Re-Configurable Antenna & Transmission Power for Location Aware MANET Routing with Multiple Objective Optimization

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***Abstract*— In this paper we develop a Directional Antenna Multi-path Location Aided Routing (DA-MLAR) scheme with On Demand Transmission Power (ODTP) support. The routing approach is based on multiple objectives. DA-MLAR is a reactive routing protocol that minimizes the protocol overhead of other reactive routing protocols. DA-MLAR also improves the packet delivery ratio and end-to-end delay. The targeted application contexts include MANET with energy awareness, and communications in space networks, where efficient and reliable packet delivery is very challenging due to the high bit error rate, intermittent connectivity, limited bandwidth, and energy. By using different transmission power based on the calculated distance from the current sender node to the destination node or the next hop node, DA-MLAR-ODTP gets the best of the directional and omni-directional modes. Compared to DA-MLAR, on demand transmission power mode further improves the packet delivery ratio by up to 37% and dwindles end-to-end delay by up to 57% with approximately the same amount of energy consumption. The multiple objective optimization is based on using a Normalized Weighted Additive Utility Function (NWAUF) approach that shows comparison of different objective performances with and without on demand transmission power capability. Simulation experiments were conducted. They show that is the developed technique strengthens the reliability of communication systems for given targeted objectives.**

***Index Terms*— Ad Hoc Network, Directional Antenna, Location Aware Routing, Mobile Ad-hoc Network, Performance Evaluation, Multi-objective MANET Routing.**

I. INTRODUCTION

Mobile Ad Hoc networks (MANET) consist of nodes (devices or terminals) equipped with transceivers that can communicate with one another without any fixed networking infrastructure. MANET can be deployed quickly without any prior planning or construction of expensive network infrastructure. Applications where such network infrastructure is either unavailable are space exploration, undersea operations, and environmental monitoring, or unreliable are communication networks in battle field and emergency rescue operations.

Nodes in ad hoc network can communicate directly with another node located within its radio transmission range. To communicate with the node outside of its communication range, a sequence of intermediate nodes in ad hoc networks is required to relay messages on behalf of this node, resulting in multi-hop wireless network. The mobility of nodes in the ad hoc network causes the nodes to be in and out of range from one another; therefore, the connectivity in MANET varies dynamically with time. This dynamic connectivity imposes major challenges for the network layer to determine the multi-hop route between a given pair of source and destination nodes. The traditional routing techniques such as distance vector and link state (proactive protocols) that are used in fixed networks can not be directly applied to ad hoc networks. First, although they do adapt dynamically to the changes of network topology, they are not designed for the kind of dynamics in MANET; second, the periodic updates of routing tables waste a large portions of the scarce bandwidth in the ad hoc network [1]. The paper on Dynamic Source Routing (DSR) [1] proposed to use Reactive or On Demand routing protocol in MANET. Instead of tracking the changes in the network topology to find better routes, DSR only determines routes when necessary so as to lower the routing overhead. AODV [2] is another example of on demand routing protocol. Systematic performance comparisons of DSR and AODV can be found in [9].

Recent advance in technology has made it possible to embed a Global Positioning System (GPS) chip in each mobile node to exploit the location information of each node for routing. Protocols such as Location Aided Routing (LAR) [6], MLAR [23], GRID [7], GEDIR [16], and Zone-based two-level routing [19] are examples of location-aware protocols take advantage of GPS or other location determination techniques. LAR protocol [6] decreases the overhead of route discovery by reducing the search space for the desired route. This search space is called the *Requested Zone* and is constructed by the source after assessing the *Expected Zone* of the destination. There are many requested zone construction schemes [6], for example, a box scheme is used by Nanda et al. in the implementation of Multi-path LAR (MLAR) [23]. In the box scheme, a source constructs a rectangular box as a requested zone that consists of both the source node and the expected zone of destination as in Fig. 1.

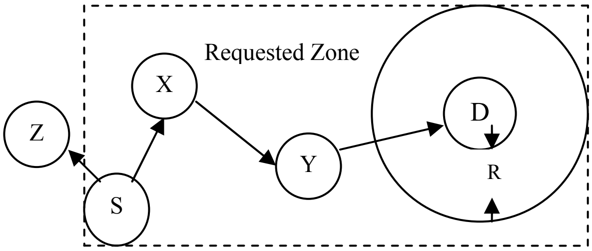

Figure 1. Requested Zone (rectangle) and the Expected Zone (Circle), X and Y are within the Requested Zone and node Z is outside. S: Source, D: Destination and $R = v (t_1 - t_0)$ where, R = radius of expected zone, v = avg. velocity of D, t_1 = current time observed by S, and t_0 = time when S last sent the packet to D

A. DA-MLAR

Multi-path Location Aided Routing (MLAR) [17] tries to reduce the protocol overhead by using two strategies. The first strategy limits the transmission area (using box method) [6] thus reducing the number of nodes participating in the forwarding of the route request packets. Only the nodes in the box region will participate in forwarding, others just discard the route request packet they received. The second strategy makes use of multiple alternative paths [11] to reduce the number of consecutive routing requests in case the first one fails. The alternative paths can be tried for sending the packet if the first priority path does not work. Gajurel et al. have implemented the Directional Antenna model in DA-MLAR [17] to provide directional capability.

One problem with MLAR is that even when some nodes are not in the box region and they do not participate in forwarding the route request packet to the destination, they are still affected as they are within the communication radio range of the sender node. As showed in Fig. 2, the rectangle is a box region set up by the MLAR for current sender S and destination D. Only the nodes X, Y and other nodes within that region will forward the route request packet for node S. Node Z receives the route request packet but it just drops that packet since it is out of the box region. However when using the directional antenna in DA-MLAR the nodes out of the box region get isolated. Node Z is not aware of source node S sending the route request and data packet to destination node D. It is free to communicate with other nodes in the network.

The other problem with MLAR is there are more cases of network partitions compared to DA-MLAR. Node Y is out of radio range from node S for MLAR using omni-directional antenna that results in network partition. However, when using the directional antenna in DA-MLAR which provides longer transmission range, node Y is found to be in communication range of node S. The network partition that could have happened using an omni-directional antenna has been avoided by using the directional antenna in this scenario.

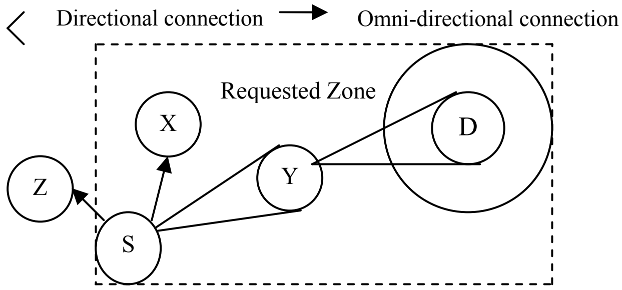

Figure 2. Region set by Directional Antenna. Node Y is in the communication range (represented by two arrows) for directional antenna only. S: Source Node D: Destination Node

This paper is intended to quantify the benefit we can get using the directional antenna and answers how helpful the directional antenna can be, what the optimal directionality value is, what are the tradeoffs, and what is the benefit of on demand transmission power control. Following are the assumptions we have made:

- Global Positioning System (GPS) is embedded in each node in the network. The GPS receiver in each node receives the transmitted signals from the GPS satellites to determine its location and the speed. Other location services can also be used for the location informations.
- The topologies We have used for simulations have node speed in the range of 5m/s to 25m/s. These topologies are targeted for rovers on the Moon or the Mars surface. The speed of the rovers that were currently launched on the Mars is about 5cm/s.
- GPS satellites are only in medium Earth Orbit. We have assumed that they will be available in the Moon and the Mars orbit in the future to provide GPS service to rovers on the Mars and the Moon.
- With GPS or other location service, individual node knows its position and speed information. The initial route request is flooded throughout the network to exchange the position and velocity information among nodes.
- Directional antenna has the capability of setting the beam width values in the order of 1 degree precision and also, the switching time among different modes will be in the range of fraction of millisecond .We are expecting that the beam forming antenna technology will solve our purpose. The beam forming antennas have multiple elements with slight physical separation that provides signal diversity. By switching among these elements, required beam width values can be obtained.

The paper also does not overlook the energy consumption issue using on demand power transmission capability given the energy consumption. The longer transmission range reduces the number of network partitions. The less number of network partitions means less frequent re-broadcasting and resending the packets i.e. less energy consumption. On the other hand long transmission power consumes more energy and also increases network interferences in the forwarding direction. That in turns results in more time outs, and ultimately more energy consumption. The on demand transmission power capability tries to check and balance the energy consumption by using power level depending on the location information of nodes.

The rest of the paper is organized as follows. In Section II, we discuss related work on antenna and transmission power and range issues in more detail. We then present our radio propagation model in Section III. Section IV describes the Normalized Weighted Additive Utility Function (NWAUF) Approach. In Section V and VI, we summarize our simulation tests and analyze the experimental results. We conclude our paper with discussions on targeted applications and future Work.

II. DIRECTIONAL ANTENNA: ON DEMAND TRANSMISSION POWER

With the technology advances and the recent trend of shifting towards higher frequency bands (5.8 GHz ISM band), it is possible to design smaller as well as cheaper beam forming antennas. The energy distribution in directions other than the intended directions, not only causes interference to other nodes, but also reduces the potential range of transmission due to lower signal strength and multi-path components. With DA-MLAR within the request zone itself it is possible to involve only those intermediate nodes that are in the direction of destination from the source.

A. Related Work

Recently implementation of protocol using dynamic power transmission has gained lots of attention in the research area of Mobile ad hoc networks. On one hand, choosing higher transmission power increases the transmission range thereby improving packet delivery ratio and reducing the number of forwarding nodes needed to reach the destination nodes. However, on the other hand, higher transmission power may cause excessive interference in a shared medium and the delays (random back-off) associated with it. Energy consumption is also critical for battery operated mobile hosts.

Paper [3] indicates that a variable-range transmission approach outperforms a common-range transmission approach in terms of energy saving and increased capacity. Three transmission strategies – most forward with fixed radius, nearest with forward progress, and most forward with variable radius, are compared in [4] and the results show the better performance (throughput and forward progress) for the strategy that involves the control of the transmission range.

Paper [5] claims that by adjusting the radio range appropriately, half of the energy can be saved than where equal radio ranges are used in case of sensor networks. Optimum one-hop transmission distance that minimizes the total system energy is evaluated in [8] and then that value is set for all the nodes. In paper [10], it has been showed that dynamic reduction of transmission range of each node during the broadcast process results in prolonging the life span of the network without sacrificing the broadcast coverage.

The algorithm to calculate the minimum transmission range that is required for full network connectivity is developed in [12] and the effect of mobility on this value and throughput was studied. Variable Transmission Range Protocol (VTRP) for sensor networks has been developed in [13] where there is a low energy broadcast in initial search phase. If search phase fails to discover the node near to the source, the protocol enters into the transmission range variation phase.

B. Our Contribution

Our work adds on demand transmission power capability to the DA-MLAR. On demand transmission power modes are used while sending the packets and re-broadcasting after getting the error message. We keep the antenna in default transmission power mode in all other times except for sending the packets and re-broadcasting after getting the error message. During those operations we use three transmission modes based on the calculated distance between the current sending node and the next hop node – low transmission mode, default transmission mode, and high transmission mode. This on demand transmission power strategy we implement for DA-MLAR will avoid excessive interference in a shared medium and also reduces the number of network partitioning.

We use simulations to study the properties of DA-MLAR with on demand transmission power capability and compare it with DA-MLAR [17]. Currently, we only toggle among three transmission power modes. We will continue on developing new heuristics for switching power modes. In our experiments, we observe the effects on network performance using on demand transmission power capability in four aspects of different network topologies: Packet Delivery Ratio, Data Overhead, Protocol Overhead, and End-to-End Delay.

The location information we obtained using MLAR is used to calculate the direction and the distance from the source node to the destination node or the next hop node. As shown in Fig. 3, If S is the Sender node, D is the destination node, direction of D from S is given by,

$$\theta = \tan^{-1}\frac{y_2 - y_1}{x_2 - x_1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The distance is calculated using Euclidean distance formula.

Here, (x_1, y_1) and (x_2, y_2) are the locations (co-ordinates) of S and D respectively. Our Algorithm can select different transmission power modes for directional antenna to cover different ranges – low power for small distance and vice versa.

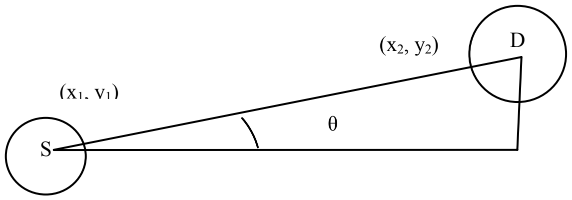

Figure 3. Distance SD and angle θ gives the distance and the direction of destination node D from the source node S.

III. DA-MLAR ON DEMAND TRANSMISSION POWER

A. Transmission Power Model

Three propagation models are often used in simulations to predict the received signal power of each packet - free space model, two-ray ground reflection model, and the shadowing model. (Table 1 gives the symbols used in the descriptions of these models.)

The free space model assumes the ideal propagation condition of clear line-of-sight path between the transmitter and receiver. The equation for this model by Friis [14] is given by

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

For omni-directional antenna $G_t = G_r = 1$ and L, is usually set to 1. Two-ray ground reflection model [15] also considers the ground refection path besides the line-of-sight propagation. For longer distance more accurate prediction is obtained by using this model; the equation given by

$$P_r(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4 L} \ldots\ldots\ldots\ldots\ldots (4)$$

Two-ray model is used for the longer distances. Usually, if d is smaller than the cross-over distance (d_c) given by

$$d_c = 4\pi h_t h_r / \lambda \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5),$$

free space model (Eq. (3)) is used otherwise Eq. (4) is used.

TABLE I
SYMBOLS FOR PROPAGATION MODELS

Symbols	Meaning
P_r	Received Signal Power
P_t	Transmitted Signal Power
G_t	Transmission Gain of Antenna
G_r	Receiver Gain of Antenna
L	System Loss
Λ	Wavelength
D	Distance Between the Transmitter and Receiver
h_r	Height of antenna for receiver
h_t	Height of antenna for transmitter
d_c	Cross Over Distance

The space model and the two-ray model both represent the communication range as the ideal circle. They do not include the multi-path propagation effects and the fading effects that impart random behavior to the received power at a certain distance. In contrast, shadowing model [15] captures these effects. Here, we choose two-ray model but in future random Received Signal Strength (RSS) will also be considered.

B. On Demand Transmission Power (ODTP)

Our Algorithm selects three transmission power modes on the basis of the range of the distances (d) between the sender and the receiver- higher transmission power for lower range and vice versa. The ranges are selected depending on the maximum coverage of transmission power - 0.0075W covers 100m, 0.2818W covers 250m and 0.5W covers 289m as shown by the equation below:

$$P_t = \begin{cases} 0.0075W \, :(d < d_1) \\ 0.2818W \, :(d_1 <= d < d_2) \\ 0.5W \;\; for\, (d \geq d_3) \end{cases}$$

Where,

Range (m)	0 – 74	75 - 199	200 - above
Distance (d)	d_1	d_2	d_3

These modes are used while sending the packets and re-broadcasting after getting the error message. On the other time, the antenna is kept in default transmission mode to prevent the deafness problem [28]. On demand transmission power feature will lower excessive interference in a shared medium and also reduces the number of possible network partitions. In future, received signal strength will also be considered for selecting different transmission power modes besides the distances.

IV. MULTIPLE OBJECTIVE OPTIMIZATION -NWAUF APPROACH

MANETs have objectives that are often conflicting and competing and some objectives have even complex conflicting relations. For example, the longer transmission range provided by higher transmission power decreases the number of hops in a particular route there by shortening the end-to-end delay. The longer transmission range also mitigates the number of network partitions that could have happened using lower transmission power mode thus improving the packet delivery ratio. However, longer transmission range on the other hand also increases the radio interference. MANET objectives will be to maximize packet delivery ratio, to minimize protocol overhead, and to minimize energy consumption.

Again, depending on the applications, some objectives have more preference than other. For example, low energy consumption is preferable for space networks than packet delivery ratio. Most of the time it is logical to have more preferable objectives in the optimum range (not the maximum) and the other objectives also near the optimum. So we need to assign different weights to given objectives accordingly – more weights for more preferable objectives and lesser weights to other objectives. Following are the steps to obtain utility.

- Find the maximum and minimum for each objective fi, i = 1, 2, … n
- Normalize each fi to bring it to the scale between 0 to 1

$$f'_{ij} = \frac{f_{ij} - f_{i\min}}{f_{i\max} - f_{i\min}}$$

- Assign weights of importance (w1, w2,…. wn > 0) for each objective, where

$$\sum_{i=1}^{n} w_i = 1$$

- Utility of each alternative is now calculated as:

$$U(a_i) = \sum_{i=1}^{k} w_i f'_{ij}$$

The alternative with minimum utility is considered as the best utility.

SIMULATIONS

We conduct all experiments in ns-2 and different network topologies used in the experiments are showed in Table 1. We assume that the initial route requests will be the flooding throughout the network but once the location information of destination is obtained, the protocol will revert to box method.

Each topology will be run for 20 times for each beam width value (θ_m), with values of θ_m ranging from 1 degree (highly directive) to 360 degrees (Omni-directional). Altogether, there are 14 directional modes as shown in Table 2.

The receiving threshold at the physical layer of each node is set to 3.65 x 10^{-10}. The packet received with the receiving signal lower than the threshold is marked as error and dropped by the MAC layer. The transmission power is set to default 0.2818W using ns-2 for the transmission range of 250m for all times except for sending the packets and re-broadcasting. On these operations, the power is switched to either high power mode of 0.5W or low power mode of 0.0075W. We have set the heights of antenna for transmitter (h_t) and receiver (h_r) each equal to 1.5m. Now using the frequency of 914MHz for Lucent WaveLAN DSSS radio interface, By using equation equations (3)(4)(5), the transmission range that can be obtained for 0.5W power is around 290m.

TABLE II
NETWORK TOPOLOGIES ; IN TOPOLOGY 3, NODES SEND PACKETS SIMULTANEOUSLY; R = RANDOM; C = CONSTANT

Topology	Number of Nodes	Grid Size (m)	Pause Time (sec)	Speed (m/s)	Nom. Trans. Range (m)	Sim. Time (s)
1	3	150 X 150	0	10.0 (R)	100	2000
2	10	500 X 500	1	10.0 (C)	250	2000
*3	10	500 X 500	1	10.0 (C)	250	2000
4	25	400 X 600	0.5	25.0(R)	250	2000
5	25	400 X 600	0.5	15.0(C)	250	2000
6	50	400 X 600	1	10.0 (R)	250	2000
7	100	700 X 700	1	5.0(R)	250	2000
8	100	700 X 700	1	20.0(C)	250	2000

We examine the performance metrics, using the Max, Min, and Average of packet delivery ratio, data overhead, protocol overhead, and end-to-end delay in Section VI. The data and protocol overhead will be expressed in terms of Bytes. The header size of *LAR Route Request*, *LAR Flood*, *LAR Route Reply*, *LAR Data*, and *LAR Route Error* are 38, 26, 38, 28, and 38 Bytes respectively. Each sending node in each topology will try to send 200 64-Bytes packets to the receiver at random times. The nodes are paired up for sending and receiving the packets except for Topology 1 and Topology 3. For example, in a 50 nodes network, node 0 sends packets to node 49; node 1 sends packets to node 48; and so on. For Topology 1, the packet sending pattern is random. For Topology 3, nodes are paired up the same as in other topologies but they are sending packets simultaneously.

In our simple approach to conduct the energy analysis, each node is initially assigned the total energy values of 100 Joules. For every DA-MLAR packet sent or received, the energy consumed by the node is deducted from its present energy value. The value of energy consumption is calculated as

Energy Consumed = Transmitting (or Receiving) Power* × *Transmission (or Reception) Time

We evaluate the following performance metrics – packet delivery ratio, data overhead, protocol overhead, and end-to-end delay. ***Packet Delivery Ratio*** is the ratio of the number of packets received to the number of packets sent. ***Data Overhead*** is the number of bytes received by the nodes to forward them to the destination, not being the recipient. ***Protocol Overhead*** is the number of bytes generated for route request, route reply, and error packets combined. ***End-to-End Delay*** is actually the Round Trip Time (RTT); the total time taken for the packet from the source node to reach to the destination node and the generated acknowledgement in the form of route reply by the destination node to reach back to the source node.

TABLE III
DIRECTIONAL MODES REPRESENTED IN WIDTH GROUP-2ND ROW FOR TOPOLOGIES 1, 4, 6 AND 7 AND 3RD ROW FOR TOPOLOGIES 2, 3, AND 5.

Width Group	Width_ in degree	
	Set #1	Set #2
1	1	10
2	3	15
3	5	30
4	7	45
5	9	60
6	11	90
7	13	120
8	15	135
9	30	150
10	45	180
11	90	210
12	180	225
13	270	270
14	360	360

VI. PERFORMANCE ANALYSIS

The performance of the mobile ad hoc network is analyzed using the data displayed in the form of tables (Only the results for Topology 6 and Topology 7 are displayed). Our observation confirms that DA-MLAR-ODTP tries to inherit not only the best results of directional mode and omni-directional mode of DA-MLAR but also further improves the packet delivery ratio and end-to-end delay. It has been observed that packet delivery ratio has always been improved for all topologies with the use of on demand transmission power capability; improvement up to 37% has been achieved. End-to-end delay has also been reduced in most of the topologies, reduction up to 57%. There is however, degradation in data and protocol overheads in some of the topologies. The higher radio range provided by higher transmission mode increases the network interferences. However, on demand adjustment tries to counter balance its effect which has been justified by the performance results analyzed using NWAUF approach.

In Topology 6 (Table IV) packet delivery ratio has been improved by around 15% but at the same time protocol overhead has also been increased by around 15%. In Topology 7 (Table V), there is the highest end-to-end delay reduction of 57% with significant improvement in packet delivery ratio up to 37%. The protocol overheads are more or less the same for both.

The Normalized Weighted Additive Utility Function (NWAUF) approach has been applied to analyze the combined performance metrics. Weight groups that have been used are shown in Table VIII. The results are depicted in Fig. 4 (for Topology 6 and Topology 7). The utility values calculated for DA-MLAR-ODTP are found to be the minimum for most of the Topologies.

In summary, we discover that with the on demand transmission power capability, there is tremendous improvement in packet delivery ratio while comparing to DA-MLAR. The use of higher range covers more area of forwarding nodes hence network overhead is higher but that is somehow compensated by less frequent re-broadcasting as verified by Fig. 4. We have obtained the comparative figures for the number of rebroadcasts for DA-MLAR and DA-MLAR-ODTP displayed in Table VI. The figures show less number of re-broadcasts for DA-MLAR-OPTP compared to DA-MLAR. The longer transmission range also decreases the number of hops as less number of forwarding nodes are sufficient. The energy consumption for DA-MLAR and DA-MLR-ODTP is also presented in Table VII that shows almost similar energy consumption pattern except for few topologies. Note that the negative percentage indicates degrading performance and vice versa.

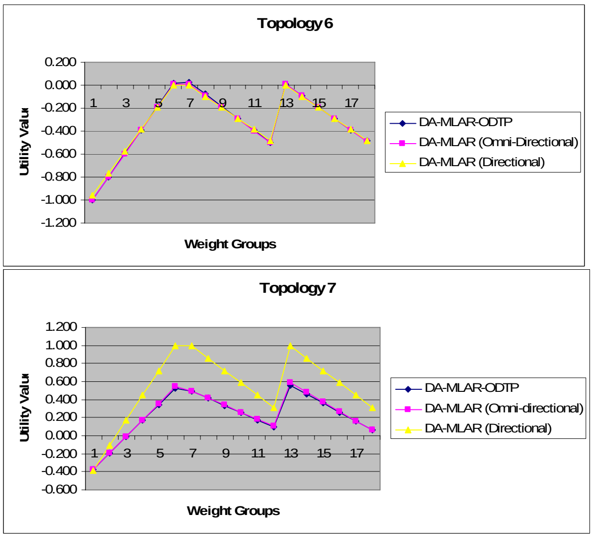

Figure 4. Utility values for DA-MLAR and DA-MLAR-ODTP

TABLE IV
*TOPOLOGY 6 WITH 50 NODES AND RANDOM MOBILITY; A: OMNI-DIRECTIONAL; B: DIRECTIONAL

Objective Measurements	DA-MLAR-ODTP	DA-MLAR		Difference (%)	
		A	B	A	B
Packet Delivery Ratio (%)	79.53	71.72	69.39	10.89	14.61
Data Overhead (Byte)	14263	12102	10632	- 17.85	- 34.15
Protocol Overhead (Byte)	1900777	1694144	1659625	- 12.20	- 14.53
End-to-end Delay (ms)	33.38	32.76	34.68	- 1.89	3.75

TABLE V
*Topology 7 with 100 Nodes and Random Mobility; A: Omni-directional; B: Directional

Objective Measurements	DA-MLAR-ODTP	DA-MLAR		Difference (%)	
		A	B	A	B
Packet Delivery Ratio (%)	43.96	35.91	36.70	22.42	19.78
Data Overhead (Byte)	183827	176624	180890	- 4.10	- 1.62
Protocol Overhead (Byte)	12435000	12531998	12310206	0.80	- 1.0
End-to-end Delay (ms)	188.41	283.48	433.32	33.54	56.50

VII. DISCUSSIONS

MLAR with directional antenna support is targeted for the space network applications that are often characterized by the high bit error rate, intermittent connectivity, limited bandwidth, and limited energy [18] [20]. DA-MLAR provides lower overhead (better bandwidth utilization), better connectivity (fewer network partitions), and fewer routing hops (shorter end-to-end delay). That has been further improved by DA-MLAR-ODTP. Varying transmission power modes on the basis of distance may not be sufficient in the highly interfered environments. So, we will also create the random received signal strength (RSS) environment in the future to show the adaptability of DA-MLAR-ODTP in such harsh environment. Dynamically and intelligently alternating different directional modes according to the requirements of the network will be our future research topic too. Another direction will involve Multi-criteria Decision Making (MCDM) [21][26][27]. We will also evaluate the energy saving by incorporating the intelligence that can be one more step towards using this protocol as a space network protocol where the energy issue is very critical besides other constraints. Finally, we will emulate the space network [22] for real traffic scenario.

VI. CONCLUSION

In this paper we developed a multiple objective optimization MANET approach for reconfigurable antenna (in terms of directions) and transmission energy use. With the augmentation of on demand transmission power capability, we demonstrate via extensive simulation experiments that DA-MLAR-ODTP tries to inherit not only the best results of directional mode and omni-directional mode of DA-MLAR but also further improves the network performance. The packet delivery ratio and end-to-end delay ratio have been improved by 37% and 57% respectively. The energy consumption however, is fairly the same for both DA-MLAR and DA-MLAR-ODTP except for few topologies.

TABLE VI
COMPARISON OF FREQUENCY OF REBROADCASTS IN DA-MLAR AND DA-MLAR-ODTP

Protocols	Topology 2	Topology 4	Topology 6	Topology 7
DA-MLAR	433	794.35	931.05	5403.95
DA-MLAR-ODTP	433	759.70	936.95	5376.20

TABLE VII
COMPARISON OF ENERGY CONSUMPTION IN DA-MLAR AND DA-MLAR-ODTP; A: Omni-directional; B: Directional

	DA-MLAR-ODTP	DA-MLAR		Difference (%)	
		A	B	A	B
Topology 2	0.21900	0.23750	0.23802	7.8	8.0
Topology 4	0.44190	0.44569	0.43745	0.85	-1.02
Topology 6	0.86400	0.82031	0.78741	-5.32	-9.73
Topology 7	2.28440	2.28268	3.01077	-0.08	24.13

TABLE VIII
Multi-objective Weight Groups for Calculation of Utility Values

Application	Objectives' Weight Groups		
	w_1	w_2	w_3
1	1.00	0.00	0.00
2	0.80	0.10	0.10
3	0.60	0.20	0.20
4	0.40	0.30	0.30
5	0.20	0.40	0.40
6	0.00	0.50	0.50
7	0.00	0.00	1.00
8	0.10	0.10	0.80
9	0.20	0.20	0.60
10	0.30	0.30	0.40
11	0.40	0.40	0.20
12	0.50	0.50	0.00
13	0.00	1.00	0.00
14	0.10	0.80	0.10
15	0.20	0.60	0.20
16	0.30	0.40	0.30
17	0.40	0.20	0.40
18	0.50	0.00	0.50

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REFERENCES

[1] *J. Broach, D.A. Maltz, and D.B Johnson, "The Dynamic Source Routing Protocol for Mobile Ad Hoc Networks", Internet Draft, December, 1998.*

[2] *C.E Perkins and E. M. Royer,"Ad Hoc On-demand Distance VectorRouting", Proc. 2nd IEEE Wksp. Mobile Comp. Sys. And Apps. , Feb 1999.*

[3] *Javier Gomez, Andrew T. Compbell,"A Case for Variable-Range Transmission Power Control in Wireless Multihop Netowrks",IEEE INFOCOM 2004.*

[4] *Ting-Chao Hou and Victor O.K. Li,"Transmission Range Control in Multihop Packet Radio Networks", IEEE Transactions on Communications, Jan 1986.*

[5] *Q. Gao, K.J. Blow, D.J. Holding, I.W. Marshall, and X.H. Peng, "Radio Range Adjustment for Energy Efficient Wireless Sensor Networks", Ad Hoc Networks 4, June 2004.*

[6] *Young-Bae Ko and Nitin H. Vaidya. "Location-Aided Routing(LAR) in mobile ad hoc networks", Wireless Network 2000.*

[7] *Wen-Hwa Liao, Tu-Chee Tseng, and Jang-Ping Sheu, "GRID: A Fully Location-Aware Routing Protocol for Mobile Ad Hoc Networks", Telecommunication Systems, 2001.*

[8] *Priscilla Chen, Bob O'Dea, Ed Callaway, "Energy Efficient System Design with Optimum Transmission Range for Wireless Ad Hoc Networks", Communication 2002, ICC 2002.*

[9] *Charles E. Perkins, Elizabeth M. Royer," Samir R. Das. And Mahesh K.Marina,"Perormance Comparision of Two On-Demand Routing Protocols for Ad Hoc Networks", IEEE Personal Communications, February 2001*

[10] *Jie Wu and Bing Wu, "A Transmission Range Reduction Scheme for Power-Aware Broadcasting in Ad Hoc Networks Using Connected Dominating Sets", VTC 2003.*

[11] *Mahesh K. Marina and Samir R. Das, "Ad hoc On-demand Multipath Distance Vector Routing", ICNP '01, Nov. 2001.*

[12] *Miguel Sanchez, Pietro Manzoni, and Zygmunt J. Haas, "Determination of Critical Transmission Rnage in Ad-Hoc Networks", Proceedings of Multiaccess Mobility and Teletraffic for Wireless Communication 1999.*

[13] *Thanasis Antoniou, Ioannis Chatzigiannakis, George Mylonas, Sotiris nikoletseas, and Azzedine Boukerche, "A New Efficient and Fault-tolerant Protocol for Data Propagation in Smart Dust Networks Using Varying Transmission Range", Proceedings of Annual Simulation Symposium (ANSS'04).*

[14] *H.T. Friis,"A Note on a Simple Transmission Formula", Proc. IRE 1946.*

[15] *T.S. Rapport,"Wireless Communications, Principles and Practice", Prentice Hall, 1996.*

[16] *X. Lin and L. Stojmenovic, "Gedir: Loop-Free hybrid single-path/Flooding routing algorithm with guaranteed delivery for wireless networks", IEEE Trans. On parallel and Distr. Stst. Oct. 2001.*

[17] *Sanjaya Gajurel, Limin Wang, Behnam Malakooti, Zhihua Wen, and Siva Tanguturi," DA-MLAR: Directional Antenna Multi-path Location Aided Routing", n. 16, p. 1-16, WTS 2006.*

[18] *Akyildiz, I.F., Akan, O.B., Chen, C., Fang, J., and Su W., "InterPlaNetary Internet: state-of-the-art and research challenges", Computer Networks, vol.43, 2003.*

[19] *M. Joa-Ng and I-T Lu, "A Peer-to-Peer Zone-Based Two-Level Link-State Routing for Mobile Ad Hoc Networks," IEEE J. Selected Areas in Communication 1999.*

[20] *Malakooti, B. and Bhasin, K., "Roadmap for Developing Reconfigurable Intelligent Internet Protocol for Space Communication Networks", 2005 IEEE International Conference On Networking, Sensing and Control; Tucson, AZ; March 2005.*

[21] *Malakooti, B and Thomas, I, "A Distributed Composite Multiple Criteria Routing Using Distance Vector", 2006 IEEE International Conference On Networking, Sensing and Control (ICNSC06), Ft. Lauderdale, Florida, U.S.A. April 23-25, 2006.*

[22] *Guo, Z .and Malakooti, B. "Towards Accurate and Efficient Network Emulation" 2006 IEEE International Conference on Networking, Sensing and Control (ICNSC06), Ft. Lauderdale, Florida, U.S.A. April 23-25, 2006.*

[23] *Nanda, S.; Gray, R.S., "Multipath location aided routing in 2D and 3D," Wireless Communications and Networking Conference, WCNC 2006, IEEE, vol.1, no. pp. 311- 317, 3-6 April 2006.*

[24] *Behnam Malakooti, Ivan Thomas, "A Distributed Composite Multiple Criteria Routing Using Distance Vector", 2006 IEEE International Conference On Networking, Sensing and Control (ICNSC06), Ft. Lauderdale, Florida, U.S.A. April 23-25, 2006. (& Chair)*

[25] *Atiken Teber., Behnam Malakooti., Ivan Thomas.,Zhihao Guo., "Multi-Criteria Routing for Deep Space", Proceedings of IERC Conference, May 14-18, Atlanta, Georgia, May 2005.*

[26] *Malakooti, B. Z. Yang, "Clustering and Group Selection of Multiple Criteria Alternatives with Application to Space-based Networks", IEEE Trans. on Systems, Man, and Cybernetics Part B: Cybernetics, Vol. 34, 40-51, 2004.*

[27] *Malakooti, B., V. Raman, "Clustering and Selection of Multiple Criteria Alternatives using Unsupervised and Supervised Neural Networks", Journal of Intelligent Manufacturing, Vol. 11, 435-453, 2000.*

[28] *Romit Roy Choudhury and Nitin H. Vaidya, "Deafness: Problem in Ad Hoc Networks when using Directional Antennas", ICNP'04, Oct. 2004.*

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