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Dynamic Topology Routing Protocol for Wireless Sensor Networks

***[1]Oloyede, A.A., [1]Faruk, N., [2]Abdulkarim, A., [1]Olawoyin, L.A. and [3]Surajudeen-Bakinde, N.T.**

[1]Department of Telecommunication Science, University of Ilorin, Ilorin, Nigeria.
[2]Department of Electrical Engineering, Ahmadu Bello University, Zaria, Nigeria.
[3]Department of Electrical and Electronics Engineering, University of Ilorin, Ilorin, Nigeria.
*oloyede.aa@unilorin.edu.ng

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ABSTRACT

Wireless sensor networks (WSNs) are important in an autonomous communication networks as they are capable of sensing the physical environment and have been deployed for variety of applications such as for monitoring road traffic, air pollution, water levels, tectonics among other things. However, nodes density and route reliability are major issues when deploying WSN in wide areas. In this work, a dynamic topology routing protocol called mobility aided routing (MAR) for Ad-hoc wireless sensor networks using java computer modelling is proposed. The performance of the proposed model was examined in terms of network energy usage, delay and route reliability, and compare with the conventional dynamic source routing (DSR). Simulation results show that at lower densities, MAR performed better than DSR when considering network-wide energy use and data extraction delay. The paper also showed that search algorithm is a fundamental part in the way MAR works. The results show that there is no significant difference between the two mobility models examined once a realistic deployment density of nodes is used.

1. INTRODUCTION

A wireless sensor network (WSN) is a collection of autonomous sensors which act together to monitor an environment (Kocakulak and Butun, 2017). Wireless sensors are capable of caring out massive measurements and are able to sometimes process them (Hancke and Hancke Jr, 2013; Doshi and Dube, 2019; Lu et al., 2019). Each sensor (or node) is able to collect information about its local surroundings and wirelessly transmit this data (Kocakulak and Butun, 2017; Rasband, 2019). WSNs are used to monitor environments where information is needed from a variety of locations over a wide area. These areas usually would not have any pre-existing infrastructure so the WSN will act autonomously to collect any data required. Once such data from all the nodes is collated, it can give useful insights to other systems. WSNs can be used for monitoring road traffic, air pollution, water levels, and tectonics among other things. As WSNs act without any infrastructure dependencies, the nodes within a WSN must form their own method of communication. Due to the limited range of the nodes within a network, a single node in a WSN may not be able to communicate with the location where the data it has gathered is needed (Guy, 2006; Gumel and Faruk, 2012). This limitation means that an ad hoc networking approach is needed and this involves finding routes through the network via other nodes. This can be in form of a 'multi-hop route' from the source to the destination.

The act of finding this multi-hop route is known as routing (Akkaya and Younis, 2005; Al-Karaki and Kamal, 2004). A method of routing needs to be established in order to allow information to be sent around the network in a reliable way (Singh et al., 2010). These methods are defined by a routing protocols (Zheng and Jamalipour, 2009). Current routing protocols such as Ad hoc on-demand distance vector routing (AODV) and dynamic source routing (DSR) exhibit an on-demand approach (Chong and Kumar, 2003). DSR is where an attempt to form a route is only executed once a route is needed. This method works very well when there is a high density of nodes in the area in question. However, when the density of the deployment is low, the reliability of routes being formed using these protocols is greatly reduced. Therefore, this work proposes a dynamic topology routing protocol for Ad-hoc wireless sensor networks using java computer modelling. The model was developed to compare the performance of mobility aided routing (MAR) with dynamic source routing (DSR).

Chand and Soni, (2012) studied the performance of AODV and DSR in terms of number of routes and the paper showed that DSR exhibits more intermediate nods in comparison to AODV. Ade and Tijare, (2010) provided a quantitative comparison of ad hoc routing protocols such as AODV, DSR optimized link state routing (OLSR) and destination sequenced distance vector (DSDV). This paper proposes mobility aided routing (MAR). MAR has previously been considered in Le et al. (2013) where it is controlled using robotics. A similar model was also proposed in Badia et al. (2007) where the sensors were controlled using on online model. The proposed model in this paper is different because the routing protocol is designed to be used for a group of autonomous robots searching an area where their movement can be controlled. Fundamental to this routing method is the assumption that each node will know its position in a set area via the Global Positioning System (GPS), or some other means. All nodes will also know the position of the sink node and the boundaries of the area.

2. METHODOLOGY

To compare the two routing protocols (MAR and DSR), the network of mobile nodes, targets and sink node was modelled. This was to allow many scenarios to be evaluated over many instances to give statistical significance to any results generated. This method is also more practical than the trial alternative when comparing protocols as it is not susceptible to hardware failures. This paper simulated the network by building the simulation program rather than using an existing computer model. Entirely building the simulator gives the advantage of being able to add any features which may be considered useful, very easily. It also allows movement control algorithms to be implemented at a low level in the software's structure, rather than an add-on to any pre-existing software.

2.1. MAR Implementation

The overview of the route formation algorithm is as follows. First it checks all the connections which exist at the current time for one which contains a reference to a target. If such a connection exists, the other node in the connection is considered a source node. The source node is then set to stationary and set as the end of the MAR branch for the target that has been found.

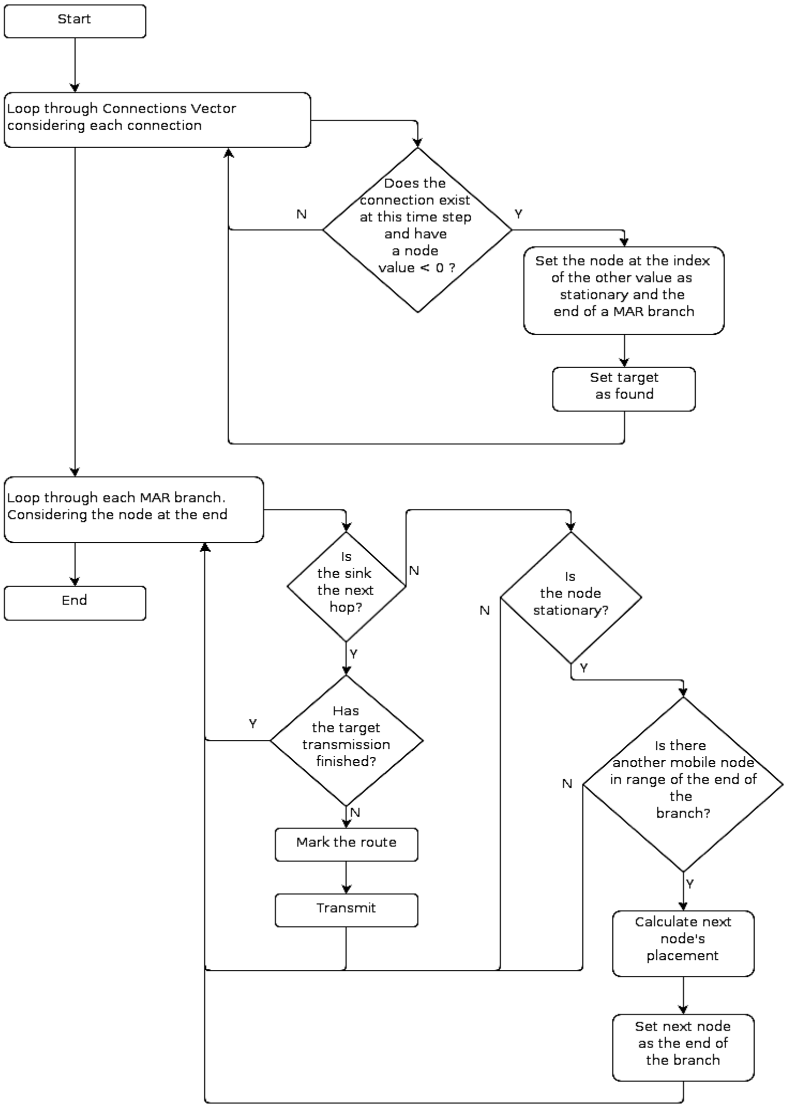


Figure 1: A design structure flowchart showing the MAR routing algorithm's structure

The algorithm then considers each target in turn. First it checks that the MAR branch associated with the target number has a connection to the sink node. If it does it will mark all the connections involved as part of the route. It will also decrease the time left that a route needs to exist for (transmission length). If this transmission length has reached zero then the nodes will be reset and allowed to move freely. If the MAR branch does not have a connection to the sink node the algorithm will search for a connection between the node at the end of the MAR branch and another node which is not stationary. If there is such a connection, then the new node will be given placement coordinates and be defined as the end of the MAR branch. The placement coordinates are calculated by measuring the distance from the current node to the sink node and choosing the point along this line 80% of the range away from the current node. 80% was chosen after experimenting with numbers and it seems to be a reasonable range at which in a real situation a radio channel would be more likely to be of a good enough quality. Figure 1 is a pictorial representation of the proposed algorithm.

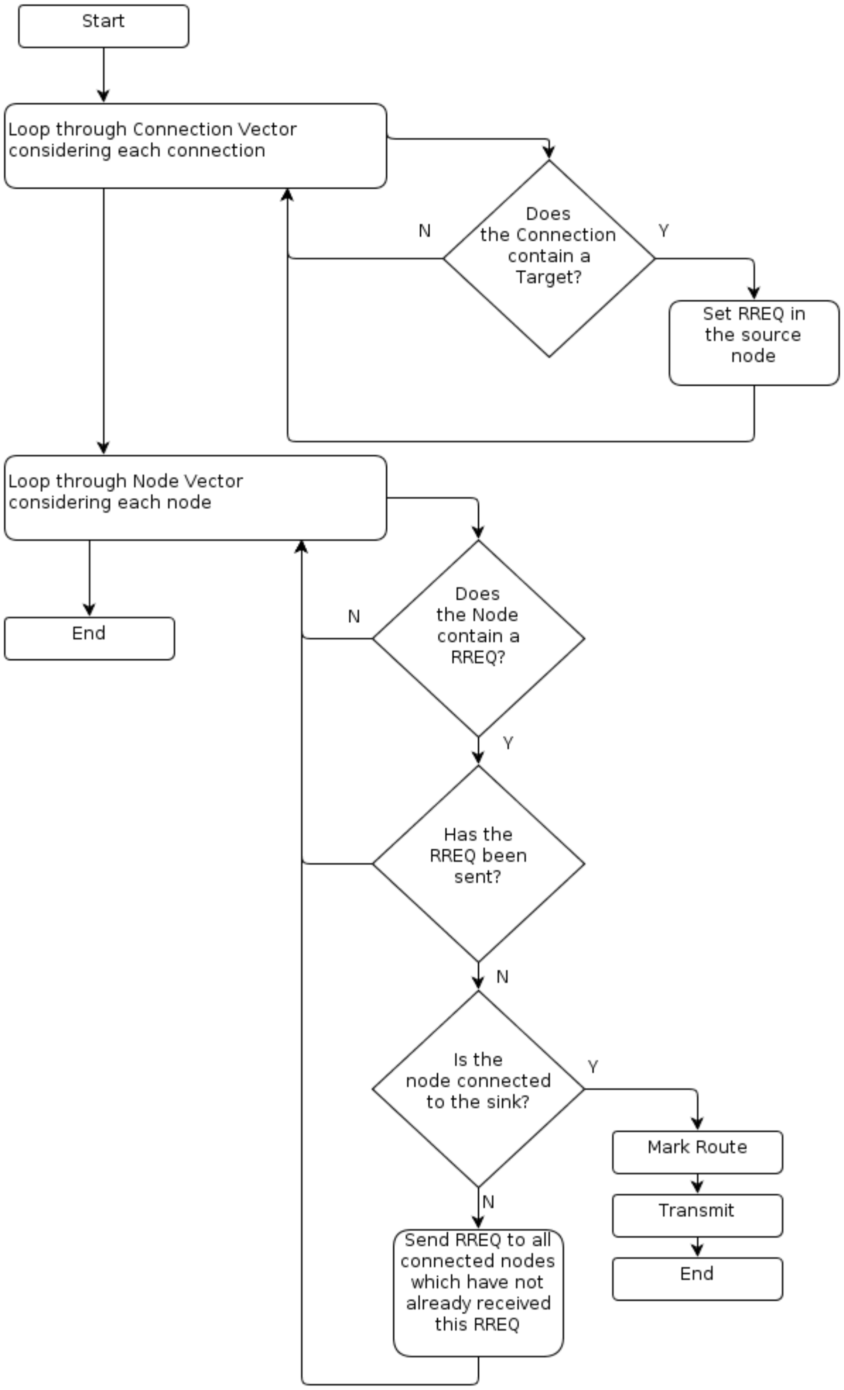


Figure 2: A design structure flowchart showing the DSR routing algorithm’s structure

2.2. DSR Implementation

To properly model DSR in the computer model a new class is written which represents a route request (RREQ) packet. This contains the source node index and the hops in the route. Each node has a RREQ object, when a RREQ is set this is the equivalent of the node receiving a RREQ packet. The algorithm begins by searching through the currently available connections until it finds a connection between a target and a node. It then sets the RREQ in the node which is in the connection with that node's index as the source value and the first value in the hop list.

The algorithm then continues by checking all other nodes to see if the RREQ has been set but not sent. If these conditions are true for a node then the node's index will be added to the RREQ's hop list. The connections will then be checked again to see if the node has a connection to the sink. If it does then the hop list will be passed to another method which marks the route and the route will be considered formed for that time step. If the node is not connected to the sink all its other connections will be analysed. If a connection to a node which has not received the RREQ is found then the RREQ will be copied and set in that node's RREQ. The original node will then be marked as having sent the RREQ. If the node attempts to send the RREQ and there are no other nodes in range then it will still be marked as sent as it has been attempted. The process of checking nodes for RREQs which have been set (received) but not sent continues until there are no more RREQs to send or a connection to the sink has been found. A diagram showing this algorithm is as shown in Figure 2.

The model was set up to obtain some initial results from the simulator and to find any trend. The number of nodes within the simulation area was initially set as fifteen and later increased in steps of one node up to a value of twenty nine nodes. The other parameters for this simulation are shown in Table 1.

Table 1: Simulation parameters

Parameter	Value
Area size	300
Maximum speed	10
Number of time steps	500
Transmission length	15
Constant speed	False
Mobility model	Random direction
Start from sink	False
Sink X coordinate	10
Sink Y coordinate	10
Number of targets	1
Range	50
Idle energy	0
Transmit energy	1
Receive energy	1
Movement energy	1
Number of runs	10

3. RESULTS AND DISCUSSION

The work was set out to compare the merits and flaws of DSR and MAR when applied to a specific scenario. The scenario in question is a large area which contains a number of targets which need to be found. A number of mobile nodes will be deployed in the area to search for the target. When a target is found the nodes will form a multi-hop transmission route to a stationary sink node. The factors which are considered are the system delay and the total energy use. The system delay is being defined as the time between the deployment of the nodes and all the information about a target being received at the sink node. The total energy is the sum of all the energy used by all of the nodes. This will be split into the energy used when performing the routing algorithms and the energy used to move around the designated area. Figure 3 shows the energy consumed by the two compared models. It shows the average routing energy over all runs used by both routing protocols in the same situations.

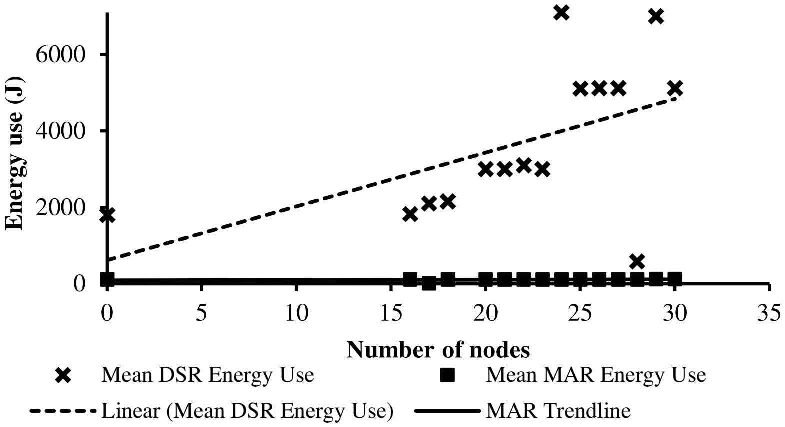


Figure 3: Energy used in routing for a one target network

Figure 3 shows that the routing energy used for MAR is much less than DSR. MAR was also successful in transmitting the data in the network over every run, so it provides both the advantages of energy efficiency and reliability. DSR does become more reliable as the network increases in density but it is also using more energy for such networks. This can be explained by considering the way a route is set up. When route requests (RREQs) are flooding the network and the connectivity of a network is high, more of the nodes will receive the RREQ (Gumel et al., 2011a; 2011b). As the density of the network is increased the connectivity is also increased, so therefore in a denser network more RREQs will be set. An extreme case of this would be in a network where there is a multi-hop route available between all nodes. This would mean that all nodes will send and receive the RREQ increasing the system-wide energy use. The model is further examined using an area size parameter to 670 and the node communication range to 100 while all nodes will be moving at a constant speed of 2 m/s.

Figures 4 and 5 show the mean delay for MAR and DSR as function of number of nodes. Although the results in Figure 5 cannot be immediately used to determine a trend or pattern, the variations seen could be due to the increments in the network density. The random fluctuations seen from one value to the next may be caused by the random nature in which the nodes move around the area. The routing protocol may have an overall effect on the delay when considered over a greater number of node densities. The result in Figure 3 and 4 does not show what happens at very high node densities. Therefore, that is a need to investigate further with extra runs made at selected node densities.

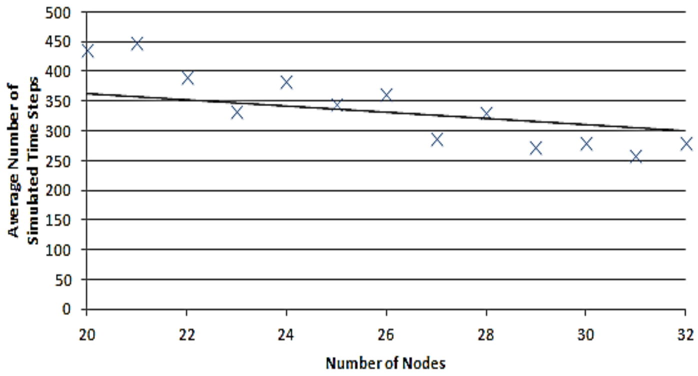


Figure 4: Mean delay for full transmission using MAR in a one target network.

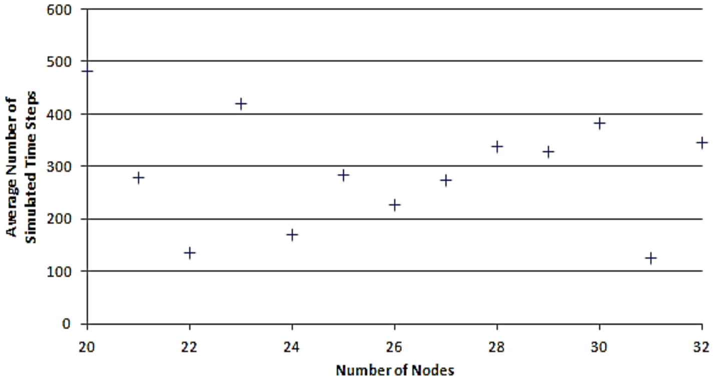


Figure 5: Mean delay for full transmission using DSR in a one target network

As well as comparing the delay between routing protocols, the number of targets in the system was also varied to be able to compare further. Figures 6 and 7 show that with an increase in the number of targets there is a general increase in the amount of energy used. This is what would be expected as there will be more RREQs being sent to set up routes for each target in the DSR network and more branches being formed in the MAR network.

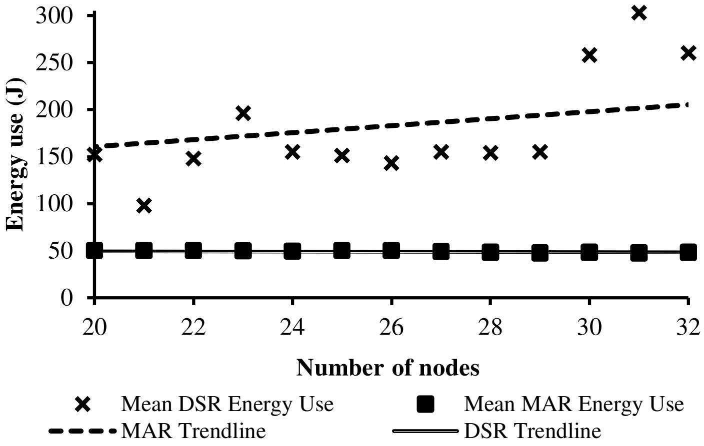


Figure 6: Routing energy use for five target networks

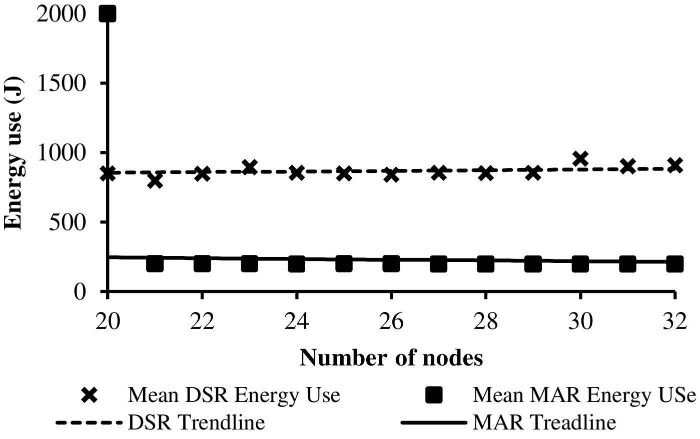
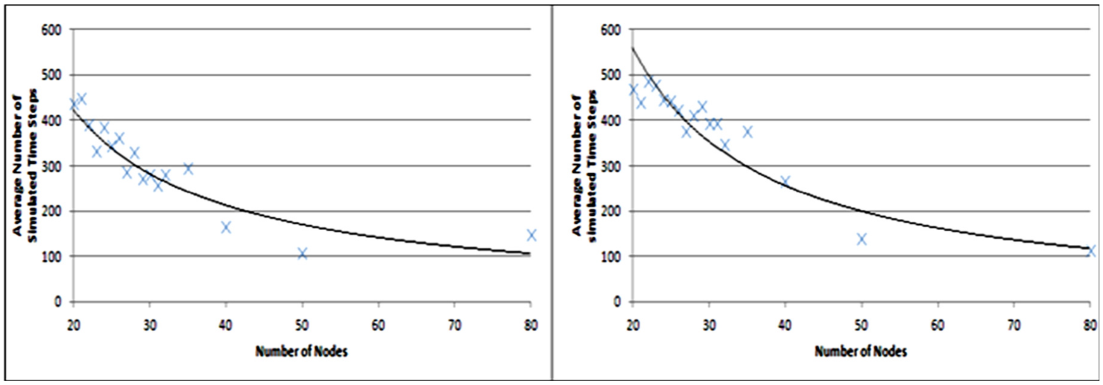


Figure 7: Routing energy use for five target networks



(a) (b)

Figure 8: A comparison of mean delay for full transmission in a network using MAR (a) one and (b) five targets

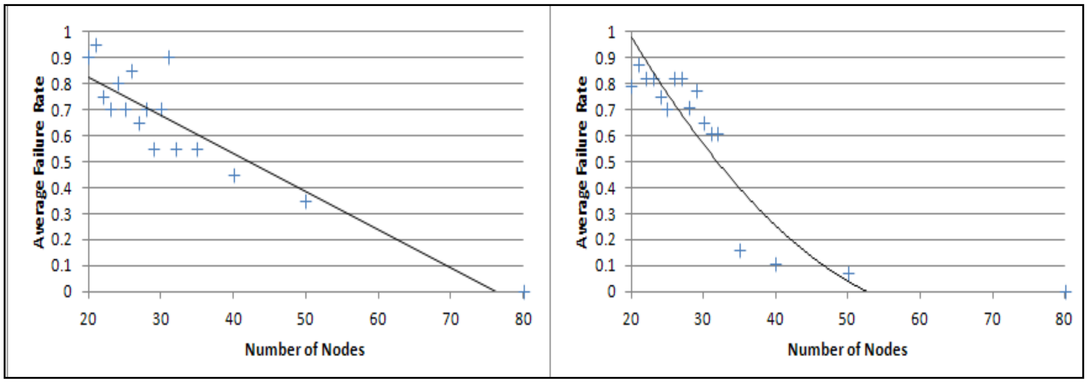
The previous results have shown that for trends to be determined and extrapolated, higher density networks must be simulated. The target values being run were one to five. It was observed in the previous runs that the difference between the system characteristics with five targets was only different in a small way to the system characteristics with one target. Therefore, the first change that will be made is that each node density will only be considered with one target and five targets.

These results show that the reduction in delay at higher node densities is slower than that at lower densities. This characteristic could be due to the number of neighbours each node is likely to have. For a route to be immediately formed in MAR, each node must have a neighbour when it is at the end of a branch. At lower densities this will be less likely, so the node will have to wait for a neighbour. As the node density increases each node will have to wait for less time before a neighbour is found which gives the fall in delay times. Eventually the network will be so dense that the time waiting for a neighbour will be very short or immediate. This will reduce the effect seen of increasing the density to reduce the delay. The delay will then be set by the random chance of how close the chosen next node is to the next placement position in the branch. In our modelling it was seen that the difference between one node and five nodes was seen to be an offset of the graph, where all densities have a slightly higher delay. Figure 8 shows the results for both the one and five node system side by side.

From Figure 8, it can be determined that the offset observation made for lower densities only applies to lower densities. This is because when the network reaches higher densities of nodes it can be seen that the number of targets has very little effect on the system delay. This is possibly due to the same phenomenon which was described when considering the change in the trend at higher densities. Again, it appears to be the case that the number of neighbours for each node has reached a level whereby the delay is no longer largely affected by an increase in node density.

When previously considering the delay results for DSR, it was thought that increasing the node density by a large degree would show any underlying trends in the data. However, this is not the case. The extra runs did not provide any extra useful information when considering the system delay when using DSR. It could be asserted that this lack of relationship between the delay of a DSR network and the density of the nodes is due to the way the nodes move in the area. The movement of the nodes is controlled by an inherently random algorithm and it is the movement of the nodes which determines whether any nodes will have neighbours. This affects the DSR algorithm as it relies on the number of neighbours for each node being high. As the configuration of the network keeps changing due to the high and random mobility, this causes major changes in the topology in a random fashion. This in turn could cause the random fluctuations in the system wide delay.

Although the delay of the system is seen to be random the failure rate is not. It would be expected that as the density of the network increases the number of failures for full transmission would decrease for a DSR network. This is because with a higher density of nodes, nodes are more likely to have more neighbours, so there is a higher likelihood that a multihop route exists between a target and the sink node. This is shown to be the case with the results from this experiment where the density of the nodes increases the failure rate eventually reaches zero. Figure 9 shows the failure rates for all densities of nodes simulated with one target and five targets.



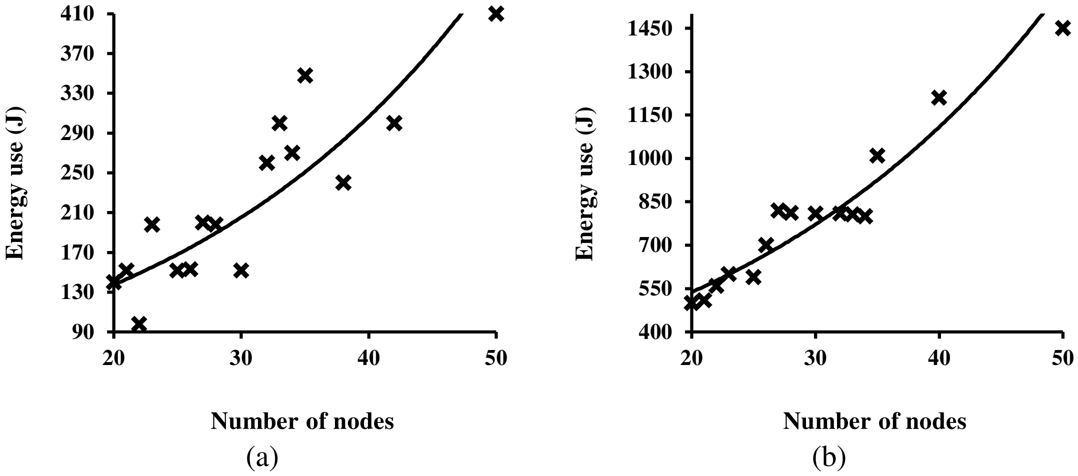
(a) (b)

Figure 9: A comparison of DSR failure rate (a) one and (b) five target networks

Figure 9 shows that the failure rate of a network which implements DSR does fall with increased deployment of nodes. What these results also show is that the decrease in failure is much faster when more targets are present in the network. It is not immediately obvious why this is occurring as having more targets in the network should not affect the chances of any of those targets failing or succeeding to have all their data transmitted successfully. This result could be explained by the way the data has been averaged. For the network with five targets, for each number of nodes the number of possible failures is five times that of the one target network for each of the twenty runs. This means that each average failure rate value in the one target system is averaged over twenty results whereas in the five target system it is averaged over one hundred results. Therefore, the five target analysis may be a more accurate depiction of the characteristics of the network as the values for the one target system are more susceptible to spurious results.

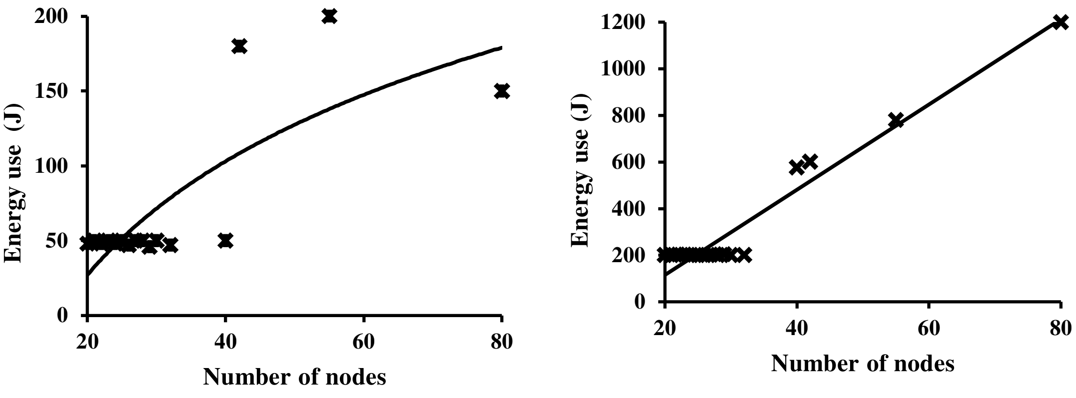
When considering DSR networks the average routing energy used per node is expected to rise in line with the density, as once all nodes are connected by multihop paths to all other nodes route requests can get access to the entire network. This effect is expected to eventually plateau as all nodes will receive and send all route requests. This is shown in Figure 10.

Figure 10 confirm the theory previously outlined that the energy use would eventually plateau. However, these results only consider node deployments up to 50 nodes. The results from the MAR networks were not as expected. These results can be seen in Figure 11. The initial results from 20 to 32 nodes all sit together; whereas the extra runs have much higher energy levels. A small increase in the routing energy for the MAR systems is expected as when a node is transmitting there will be a higher likelihood that more nodes will be within range receiving the signal. However, the stark change in the range of these new results challenges their validity. Further work needs to be carried out so that these results can be challenged as their validity is too questionable to draw results upon. Furthermore, a different aspect of the system which was not previously considered was investigated. From the analysis and visual representations of the previously results, it can be inferred that search is a fundamental part of how the MAR algorithm works. This is more apparent in a low density network with few targets.



(a) (b)

Figure 10: A comparison of routing energy for DSR (a) in one and (b) five target networks



(a) (b)

Figure 11: A comparison of routing energy for MAR (a) one and (b) five target networks

MAR does not start taking effect until one mobile node finds a target. Once this happens, the mobile node which found the target effectively becomes a new target which needs to be found. This will continue until the route has been set up. This observation is important because it shows that the speed at which MAR routes are formed can be improved by choosing a search algorithm which is more effective. In the previous results the movement of the nodes was dictated by the random direction mobility model. This was chosen as it was shown by Camp (Camp et al., 2002) that this model explores the area in a more uniform manner. From this, it was assumed that it would be a more reliable model to use when searching for targets. However, this may not be the case for speed.

To compare the speed at which targets are found when using the random direction mobility model and the random waypoint mobility model, we show a comparison between these results with an increasing number of nodes. This analysis was carried out by creating a situation where all nodes start from the sink node position and move according to the mobility model being investigated. As well as the sink node and mobile nodes there will be one target in the simulated area. This experiment was logged using the time from the start of the modelling to the point where the target was found. The results produced a list of times of when the target was found alongside the related node numbers and which mobility model was used. For the purpose of finding which was the fastest to find targets this data was put into a series of cumulative density functions (CDFs). The first CDF can be seen in Figure 12.

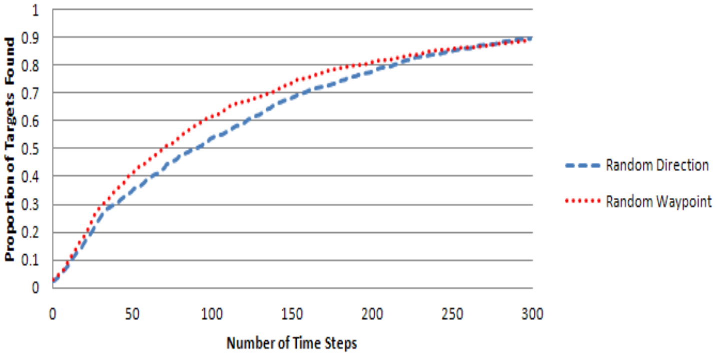


Figure 12: A CDF comparing the time taken for one node to find one target

Figure 12 shows that for this scenario, random waypoint is a better mobility model to use when performing a search. This can be seen by the steeper rise of its curve and that it is consistently above the line for random direction. However, both are not completely reliable as in the three hundred-time steps which were simulated neither found the targets in allotted time. At the higher time values, it can be seen that the lines do cross over and it could be argued that random direction would reach the one thousand two hundred ceiling first. This situation was also generated for an experimental case and does not represent how a real network would act. This is because a real network would have more than one node so the cumulative effect of the searching of all the nodes is more important. Figures 13 and 14 show two CDFs, the first is for a network of 10 nodes, the second is for a network of 20 nodes.

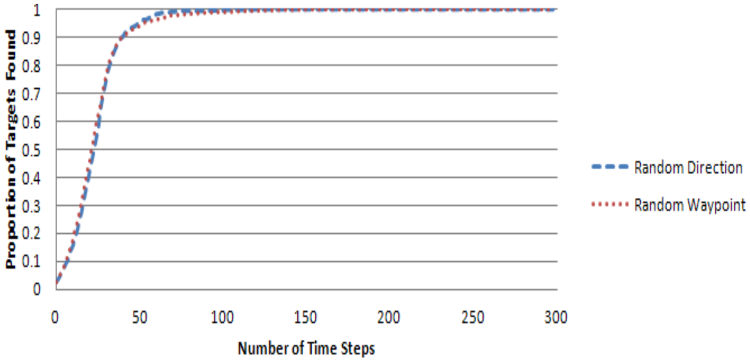


Figure 13: A CDF comparing the time taken for ten nodes to find one target.

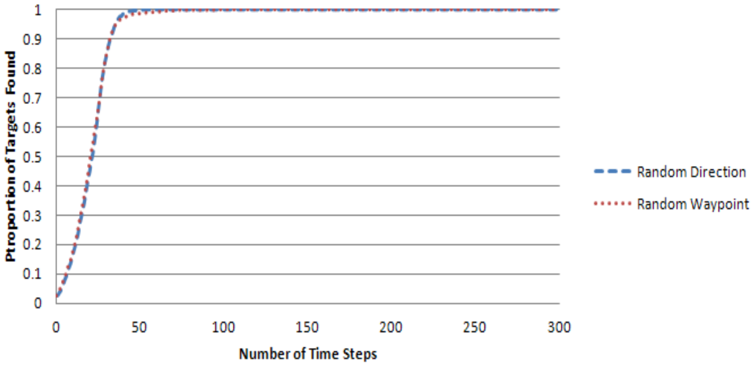


Figure 14: A CDF comparing the time taken for twenty nodes to find one target

The CDF graphs for ten and twenty nodes show the same trend as the previous graph. However, there is less of a difference between the two mobility models. It can be observed that in both cases the runs using random waypoint will find most nodes faster than those using random direction. However, the runs which use random direction will reach the maximum before those using random waypoint. Therefore, from these observations it can be determined that random direction is more reliable when finding all the targets, whereas random waypoint is faster in the majority of cases. However, this difference is diminished as the number of nodes present in the simulation area increases. Therefore, no significant difference can be asserted between the two mobility models once a realistic deployment density of nodes is used.

4. CONCLUSION

In this paper, a new protocol called the mobility aided routing (MAR) was designed, implemented and tested. A computer model was successfully implemented in a software package to investigate the properties of the protocol. The proposed protocol has allowed for lower density networks with highly mobile nodes to have a reliable and predictable delay for all data to be sent to the sink node. This has been achieved while still keeping the routing energy used by the MAR system comparable to that of an existing protocol. The results showed that at lower densities MAR performed better than DSR when considering network-wide energy use and data extraction delay. The paper further examined if search algorithm is a fundamental part in the way MAR works. The results show that there is no significant difference between the two mobility models examined once a realistic deployment density of nodes is used.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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