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A Reliable Position-based Clustering Routing Protocol for Mobile Ad Hoc Network

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***Abstract*— Mobile Ad Hoc Network (MANET) is a special and attractive type of new wireless networks. It is an autonomous system that can dynamically be set up anywhere and anytime without using any pre-existing network infrastructure and its mobile hosts are free to move randomly. Host mobility in MANET causes failure of wireless links between nodes and breaks all the routes that use these links. Consequently, route reconstructions are needed, which is one of the most crucial issues for this type of wireless networks. There are two common solutions to this problem which increase the route reliability (lifetime) in MANETs; increasing the reliability of the links by using more reliable links and multipath route discovery. In this paper, both these schemes are used to develop a reliable unicast routing protocol for MANETs. As the first step, efficient cross layer link reliability metric is proposed for reliable link selection. Reliable routing protocols for MANETs use many link reliability metrics for finding reliable links; four of the most commonly used are: Link Expiration Time, Probabilistic Link Reliable Time, Link Packet Error Rate and Link Received Signal Strength. The cross layer metric combines the aforementioned metrics by means of a weight function. The value of the weighting factors of this function are determined by the Response Surface Methodology. Next a reliable position based clustering routing protocol is designed. In this protocol the mobile nodes form disjoint sets of clusters, and for increasing the stability of these clusters, the aforementioned cross layer link reliability metric is used for cluster formation. A route is constructed and represented by a sequence of clusters and more reliable links are selected for data transfer inside and between the clusters. Because of the multiple links which usually exist between the clusters, multipath route scheme is used in this routing protocol in addition to the reliable link selection. Simulation results show that by using this protocol the lowest number of route reconstructions is achieved in comparison with the other related protocols.**

***Keywords*— MANET, Reliable Routing, Long Lifetime Route, Link Reliability Metric.**

I. INTRODUCTION

A Mobile Ad Hoc Network (MANET) is a new type of wireless network which does not need any type of pre-existing infrastructure in order to operate. In this network, the hosts are free to move around while they communicate among each other. These properties cause MANETs to be considered as a suitable network for some special applications such as in military use, but it is also used in some other applications including: Disaster recovery, Rescue and emergency operations, Maritime communications, Vehicle networks, Meetings and conferences networks, Robot networks. Highly dynamic topology of MANETs causes a large number of unicast routing protocols to be proposed for this type of wireless network.

Most of these protocols use different methods for routing in comparison to wired network routing protocols [1]. Also, each protocol has a different efficiency according to the deployment scenarios and application requirements which shows that we cannot use a single solution for efficient routing in MANETs. In most of the proposed routing protocols for MANETs, the reliability or lifetime of the routes is not considered for route selection. Consequently, the routes may be unstable and we have route breakups because of the nodal mobility and node or link failures. Many efforts have been made to design reliable routing protocols that enhance stability of the routes [2 – 18].

SWORP[2], RSR[4], CLRR[8], RFAR[9], LSBRP[10], RA-AODV[12], BNDP[13], SAG[14], RFBRP[17] and EESRQMA[18] protocols increase link (hop) reliability of the routes by using link reliability metrics in the route discovery phase. They use following link reliability metrics:

- Link Expiration Time (LET) and Link Errors (LE) are used in SWORP and RFBRP,
- RSR uses Node Successful Data Transmission (NSDT),
- Probabilistic Link reliable Time (PLRT) and Link capacity (LC) are used in RFAR,
- LLRR and LSBRP use Link Received Signal Strength (LRSS),

- RA-AODV uses Node Speed (NS) and Distance,
- BNDP uses Link Failure Rate (LFR),
- SAG uses a new LET and
- EESQQMA uses LET, LFR, PLRT, LRSS.

DLLR[3], LRHR[5], ARMBR[6], SSBRP[7], MP-OLSR[11], PST-MR[15] and EESMR[16] protocols use multipath routing scheme which increases the route reliability in MANETs. We expect higher route reliability from this scheme, but it does not have such a high reliability, simply because in these protocols all routes are discovered at the same time and in most of the cases the backup routes are also broken after the primary route breakage.

The reliable routing protocol, Group Dynamic Source Routing (GDSR) [19], uses a different idea to implement the multipath scheme. It uses group path (cluster route) and because of the parallel links which usually exist between the clusters, the multipath route can be discovered leading to an increase in route reliability.

We can expect a high efficiency from this protocol because it uses a multipath scheme which leads to higher route reliability and we have a dynamic and adaptive multipath scheme, which can show an optimal efficiency level. Also when a link between two clusters is broken, we have the probability of a new link creation between these two clusters which increases the route reliability too. According to the aforementioned differences, we expect high reliability for the routes which are selected by the GDSR protocol, but it does not show high efficiency. The most important reason for this problem is low stability of the clusters and routes in this protocol. It does not use any link reliability metric for selecting more reliable links in cluster and route construction.

In Reliable Position-based Clustering Routing Protocol (RPCRP), the proposed reliable routing protocol in this paper, like GDSR, the cluster route is used. But in this case, first an efficient cross layer link reliability metric (CLM) is proposed to find more reliable links in MANETs. This metric is used in the cluster formation and route construction phases, which increases the stability of the clusters and routes.

Therefore, both of the schemes for increasing the route reliability (i.e. increasing the reliability of the links and multipath route discovery) are used. Also we have a dynamic and adaptive multipath scheme, like GDSR, and we can expect a higher efficiency for this protocol.

The rest of this paper is organized as follows. In section II, the new cross layer link reliability metric are described. Section III explains the proposed protocol, RPCRP. Section IV presents the results of the simulations and finally conclusion of paper comes in section V.

II. CROSS LAYER LINK RELIABILITY METRIC (CLM)

In wireless communications, multipath propagations caused by multiple radio signals are received at the destinations via different paths. As a result at the receivers, we have signals which are the summation of all the received signals. This type of signal is characterized by a highly variable power distribution at different times and spaces which changes the signal quality at the destination nodes.

Realistic physical layer factors are too complicated to be modeled precisely and to be analyzed with a few mathematical equations. As a result, link reliability metrics are used for reliability estimation of the wireless links. Reliable routing protocols try to find more reliable links for route construction by using different reliability metrics in the route discovery phase. Four mostly used link reliability metrics in the aforementioned reliable routing protocols are:

- Network layer “Link Expiration Time” (LET),
- Network layer “Probabilistic Link Reliable Time” (PLRT),
- Data link layer “Link Packet Error Rate” (LPER),
- Physical layer “Link Received Signal Strength” (LRSS).

Link Expiration Time (LET): LET is one of the position based network layer metrics for reliability of a wireless link. Free space propagation is assumed and the motion parameters of two neighbouring nodes are needed. This means that each node of MANET must have a Global Positioning System (GPS). For LET computation, with the motion parameters of two nodes, we calculate the duration of the time that these two nodes remain connected. Assume that the nodes have equal transmission radius r and let (x_1, y1) and (x_2, y_2) denote their respective positions. Also let v_1 and v_2 denote their speeds along the directions Θ_1 and Θ_2 respectively. Then the LET can be computed by the following equation:

$$LET = \frac{-(ab+cd)+\sqrt{(a^2+c^2)r^2-(ad-cb)^2}}{(a^2+c^2)} \quad (1)$$

Note that:

$$a = v_i cos\theta_i - v_j cos\theta_j , \qquad b = x_i - x_j$$

$$c = v_i \sin\theta_i - v_j sin\,\theta_j , \qquad d = y_i - y_j$$

In addition, the equation cannot be applied when

$$v_i = v_j \;, \theta_i = \theta_j \;, LET = \infty$$

Probabilistic Link Reliable Time (PLRT): The second network layer link reliability metric is PLRT. For PLRT computation, in the first step, the simulation experiments must be run for the unreliable base protocol. During these simulations, we measure lifetime of the links and compute the average lifetime of the links. Rho (ρ) is the inverse of this lifetime and shows the average link failure rate. After that we can compute link reliability with system reliability equation:

$$Probability(linkworkattimet) = e^{-\rho t} \quad (2)$$

PLRT can be estimated through the above equation with an estimation rule, such as from now to when the link reliability is higher than a certain threshold (in this implementation, 10% threshold is used).

Link Packet Error Rate (LPER): The best metric for reliability of a wireless link is Signal to Noise Ratio (SNR) and Bit Error Rate (BER) of the link. Unfortunately, we cannot obtain these metrics for each received frame in realistic scenarios. However, another metric can be obtained which is related to these two metrics. It is called LPER, a data link layer metric for link reliability.

LPER can be computed by finding the number of damaged receiving packets (packets received with error) in a time interval and normalizing it by the time interval duration. Note that for this metric higher value means lower reliability and it must be transferred to the network layer for using in the routing protocols (a cross layer metric).

Link Received Signal Strength (LRSS): The physical layer received signal strength is another good metric for reliability of a link. For obtaining this metric, we must have received signal strength measurement at the physical layer. Like LPER, this metric must also be transferred to the network layer (a cross layer metric).

Proposed Cross Layer Metric (CLM): For enhancing the efficiency of the above reliability metrics, they are combined in the following weight function and a new metric CLM is proposed which consider all the metrics for reliability measurement of the links.

$$CLM = \left(C1 * \frac{LET}{MAX(LET)}\right) + \left(C2 * \frac{PLRT}{MAX(PLRT)}\right) - \left(C3 * \frac{LPER}{MAX(LPER)}\right) + \left(C4 * \frac{LRSS}{MAX(LRSS)}\right) \quad (3)$$

C3 is negative because if the LPER metric increases, the link reliability actually decreases. MAX (LRSS) is the transmitted signal strength and MAX (PLRT) is the average lifetime of the links (1/ρ). For MAX (LET) and MAX (LER), the simulation scenario is run with unreliable base routing protocol and measure the maximum value of these two parameters. After that if in a new or a realistic scenario we have a greater value, we can replace them with the new values. The value of the weighting factors of this function are determined by the Response Surface Methodology (RSM) which is an optimization method based on statistical and mathematical techniques. This methodology was first designed for industrial processes, but Vadde et al. [20] showed that it can be used for networking computation too. When there are one or more response variables and a set of quantitative experimental variables or factors, we can use RSM to determine the values of the factors which maximize or minimize the response variables. In this case the response variable is the reduction in the number of route reconstructions and the experimental variables are the weighting factors of the CLM.

The Minitab 16 statistics package has been used for this purpose. In the RSM first we must use some special values for the factors (which are determined by the RSM) in the experiments and the results are transferred to the RSM optimization software. In scenarios, the Minitab computes the Root Sum Squared (RSS) of the route reconstructions number reductions in the experiments for CLM and use it as the response variables. This variable shows the total efficiency of the protocols and we can use it for efficiency comparison of the protocols.

Location Aided Routing (LAR) protocol [21] is chosen as the base protocol for simulation experiments. LAR is a reactive position based routing protocol, and it is chosen because position information is used in the link reliability metrics computation. In the reliable routing protocols, each node computes the link reliability metric and updates the route reliability metric in the RREQ packet. Also the destination node sends the Route Reply (RREP) packet with a certain delay to receive RREQ packets from other routes. On the other hand, given a packet which MAC layer was unable to transmit to the neighbor node listed in the source route, the route broken is detected at this link. These changes are applied to LAR and the Reliable LAR (REL-LAR) protocol is prepared. On the other hand, we can find more routes from the source to the destination if packet broadcast is used for RREQ packet (more routes increase our selections and lead to better selection of a reliable route). So in REL-LAR broadcast is used for route discovery, instead of limiting the scope of the route request as what is used in the position based routing protocols.

QualNet simulator Version 5 is used as the simulator for this study. QualNet is ultra high-fidelity network evaluation software that predicts wireless, wired and mixed-platform network performance for networking devices and protocols.

The purpose of the simulations is to test the efficiency of the reliable routing protocol under different network conditions. The focus is on the number of route reconstruction as performance metric. The base protocol LAR is simulated in the first step and afterwards, the simulation is repeated for the new reliable protocol.

Outdoor scenarios are assumed with nodes moving in car-speed in simulations. The control parameters used in the simulation experiments are network node density, maximum node mobility speed and propagation shadowing mean value. The last parameter is related to the number of obstructions along the propagation path. Most of the parameters in the input configuration file are tested, and it is found that these three parameters are the most effective ones on the link reliability (lifetime) in a wireless network. The average number of the route reconstruction is then measured for the source nodes in three different experiments:

- Variable node density (Experiment 1),
- Variable mobility speed of nodes (Experiment 2),
- Variable number of obstructions (Experiment 3).

For realistic wireless channel model, the Two-Ray Propagation Model with Shadowing and Rayleigh Fading is used in all the experiments. Ten different runs (with different seeds for random variables) were conducted in each experiment and the average value of the results is computed. The values of important parameters are shown in Table1. In the first experiment, the terrain area was changed from 1 sq km to 3 sq km area (so the node density is decreased). For the second experiment, the Mobility MAX Speed for Random Waypoint Mobility Model is changed from 10 m/s to 50 m/s. Finally, in the third experiment, mean of the propagation shadowing model is changed from 4dB to 7dB. For selecting the appropriate values for parameters, most of the possible values are tested and the most effective ones are chosen.

TABLE I
IMPORTANT PARAMETERS IN THE SIMULATIONS

Parameter	Value
SIMULATION-TIME	10 Minute
NUMBER OF NODES	25
NODE PLACEMENT	UNIFORM
TERRAIN AREA	1 Sq km (1000m * 1000m)
MOBILITY MODEL	RANDOM-WAYPOINT with MOBILITY PAUSE TIME = 1s MOBILITY MIN SPEED = 0 MOBILITY MAX SPEED = 10m/s
PROPAGATION PATHLOSS MODEL	TWO-RAY
PROPAGATION SHADOWING MODEL	LOGNORMAL with PROPAGATION SHADOWING MEAN = 4.0dB
PROPAGATION FADING MODEL	RAYLEIGH
PHYSICAL LAYER MODEL	IEEE 802.11b
DATA RATE	2 Mbps
MAC PROTOCOL	MACDOT11
APPLICATION LAYER MODEL	3 CBR SOURCES, 1 PACKET PER SECOND, PACKET SIZE = 32 Bytes

For each point (condition) of the simulation scenarios, we have ten different runs (with different seeds for random variables) in QualNet and the average value of the results is computed by Minitab. Then Minitab computes the Root Sum Squared (RSS) of the average route reconstructions number reductions from the LAR to the REL-LAR-CLM for all 12 points (5 points in Experiment 1, 4 points in Experiment 2 and 3 points in Experiment 3). Note that the first point of each experiment is a common point (condition). Table 2 shows the values of the experimental factors determined by RSM together with the RSS values of the route reconstructions number reductions, as the response variable.

It is assumed that the weighting factors varies from zero to one (zero means it has no effect on the CLM, and one means it is considered completely in the CLM computation) and all three experiments are repeated for each set of values for the weighting factors C1, C2, C3 and C4.

Next “Analyze Response Surface Design” of Minitab is used to fit a model to the experimental data. In this step Minitab uses a regression analysis to find the best model for the relationship between the response variable and the experimental factors.

Finally, to optimize the responses “Response Optimizer” of the Minitab is used to obtain a numerical and graphical analysis of the best values for the experimental factors C1, C2, C3 and C4.

By using this optimizer the following values are obtained for the weighting factors of the CLM:

C1 = 0.29, C2 = 0.57, C3 = 0.56, C4 = 1

TABLE 2
RESULTS OF THE RSM EXPERIMENTS

C1	C2	C3	C4	RSS of the route reconstructions number reductions
0.0	0.0	0.0	0.0	0
1.0	0.0	0.0	0.0	49
0.0	1.0	0.0	0.0	109
1.0	1.0	0.0	0.0	111
0.0	0.0	1.0	0.0	104
1.0	0.0	1.0	0.0	106
0.0	1.0	1.0	0.0	120
1.0	1.0	1.0	0.0	122
0.0	0.0	0.0	1.0	128
1.0	0.0	0.0	1.0	130
0.0	1.0	0.0	1.0	137
1.0	1.0	0.0	1.0	138
0.0	0.0	1.0	1.0	135
1.0	0.0	1.0	1.0	136
0.0	1.0	1.0	1.0	155
1.0	1.0	1.0	1.0	140
0.0	0.5	0.5	0.5	154
1.0	0.5	0.5	0.5	150
0.5	0.0	0.5	0.5	138
0.5	1.0	0.5	0.5	140
0.5	0.5	0.0	0.5	140
0.5	0.5	1.0	0.5	142
0.5	0.5	0.5	0.0	124
0.5	0.5	0.5	1.0	170
0.5	0.5	0.5	0.5	158

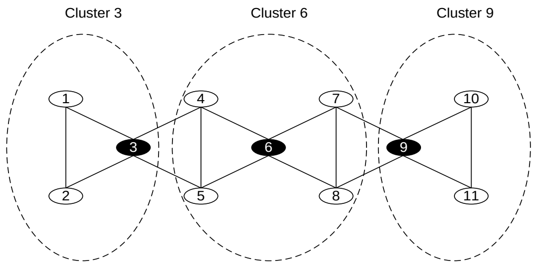

Figure 1. Cluster route (3-6-9) from node 1 to node 10

III. Reliable Position based Clustering Routing Protocol (RPCRP)

In this section the Reliable Position based Clustering Routing Protocol (RPCRP) is described. In this protocol the mobile nodes form disjoint sets of clusters and a route is constructed and represented by a sequence of clusters (Figure 1). In this figure, nodes which have a connection between them are assumed to be neighbor nodes and they are within radio range of each other. Also it is assumed that nodes 3, 6 and 9 are the clusterhead nodes. In this example, between node 1 and 10, the cluster route (3-6-9) is used instead of the traditional node route (for example 1-3-4-6-7-9-10). In this cluster route, we have two parallel links between the clusters which leads to multipath route discovery opportunity. In RPCRP, the efficient Cross layer Link Reliability metric (CLM) described in previous section is used in the cluster formation and route construction phases respectively, and this increases the stability of the clusters and routes in this protocol.

Reliability based Distributed Mobility Adaptive Clustering (RDMAC): As mentioned in [22], the Distributed Mobility Adaptive Clustering (DMAC) one-hop clustering protocol [23] is a weight based, distributed and mobility adaptive algorithm which can be used when mobility of nodes cannot be avoided during cluster setup. Because of these properties, this protocol is used as the base clustering procedure in the RPCRP. For the proposed reliable routing protocol RPCRP, the cluster formation mechanism is modified to form the RDMAC protocol. First, in the RDMAC, the weights of the nodes are computed by adding the cross layer link reliability metric, CLM, of all links between the corresponding node and its neighbors. The choice of the clusterheads here is based on the weight associated to each node: the bigger the weight of a node the better the node is for the role of clusterhead. Cluster formation in RDMAC protocol is done according to the CLM link reliability metric computations in the nodes. Therefore, we can expect higher stability for those clusters which are formed by means of this mechanism.

Reliable Cluster based Hierarchical Routing (RCHR): The proposed routing protocol, RPCRP, is a source routing protocol. In these routing protocols, the intermediate nodes only find the next node in the route and send the packets. But in RPCRP, the routes are based on clusters, and therefore we need a new routing scheme for forwarding the packets. The Reliable Cluster based Hierarchical Routing (RCHR) scheme is designed for this purpose.

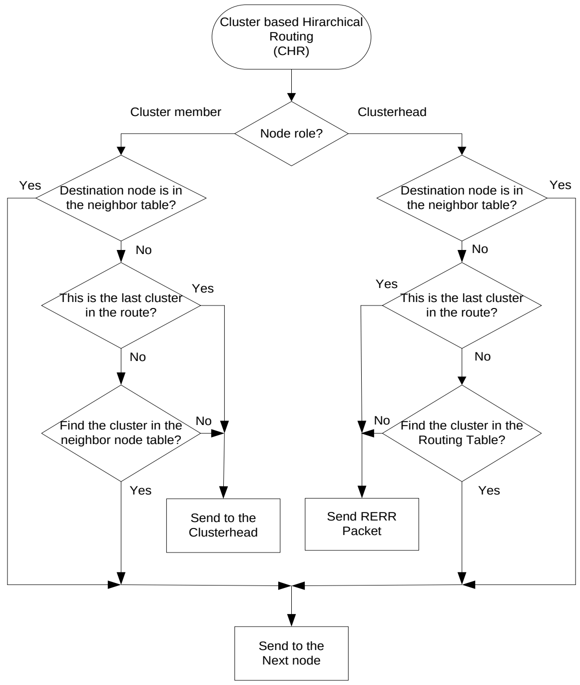

Figure 2. Flowchart of the Reliable Cluster based Hierarchical Routing (RCHR)

Each member node of the clusters send the neighbor nodes/clusters table to the clusterhead when it joins the cluster and each time we have changes in this table due to the link failure or a new link is established. The clusterheads use these tables to construct a routing table which is used for routing the data packets. In this table, for each neighbor cluster, the next hop node with the most reliable link (i.e. link with the highest link reliability metric, CLM) is determined. Figure 2 shows the flowchart of this routing scheme. As can be seen in Figure 2, the RCHR selects more reliable links from the source to the destination and because of the up-to-date routing table in the clusterheads, if a link between two clusters is broken, one of the other existing links can be selected automatically.

IV. Results and Discussions

For the simulation experiments, the following changes are applied to the LAR routing protocol:

- Distributed Mobility Adaptive Clustering (RDMAC) procedures, related messages and data structures are added to the protocol.

- The Reliable Cluster based Hierarchical Routing (RCHR) scheme is implemented and the related tables are defined for all nodes.

These changes are applied to LAR and hence the Reliable Position based Clustering Routing Protocol (RPCRP) is developed. For comparison with GDSR, the Clustering Routing Protocol (CRP) is developed. QualNet simulator Version 5 has been used as the simulator for the study. The purpose of the simulations is to compare the efficiency of these two routing protocols (CRP, RPCRP) and the REL-LAR-CLM protocol (reliable routing protocol introduced in the previous chapter) under different network conditions.

The numbers of route reconstructions are considered as performance metrics. The base protocol LAR is simulated first and afterwards, the simulation is repeated for three protocols, i.e. REL-LAR (CLM), CRP and RPCRP. Same experiments are used in this section as the previous section. Figures 3, 4 and 5 show the results of the three experiments respectively for all routing protocols. They compare the efficiencies of the REL-LAR protocol and the two clustering routing protocols (CRP, RPCRP). The figures show that the smallest reduction in route reconstruction is associated to the REL-LAR. The CRP has a higher efficiency in route reconstructions reduction. The multipath scheme which is used in CRP, increases the route reliability with a higher efficiency over that of the pure link reliability increase used in REL-LAR.

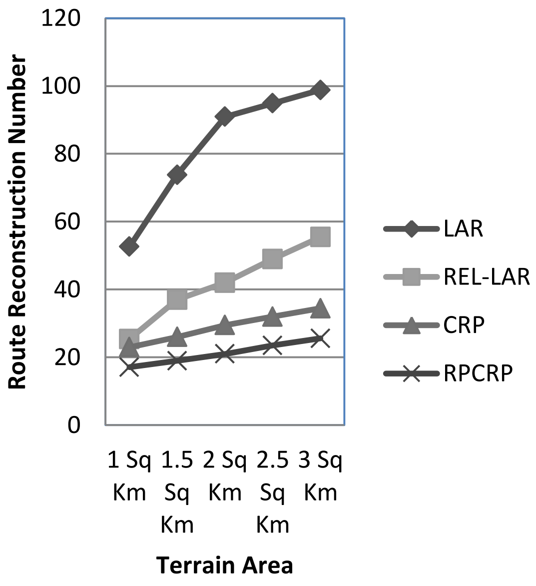

Figure 3. The effect of terrain area (node density) on route reconstruction

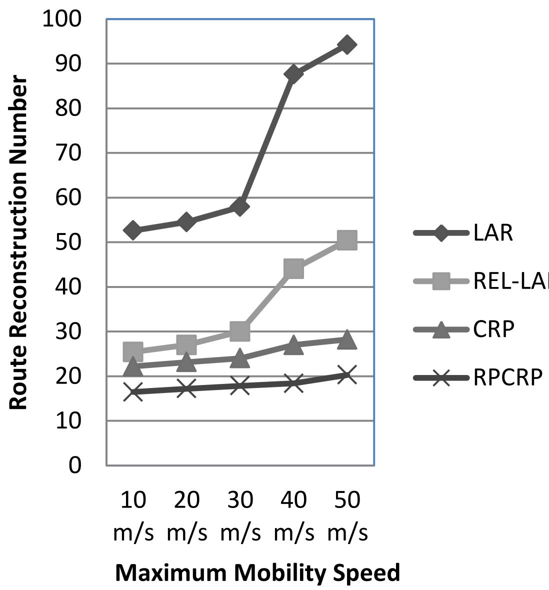

Figure 4. The effect of node mobility speed on route reconstruction

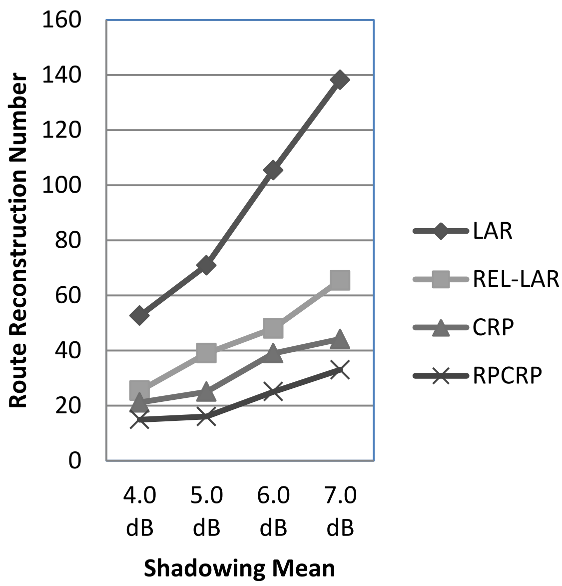

Figure 5. The effect of number of obstructions on route reconstruction

Finally, the highest route reconstructions reduction is found in the proposed protocol, RPCRP. This higher efficiency is attributed to the following factors:

- Use of both reliability increasing schemes; increasing the link reliability and the multipath routes.
- Use of the link reliability metric, CLM, in cluster formation and route construction, which increases the stability of the clusters and routes.
- Clusterheads have an up-to-date routing table and each time they want to send a data packet to the next cluster in the route, they select a link which exists at

that time. Therefore a dynamic and adaptive multipath scheme is used, which shows a good efficiency.

V. CONCLUSION

In this paper, an efficient reliable unicast routing protocol, RPCRP, has been developed for MANETs. In this protocol, the idea of cluster route is used, i.e. the route is constructed and presented by way of cluster IDs, and node IDs are not used unlike the conventional routing algorithms. Based on this idea, a route is broken when two clusters completely disconnect from each other. In the first step, a cross layer link reliability metric, CLM, is proposed, in which it combines four different link reliability metrics in a weight function. The value of the weighting factors of this function are determined by the Response Surface Methodology (RSM). In RPCRP, this reliability metric (CLM) is used in the cluster formation and route construction phases and this increases the stability of the clusters and routes in this protocol.

Simulation results show that by using this reliable routing protocol, the smallest number of route reconstructions is needed in comparison with the other related protocols. The increasing spread of mobile nodes along with the technical advances in multi-hop MANETs makes this kind of networks an important type of access network for the next generation networks. The demand of multimedia services from these networks is expected to grow significantly in the coming years. Multimedia services though, require the provision of Quality of Service (QoS) guarantee. Nevertheless, the highly dynamic nature of MANETs, the energy constraints, the lack of centralized infrastructure and the variable link capacity, makes the QoS provision over MANETs a big challenge.

As a suggestion for future research, this method can be used for QoS based routing protocols for MANETs which are routing mechanisms under which paths for flows are determined based on some knowledge of resource availability in the network, as well as the QoS requirement of flows. In the first step, we must define a new link selection metric according to the QoS requirement (packet delay, delay jitter, packet loss ratio, bandwidth, battery power). After cluster formation and construction of the cluster route, for link selection between the clusters, the aforementioned link selection metric is used and a suitable link is chosen. Therefore, without any changes in the cluster route, we can select different paths according to the QoS requirement.

REFERENCES

[1] Oo, M.Z., and Othman, M. (2010). Analytical Studies of Interaction between Mobility Models and Single-Multi Paths Routing Protocols in Mobile Ad Hoc Networks, Wireless Personal Communications, DOI 10.1007/s11277-010-0205-3, pp1-24.

[2] Wang, N.C., Huang, Y.F., and Chen, J.C. (2007). A stable weight-based on-demand routing protocol for mobile ad hoc networks, Elsevier Information Sciences, Vol. 177,pp. 5522–5537.

[3] Cheng, Z., and Heinzelman, W.B. (2008). Discovering long lifetime routes in mobile ad hoc networks, Elsevier Ad Hoc Networks, Vol. 6, pp. 661–674.

[4] Jawhar, I., Trabelsi, Z., and Al-Jaroodi, J., "Towards More Reliable Source Routing in Wireless Networks", IEEE International Conference on Networking, Architecture, and Storage proceedings, 2008, pp. 167-168.

[5] Xiaochuan, X., Gang, W., Keping, W., Gang, W., and Shilou, J. (2008). Link reliability based hybrid routing for tactical mobile ad hoc network, Elsevier Journal of Systems Engineering and Electronics, Vol. 19, No. 2, pp. 259– 267.

[6] Yu, K.M., Yu, C.W., and Yan, S.F. (2009). An Ad Hoc Routing Protocol with Multiple Backup Routes, Wireless Personal Communications Journal, Vol. 1, pp. 1-19.

[7] Taj, Y., and Faez, K., "Signal Strength Based Reliability: A Novel Routing Metric in MANETs", Second International Conference on Networks Security, Wireless Communications and Trusted Computing Proceedings (NSWCTC), 2010, pp. 37-40.

[8] B. Ramachandran, S. Shanmugavel1. (2008). Received Signal Strength-based Cross-layer Designs for Mobile Ad Hoc Networks, IETE technical review, vol. 25, Issue 4, pp. 192-200.

[9] I. Rubin, R. Zhang. (2009). Robust throughput and routing for mobile ad hoc wireless networks, Elsevier Ad Hoc Networks, Vol. 7, pp. 265–280.

[10] Sun, J., Liu, Y., Hu, H., and Yuan, D., "Link Stability Based Routing in Mobile Ad hoc Networks", The 5th IEEE Conference on Industrial Electronics and Applications Proceedings (ICIEA), 2010, pp. 1821 – 1825.

[11] Yi, J. , Adnane, A., David, S., and Parrein, B. (2011). Multipath optimized link state routing for mobile ad hoc networks, Elsevier Ad Hoc Networks Journal, Vol. 9, No.1, pp. 28–47.

[12] S. Tyagi, S. Som, Q. P. Rana. (2016). A Reliability Based Variant Of AODV In MANETs: Proposal , Analysis And Comparison, Procedia Computer Science, Vol. 79, pp. 903–911.

[13] A. Cornejo, S. Viqar, J. L. Welch. (2014). Reliable neighbor discovery for mobile ad hoc networks, Elsevier Ad Hoc Networks Journal, Vol. 12, pp. 259–277.

[14] H. Noureddine, Q. Ni, G. Min, H. Al-Raweshidy. (2014). A new link lifetime estimation method for greedy and contention-based routing in mobile ad hoc networks, Telecommun Syst, Vol. 55, pp. 421–433.

[15] I. Das, D. K. Lobiyal, C. P. Katti. (2015). Multipath routing in mobile ad hoc network with probabilistic splitting of traffic, Wireless Networks, DOI 10.1007/s11276-015-1093-y.

[16] A. P. Reddy, N. Satyanarayana. (2016). Energy-efficient stable multipath routing in MANET, Wireless Networks, DOI 10.1007/s11276-016-1220-4.

[17] S. M. Khan, R. Nilavalan, A. F. Sallama. (2015). A Novel Approach for Reliable Route Discovery in Mobile Ad-Hoc Network, Wireless Pers Commun, Vol. 83, pp. 1519–1529.

[18] S. Palaniappan, K. Chellan. (2015). Energy-efficient stable routing using QoS monitoring agents in MANET, EURASIP Journal on Wireless Communications and Networking, Vol. 13, pp. 1-11.

[19] Oh, H., and Do, M.N., "Highly Scalable Group Dynamic Source Routing Protocol for Wireless Mobile Ad Hoc Networks", Wireless Communications and Networking Conference (WCNC) proceedings, 2008, pp. 2591-2596.

[20] Vadde, K.K., Syrotiuk, V.R., Montgomery, D.C. (2006). Optimizing Protocol Interaction Using Response Surface Methodology, IEEE Transactions on Mobile Computing, Vol. 5, No. 6, pp. 627-639.

[21] Ko, Y.B., and Vaidya, N.H., "Location Aid Routing (LAR) in mobile ad hoc networks", ACM/IEEE MOBICOM conference proceedings, 1998, pp. 66-75.

[22] Chinara, S., and Rath, S.K. (2009). A Survey on One-Hop Clustering Algorithms in Mobile Ad Hoc Networks, Network System Manage, Vol. 17, pp. 183–207.

[23] Basagni, S., "Distributed and mobility-adaptive clustering for multimedia support in multi-hop wireless networks", Proceedings of the Vehicular Technology Conference (VTC), 1999, Vol. 2, pp. 889–893.