadcast as compared to that of original (OLSR) MPR selection algorithm

Table 1: Average results for simulator with 50 to 400 nodes and radio range of 200m

Discussion of Results:

In these experiments, it was seen that as expected, using of MPR nodes reduce dramatically, the number of transmissions and receptions, hence the traffic reduced in a single broadcast in comparison to full flooding is high.

As the MPR set size gets smaller, the reduction in packet transmission gets more significant. In the case of new MPR selection algorithm, the average MPR per node was usually the same or increased for the new algorithms, causing the transmissions to either remain the same or increase too. In case of in-degree algorithm, the increase in MPR count is higher and so the performance of the algorithm is the weakest. In case of MinOverlap algorithm, the number of MPRs per node is in average slightly higher, thus increasing the average retransmission count too. Since one more MPR node usually means m more transmissions by the m MPR nodes for this new MPR node, the number of receptions increased in both these algorithms. In case of MinOverlap algorithm only, the ratio of covered and uncovered nodes is started as soon as the essential step 2 is completed (see section 4.3.2), and in this stage, there maybe a large number of one-hop neighbours for which none of the two-hop neighbours that they can reach have yet been covered by any selected MPR node. Thus the ratio of covered to uncovered nodes is 0, and the algorithm chooses randomly among node with ratio 0. This might lead to the choice of a one-hop node that covers very few two-hop nodes, thus increasing the total MPR nodes selected. Thus, MinOverlap algorithm results in higher MPR count, and thus more retransmissions and receptions. This situation is improved in case of the Min Non-random algorithm, where preference is given first to minimum overlap, then to the highest uncovered degree. Thus, the number of MPRs is reduced for this modified algorithm, and consequently the retransmissions and receptions are reduced as well.

In case of the OLSR random high degree selection and the prioritised algorithm, the number of MPR nodes per node was on average, the same as that in the original algorithm, so the number of retransmissions for each broadcast was almost the same, increasing by less than 2.5% and 3.5% respectively.

From the results, it can be inferred that though the new algorithms, especially the ones that assure minimum overlap, might produce some non-overlapping transmissions in the beginning, as the transmission spreads across the network area, they finally overlap towards the end of broadcast, creating more retransmissions and receptions.

The results also show an increase in the number of receptions, but this is expectant, as more retransmissions mean more receptions. However, the increase in receptions is lower in comparison to increase in retransmissions (for example, 9.71% and 15.13% respectively for minimum overlap algorithm), showing that the new algorithms did introduce some decrease in receptions, but the decrease was not too significant due to increase in retransmissions.

It should be noted that the second common stage in all algorithms, were the neighbour node that is the only node covering any two-hop node is added to the MPR set, results in the selection of about 68% of the total MPR node selected for each node in average. Thus, the new algorithms can bring an improvement to only 32% of the selected nodes. This affects the overall performance of each algorithm.

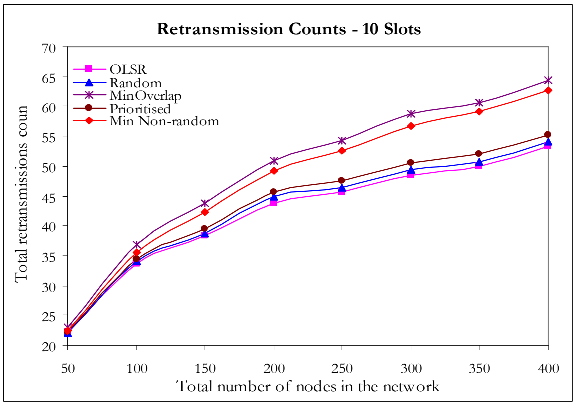
6.2 Scheduled Collision

This experimentation was done in order to have more realistic simulation conditions, since the above experiment assumes a perfect environment with no collisions of packets. A scheduler as described in the previous section was introduced in order to simulate packet collision scenario.

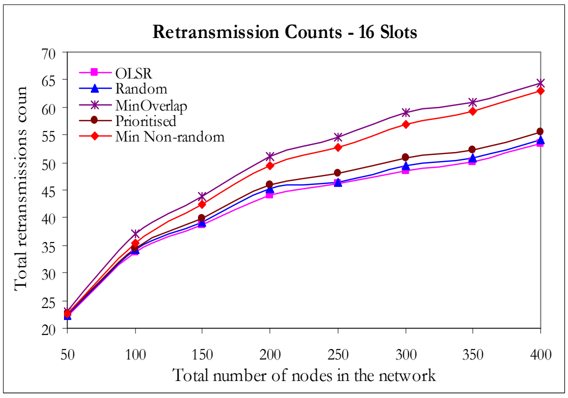
Simulation Conditions:

- The main conditions are same as in section 6.1. In addition, slots have been introduced, which represent time frames. The number of slots used are either 10, 16 or 24
- Since the above experiments show that in-degree MPR selection algorithm gives the weakest results, this section will exclude this algorithm and only compare the other four new algorithms to the original MPR selection algorithm.

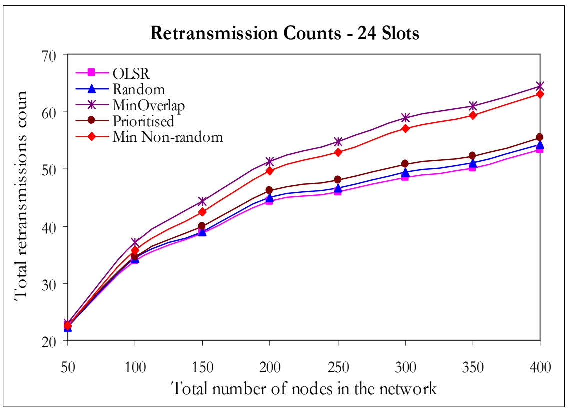
Simulation Results:



Retransmission Count – 10 slots

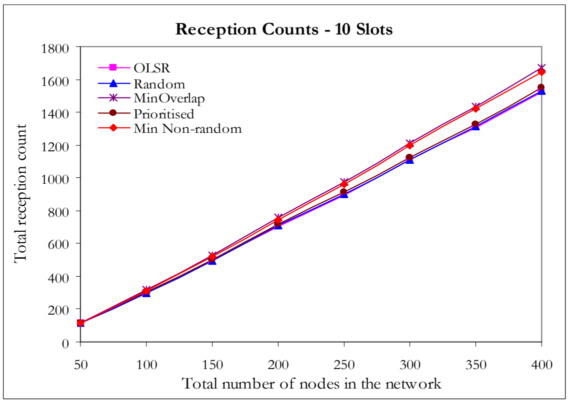


Retransmission Count – 16 slots

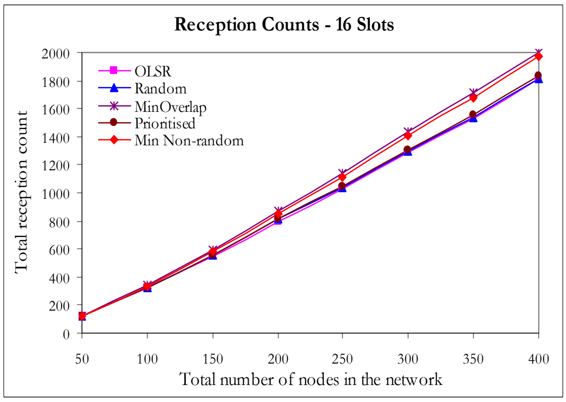


Retransmission Count – 24 slots

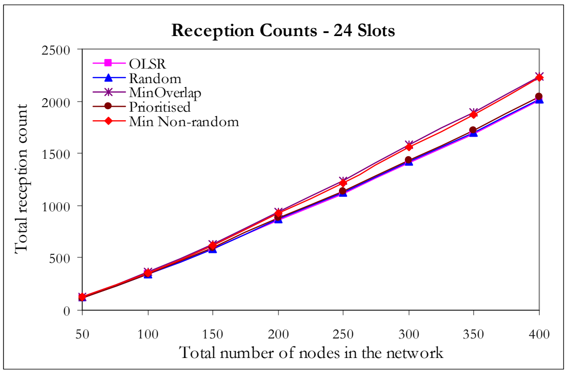
Figure 7: Retransmission Counts for scheduled network with various slot sizes



Reception Count – 10 slots

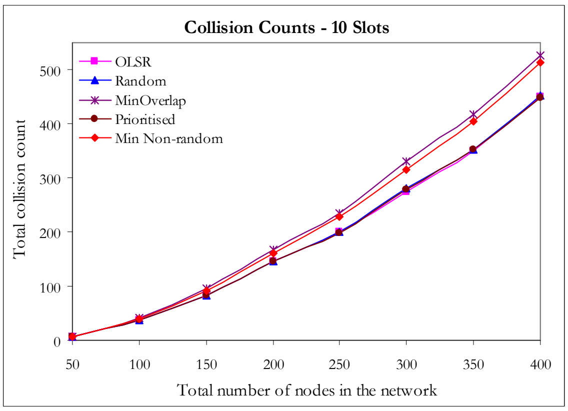


Reception Count – 16 slots

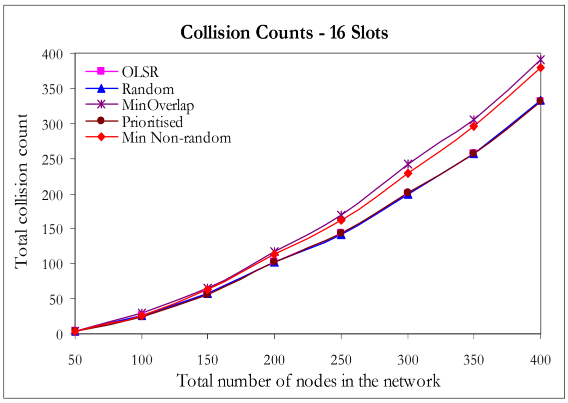


Reception Count – 24 slots

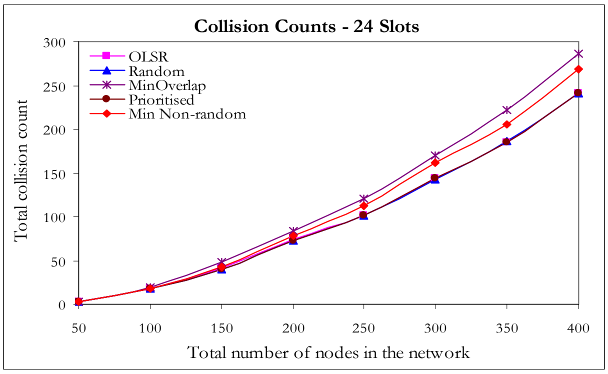
Figure 8: Reception Counts for scheduled network with various slot sizes



Collision Count – 10 slots

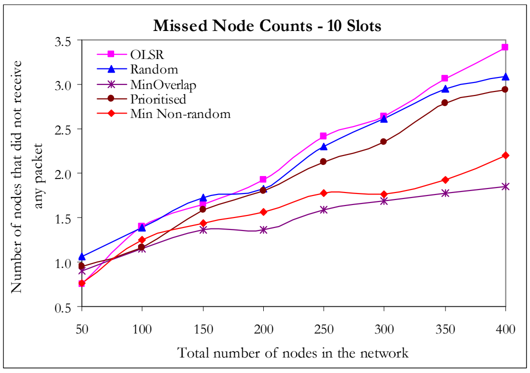


Collision Count – 16 slots

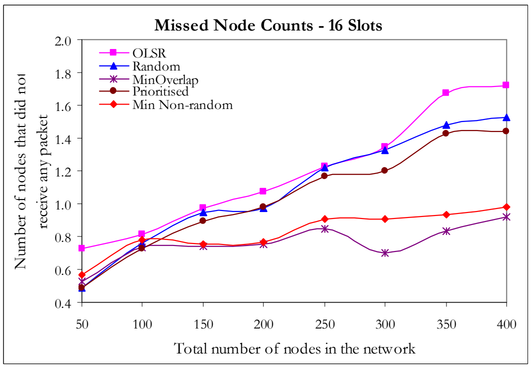


Collision Count – 24 slots

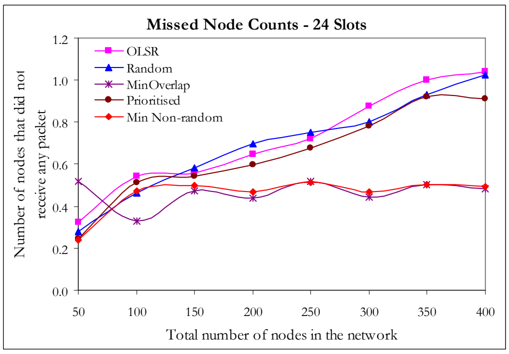
Figure 9: Average Collision per broadcast for various slot sizes



Missed node count – 10 slots



Missed node count – 16 slots



Missed node count – 24 slots

Figure 10: Average number of missed nodes per broadcast for various slot sizes

It was seen that the number of collisions in the network in case of both random and prioritised selection algorithms were similar in most of the cases to the original MPR selection case, despite the expectation that the prioritised algorithm will introduce less collisions. The collision counts improved by up to 0.57% for the prioritised algorithm, which is still marginal. As expected, when the slot size was increased from 10 to 25, the average number of collision per broadcasts decreased for each algorithm (see table 2), as fewer slots mean more collisions. However, the improvement from original MPR selection algorithm to the new algorithms was marginal, and in fact, the collisions increased by up to 18% in case of MinOverlap algorithm.

Regarding retransmissions, the new algorithm resulted in a small increase in the number of retransmissions by around 1.5% in case of random algorithm, 3.4% in case of prioritised, 12.1%

in case of Min Non-random, and 15.7% in case of MinOverlap. The number of receptions that occurred also increased slightly by up to 0.8%, 1.9%, 7.4% and 9.2% for the four algorithms respectively.

The number of nodes that did not manage to get any packets at the end of the each transmission due to the collisions was also measured. The new algorithms mostly brought slight improvements in this number as can be seen in the table below. The best improvement was in case of min-overlap algorithm (despite the increase in number of collisions, the number of nodes that did not receive the broadcast packets were less).

	Slot Count	**10**	**16**	**24**
Average Retransmission Ratio*	**Random**	1.34	1.50	1.30
	Min Overlap	15.55	15.77	15.65
	Prioritised MPR	3.29	3.49	3.39
	Min Non-random	12.15	12.10	12.15
Average Reception Ratio**	**Random**	0.30	0.83	0.62
	Min Overlap	7.51	8.79	9.18
	Prioritised MPR	1.93	1.48	1.61
	Min Non-random	5.77	6.49	7.41
Average # of Collisions	**Original OLSR**	193.35	140.26	100.84
	Random	194.63	139.99	100.45
	Min Overlap	227.66	165.52	119.02
	Prioritised MPR	193.41	139.79	100.26
	Min Non-random	219.57	159.01	111.10
Average Collision Ratio***	**Random**	0.67	-0.19	-0.39
	Min Overlap	17.75	18.01	18.03
	Prioritised MPR	0.03	-0.33	-0.57
	Min Non-random	13.57	13.37	10.18
#of nodes that did not receive any packets	**Original OLSR**	2.16	1.20	0.71
	Random	2.12	1.09	0.69
	Min Overlap	1.46	0.76	0.46
	Prioritised MPR	1.96	1.04	0.65
	Min Non-random	1.58	0.83	0.46

*ratio of number of retransmission for each broadcast for the algorithm to that of original algorithm
**ratio of number of receptions for each broadcast for the algorithm to that of original algorithm
**ratio of number of collisions for each broadcast for the algorithm to that of original algorithm

Table 2: Average results for scheduler with 50 to 400 nodes and radio range of 200m

Discussion of Results:

The introduction of scheduling in the simulator created a more realistic environment, where the nodes contend for network resources, and so there might be delay between reception of a message and its forwarding, and also there is a possibility of collision of packets. The prioritised algorithm was introduced in order to decrease the possibility of collision of packets by reducing the overlap between nodes covered by MPR nodes of a sender node, so that when the sender sends a packets to its MPR nodes, even if all the MPR nodes retransmit at the same time, the number of collisions is less, as the overlapping nodes are fewer. However, when collision scenario was introduced with the help of a scheduler, the algorithm did not improve the performance as expected. It did reduce the collision counts slightly by around 0.6% in the best case, but this reduction is not significant.

This overall increase is probably due to the overlap of the transmissions towards the end of broadcast, as explained in the previous section.

The average number of nodes that did not receive any packets in case of scheduled simulations decreased in case of the new algorithms, the most interesting results being achieved in case of MinOverlap algorithm. This result shows that in case of large networks the original MPR selection may results in more chances of some nodes not receiving a broadcast packet at all. Also, it was noted that as the average MPR count, retransmissions, receptions and number of collisions increased, the number of nodes that did not receive any packet decreased, showing that there is a tradeoff between algorithm induced redundancy and reliability.

6.3 Energy Costs

Each retransmission and reception costs some unit of energy for the nodes involved. According to Feeney's paper [10] the power consumption in case of Lucent IEEE 802.11 2Mbps WaveLAN PC Card was measured to be 843mW in idle state, 967mW while in reception mode and 1327mW in case of transmission mode. From this information and other similar data available on Network Interface cards, it can be deduced that on average, the ratio of costs of transmitting a packet to that of receiving a packet is around 1.5. So it can be said for each broadcast, each node that is involved in transmitting a packet will lose 1.5 unit of energy, while each node that receives the packet (to forward or discard) loses 1 unit of energy. Thus, in order to reduce power consumption, the most effective technique will be to reduce the transmissions. Reduction in number of receptions can help further reduce the power costs.

This set of experimentation was done in order to compare the total energy spent by all the nodes involved in transmitting and broadcasting in case of a single broadcast.

Simulation Conditions:

- The simulation conditions are same as in section 6.1
- For each transmitting node, the total energy of the network spent is TransmitterEnergy (TE) + NeighborCount * ReceiverEnergy (RE), where TE = 2 units and RE =1 unit. Thus, if a sender node S has n neighbours, it will be using 2 + 1 * n units of the total units of energy in the network. The total energy spent is then the addition of this value for each transmitting node. As another way to calculate the total energy spent the total number of transmissions (#T) and total number of receptions (#R) for each broadcast was first calculated, then the total energy spent = #T * TE + #R * RE.
- Since the above experiments show that in-degree MPR selection algorithm gives very bad results, this section will show only results of the min-overlap, prioritised algorithm and the random high degree selection algorithm as compared to original MPR selection algorithm.

Simulation Results:

RE = 1, TE = 2, Total Energy = #T * TE + #R * RE = 2 * #T + #R

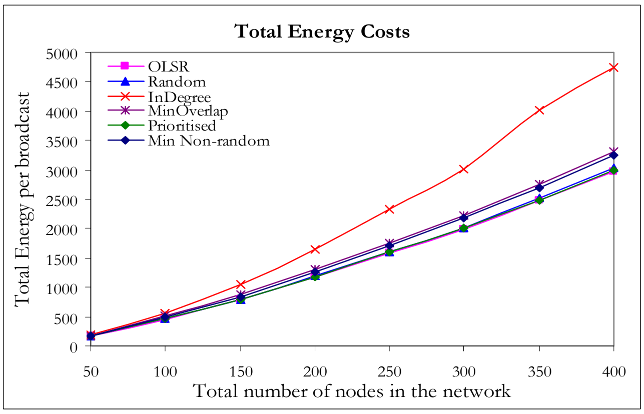


Figure 11: Average total energy costs for a single broadcast

The calculation was also made for the ratio of RE = 1, TE = 1, so that Total Energy = #T * TE + #R * RE = #T + #R. The values for both the ratios are presented in the table below:

	OLSR	Random	In-Degree	Min-Overlap	Prioritised	Min Non-random
Average Total Energy (T:R = 2:1)	1448.16	1474.50	2190.01	1611.16	1461.76	1572.25
Average Energy Ratio	-	1.51	40.54	10.12	0.84	7.15
Average Total Energy (T:R = 1:1)	1402.26	1427.38	2121.87	1557.81	1414.29	1520.57
Average Energy Ratio	-	1.45	40.45	9.93	0.73	6.98

Table 3: Total Energy costs for a single broadcast

Thus, it was noticed that for all the new algorithms tested here, the energy spent increases in comparison to the original MPR selection algorithm, from about 0.98% to almost 40.6%.

Discussion of Results:

As discussed in the results of section 6.1, the number of retransmissions and receptions in case of the new MPR selection algorithms is higher than the original MPR selection algorithm. Thus, as expected, since the total energy is the sum of total transmission costs times transmission cost unit and total reception times reception cost unit, the total energy spent in one broadcast is higher for the new algorithms. The two algorithms, random selection and prioritised selection, result in slight increase in the energy spent, since these algorithms have slight increase in the reception and retransmission costs. In-degree MinOverlap and Min Non-random algorithms however, bring more increase in the energy spent by up to about 40.6%.

Thus, all the experiments here show that in case of transmission and reception costs, and thus the energy used in broadcasting a packet, the original MPR selection algorithm performs the best, thus showing that it is a robust and efficient algorithm.

7. Conclusion

The main aim of the project was to evaluate some new algorithms for MPR selection in an ad hoc network, and check their performance in terms of transmission and reception costs when a message is broadcast into the network. A simple simulator was designed to test these parameters for different MPR selections proposed, and the results were generated for a simple collision free model, as well as a more realistic network model with delay and collisions. It was noticed that though theoretically the four new algorithms were expected to perform better than the MPR selection algorithm, practically, the values measured for these three new algorithms were weaker than in the case of original algorithm, showing that the original algorithm was in fact a competitive algorithm.

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9. Acronyms

IETF - Internet Engineering Task Force

MANET – Mobile Ad hoc Network

MPR – Multipoint Relay

OLSR – Optimized Link State Routing

RFC – Request for Comments