Adaptive Link-Weight Routing Protocol using Cross-Layer Communication for MANET

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Abstract: - Routing efficiency is one of the challenges offered by Mobile Ad-hoc Networks (MANETs). This paper proposes a novel routing technique called Adaptive Link-Weight (ALW) routing protocol. ALW adaptively selects an optimum route on the basis of available bandwidth, low delay and long route lifetime. The technique adapts a cross-layer framework where the ALW is integrated with application and physical layer. The proposed design allows applications to convey preferences to the ALW protocol to override the default path selection mechanism. The results confirm improvement over AODV in terms of network load, route discovery time and link reliability.

Key-Words: - Reliable Routing Protocol, Mobile Ad Hoc Network (MANET), Adaptive Routing, QoS

1 Introduction

MANETs have been under the focus of research community since the last decade. It forms an infrastructure-less network on the fly and supports a variety of services. Initially, the use of MANETs was proposed for emergency situations like natural disasters, military conflicts, emergency medical facilities etc [1]. Today, MANETs are required to support increasing demand for multimedia communications. Maintaining real-time media traffics such as audio and video in presence of dynamic network topology is particularly challenging due to high data rate requirements and stringent delay constraints.

In multi hop wireless mobile networks, one of the key issues is how to route packets efficiently. Some of the important factors that need to be considered in designing a routing protocol for MANETs are: energy efficiency, minimum delivery latency, higher probability of packet delivery, adaptability and scalability. Several routing protocols for MANETs have been proposed to cope with similar problems and meet various application requirements. For instance, traditional proactive routing protocols eliminated the initial route discovery delay but could not perform efficiently in specific ad hoc conditions [2][3]. The reason is that they waste the limited system resources to discover routes that are not needed. On the other hand, reactive routing protocols have been proposed as an effective solution to the problem. Their main advantage is that a route discovery is performed only when there is a request for communication between two network nodes.

This paper presents a new reliable ad hoc routing protocol, which is essentially a succession of on-demand and link-weight routing protocols. ALW is able to provide a reliable route with assurance of required bandwidth, low delay and longer route lifetime. ALW makes use of new cross layer interfaces, designed to combine the functionality of the Routing layer with Application, Medium Access Control (MAC) and Physical (PHY) layer parameters to provide the routing algorithm with more accurate information about the current status of the link. It helps to find a more appropriate path that is able to guarantee the QoS requirements during the whole connection.

The remainder of the paper is organized as follows. Section 2 describes related work. Section 3 provides the operations of the proposed ALW protocol. Simulation results are presented in Sections 4. Finally, Section 5 concludes the paper.

2 Related Works

There are several approaches for QoS routing protocols based on on-demand principle of route discovery. The first approach is based on distributed on-demand path search, which uses known link bandwidth between nodes [8]. Due to the distributed path calculation, this approach is scalable. Further, by limiting the number of path search requests, flooding is prevented. Although scalability and limited protocol overhead are clearly desirable in all ad hoc QoS routing techniques, we believe there are potential drawbacks to this approaches. In particular, the path finding procedure is not designed to take advantages of QoS information available at the MAC layer. The second approach of QoS implementation over ad hoc networks [9][10][11][12][13][14][15] focuses specifically on the MAC layer . It is based on reservation of a node's MAC layer time. In this approaches single or multiple paths to destination are discovered, and the path bandwidth to the destination node is calculated. However, acquiring the complete path information has several potential drawbacks, such as low scalability, poor tolerance to fast topology changes and message flooding. The third approach is different from above solution; its incorporated QoS path finding procedure is based on bandwidth-scheduling mechanism. The routing protocol is made aware of the bandwidth resources availability by coupling routing and MAC TDMA layers [16].

This paper proposes a newer approach by introducing an adaptive mechanism for route selection. Under the proposed mechanism, a route is selected based on the link bandwidth, delay and route lifetime using a set of default/custom link weight parameters.

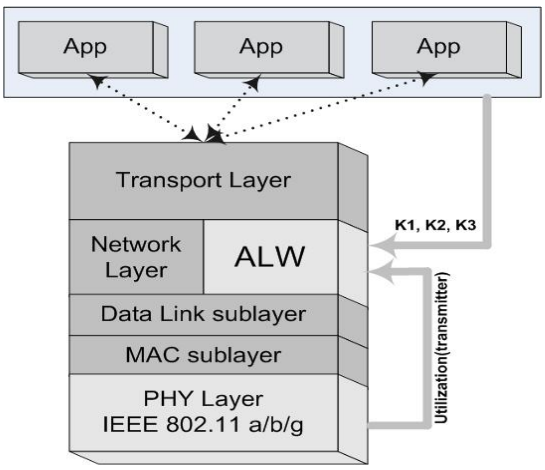

Fig.1: Cross-layer framework for PHY and MAC parameters exchange

3 Adaptive Link-Weight Routing Protocol (ALW)

ALW routing protocol is designed for multi-hop ad hoc wireless networks. The proposed protocol works like the on-demand principle of route discovery and is a part of a cross-layer framework shown in Fig.1.

The ALW protocol always selects an optimum route using a combined link weight of bandwidth, link delay and route lifetime. The route selection process is adaptive and closely matches the application requirements. Different types of applications have dissimilar QoS requirements. Although, an optimum route is always selected by default; however, various applications can convey their individual requirements to the ALW protocol using three QoS parameters: K_1, K_2 and K_3 as shown in Table1. For an example, a video conferencing application requires larger bandwidth and is also delay sensitive. In this case, ALW parameters for a video conferencing application will be configured as follows: K_1=0.5, K_2=0.4 and K_3=0.1; where Here, K_1 corresponds to Bandwidth (data rate); K_2 corresponds to Delay (latency) and K_3 corresponds to Node lifetime (which is determined by the minimum battery lifetime of nodes in the route). The ALW protocol uses the information given by applications in the form of K_1, K_2 and K_3 to calculate the link-weight for selecting a route using the following equations:

$$LinkWeight = (K_1 \times Bandwidth) + (K_2 \times Delay) + K_3 \times Node\_lifetime) \text{ and } K_1 + K_2 + K_3 = 1 \quad (1)$$

It implies that a different route may be selected between the same source and destination nodes if different types of applications are hosted at these nodes.

Table 1: Configuration Parameters

Applications	K_1	K_2	K_3
Video Conferencing	0.5	0.4	0.1
FTP	0.5	0.3	0.2
Messaging Service	0.1	0.4	0.5
Default (Optimum)	0.33	0.33	0.33

3.1 Packets Format

The ALW routing protocol finds the best route with QoS assurance by using two control packets: Route Request Message (RREQM) and Route Reply Message (RREPM) in Fig.2 and 3, respectively.

The RREQM packet consists of the following fields: source ID, Intermediate ID, Destination ID, Required Bandwidth, Link Weight which mainly based on three QoS factors (Bandwidth, Delay, Node lifetime) and Request ID. The source node fills the field value in the PREQM message and broadcast it to the neighboring nodes. When an intermediate node received the RREQM message, it compares among all other RREQMs received from the neighboring nodes, and records the link weight information of the route that meets the required bandwidth, and has low accumulated delay and long route lifetime. In a similar fashion, the RREQM messages are updated at every intermediate node and re-broadcasted to its neighboring nodes till it reaches the destination. Every intermediate node has a table that keeps the optimum route with best link weight values that meets the QoS requirements. This route will eventually be traced back using the RREPM in unicast nature. The route discovery mechanism used in ALW avoids unnecessary flooding and overloading of the ad hoc network. It does not use *'HELLO'* messages for route maintenance; instead an alternative route is always available at every node.

Fig.2: Route Request Message (RREQM)

Fig.3: Route Reply Message (RREPM)

3.2 Route Parameters (Link Weight)

In order to select an optimum path this protocol uses the three QoS parameters: available bandwidth (B_A) in terms of data rate, delay and node lifetime. A simulation model for the ALW protocol is developed in OPNET Modeler [17].

The available channel bandwidth is calculated using the transmitter-utilization parameter directly from the PHY layer to the routing layer using a cross-layer interface shown in Fig.1. In order to calculate the available bandwidth from the utilization-parameter we use the following equation [10]:

$$B_A = \frac{(100 - Utilization) * channel\_bandwidth}{100} \qquad (2)$$

where channel_bandwidth is a constant value and depends on different extensions of IEEE 802.11 standard.

The link delay is calculated after reception of every RREQM by using the RREQM packet creation time information and reception time. The Node lifetime is an important parameter for route selection and our implementation provides an estimated value of remaining battery lifetime in each RREQM and is interpreted as shown in Table 2.

Table 2: Node Lifetime Weighting

Remaining Battery	up to 100%	up to 80%	up to 60%	up to 40%	up to 20%
Node lifetime weighting	1	2	3	4	5

3.3 Route Discovery Process

The route discovery process begins when a source node needs a route to some destination. It places its own ID, destination ID, required bandwidth and request ID in RREQM. Also RREQM will contain the node's available bandwidth, link delay and node lifetime. The receiving node will compare this RREQM and update its local tables. The table contains Node-ID, the link-weight parameters and the Request-ID. When processing the received RREQM from neighboring nodes, the current node selects the route that meets the required bandwidth, low accumulated delay and long node lifetime.

Referring to Fig.4, node-A wants to communicate with node-J, node-A will broadcast RREQM to look for the destination. The relay node-B when receives RREQM from node "A" and "E", the local table that it shall generate will look like: {[A,5,1,2], [E,2,4,4]} respectively. Node-B will compare the requirements mentioned in RREQM from A with the available entries in its local table. In this case, it will compare it with its second entry which is [E,2,4,4]. Then, it will make a new RREQM with the same Request-ID and the following information :{ BW=5, Delay=1, and Node lifetime=2}. The successive node-A is recorded as best route in node-B. In this process of route discovery, Source-ID, Destination-ID, Required Bandwidth and Request-ID will remain unchanged. While at every intermediate node, a new link weight will be calculated from the available information at each node.

At the destination multiple RREQMs will arrive and the node-J has a list of the qualified routes through nodes H, F and C. In this case, node-J will choose the best path through node-H which meets the requirements. When Node-H receives the RREPM sent by node-J, it shall check the Request-ID to search for corresponding table-ID and then update the intermediate-node-field in the RREPM and unicast again. This process is repeated and RREPM fields are updated from node to node until the original source is reached. In some cases the selected route is longer than others but it offers better data rate, longer route lifetime and at the same time offers minimal delay. The other path through node-C is one of the other available paths to reach the source node-A but the node lifetime is 5 which shows that the node has only up to 20% remaining battery life (see Table 2). The node lifetime is very important because if the node runs out of battery, the source node would have to find an alternative path to the destination again. However, an alternate route is always exits in the ALW routing protocol and it can be used in case of failure of a node on the initially selected route.

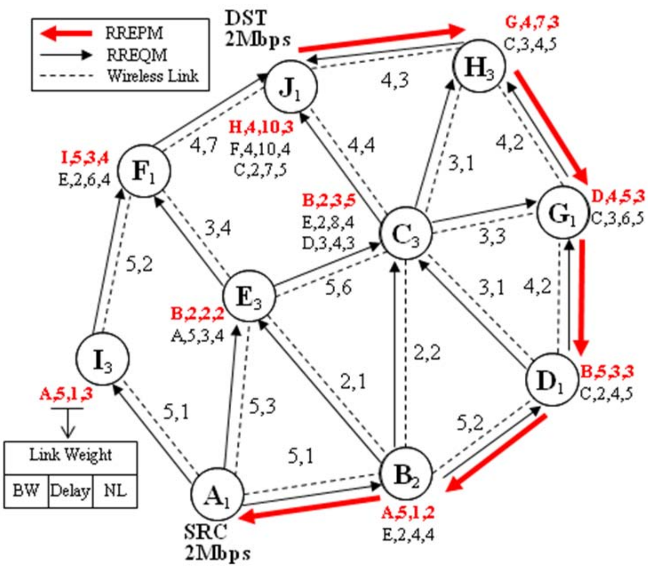

Fig.4: Route Establishment of ALW

As mentioned previously, ALW is a succession of AODV protocol and inherently it follows similar mechanism. Table 3 provides a comparison of various features between AODV and ALW.

Table 3: Comparison OF ALW and AODV

	ALW	AODV
On-Demand Route Selection	Yes	Yes
Neighbor Maintenance	Yes	Yes
QoS Support	Yes	No
Routing Path	Adaptive	Fixed
Primary Route Failure	Alternative Route	Rediscovery

However, in case of ALW there is support of QoS parameters and an optimum route is selected according to a request. The route selection mechanism in ALW is dependent on the selection of Link weight parameters and is not fixed as AODV where it always selects a route with minimum hops to the destination. In scenario, where a node using ALW protocol and particularly requests any one of the three link-weight parameters; the route discovery process will be initiated with a higher priority to that parameter. So, the route discovery process is adaptive and depends on the requested QoS features. Likewise, in case of failure of the primary route, the AODV initiates a rediscovery process while in case of ALW. An alternative route is always available in all nodes from source to destination. The flowchart given in Fig.5 explains the ALW protocol operation in detail.

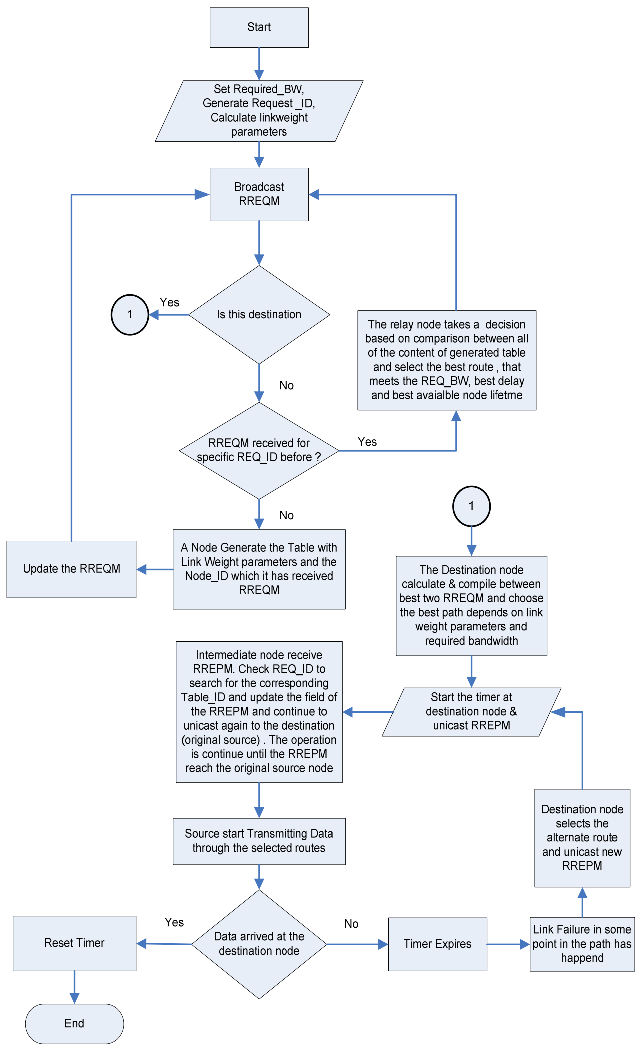

Fig.5: Route Discovery and Establishment Process Chart

3.4 Route Maintenance

Route maintenance procedure triggers whenever selected route between source and destination is broken or changed due to the nodes mobility. Once selection is made, destination node starts a timer to keep track of the availability of the selected route. If data packets from source do not arrive to the destination node and timer expires, it is assumed that the selected route between source and destination is lost or broken. In this case destination node selects alternative best route and unicasts a new RREPM after starting the timer again. The alternative route is available for all the nodes, which received the RREQM.

4 Simulation Results

The environment that we consider consists of 10 mobile nodes, each one operating at different a data rate (1Mbps, 2Mbps, 5.5 Mbps and 11Mbps), in an area of 4100x4100 meters as shown in Fig.6. We developed a complete simulation model of ALW protocol in OPNET Modeler. In similar scenarios (same number of nodes, mobility patterns etc.), we compared the performance of ALW with AODV protocol using network load and route discovery time. The individual route link weights from source to destination are also presented to highlight the difference between ALW and AODV path selection procedure.

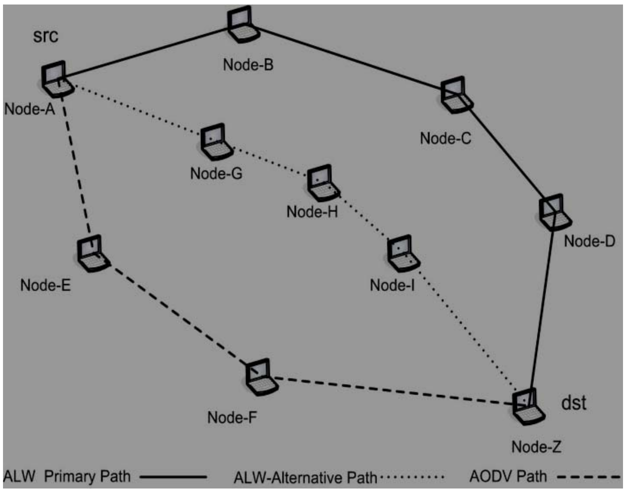

Fig.6: Simulation Scenario

4.1 Network Load

Fig.7 shows the network load using AODV and ALW routing protocols. It is obvious from the curves in Fig.7 that the network load in case of ALW is much lower than that offered by AODV. The reason for a higher network load lies in the inherent design of the AODV protocol, where mobile nodes periodically send '*HELLO*' messages for monitoring connectivity to their neighbours. In an ad hoc network, with a large number of mobile nodes, these periodic '*HELLO*' messages account for a higher network load.

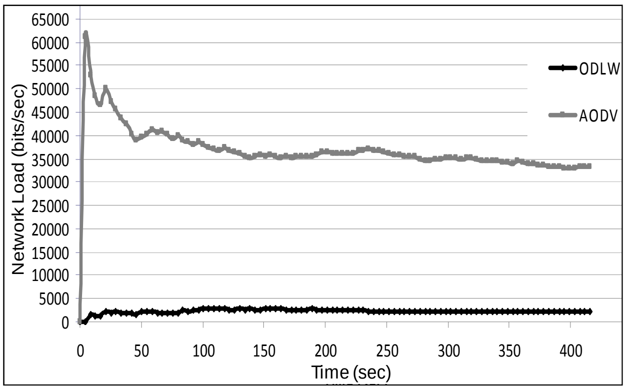

Fig.7: Network Load (bits/sec)

4.2 Network Load

In another scenario, the data rate values of all the mobile nodes along the shortest path to destination were kept at the lowest value (1Mbps). Other nodes along other paths operated at a higher data rate. As mentioned early, the ALW selects a route which meets the required bandwidth and most of the time the selected path offers comparatively higher data rate. The AODV selects the minimum hops, but all the nodes along the shortest path operated at lower data rate. The route discovery time is lower in case of ALW than AODV because the RREPM follows a route where all the nodes operate a comparatively higher data rate. Fig.8 shows the route discovery time curves for both ALW and AODV protocols.

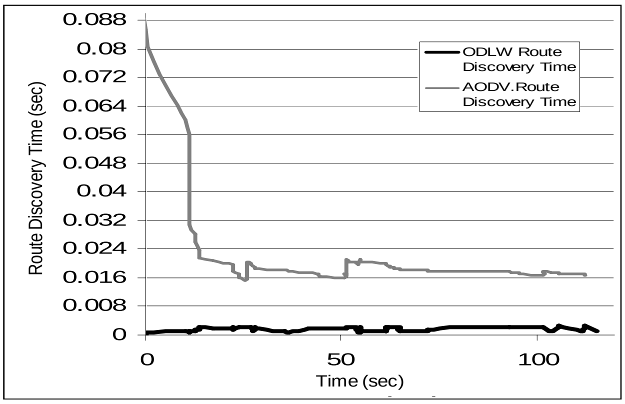

Fig.8: Route Discovery Time

4.3 Individual Route Link Weights

Fig.9 and 10 show the individual node link-weight along with the path link-weight for the routes selected by AODV and ALW respectively. Although, AODV always selects a route with minimum hops, but it does not guarantee minimum delay, higher data-rate and route reliability. Here, in the case, the path (A-B-C-D-Z) is selected by ALW because it has the lowest path link weight value of 110 (combination of A=15, B=30, C=20, D=30, Z=15) as shown in Fig. 9. This is the selected primary path which supports higher data-rate (bandwidth), with minimum delay and higher route reliability. ALW has also found an alternative path (A-G-H-I-Z) in which the path link weight value is slightly higher than the primary. On the other hand AODV selects a path with minimum number of nodes along the path A-E-F-Z but this path has a path link weight of 135 (combination of A=15, B=50, C=60, D=10) as shown in Fig.10, which is higher than the ALW. This result manifested that a shortest path may not always be the best in terms of delay, bandwidth and route reliability.

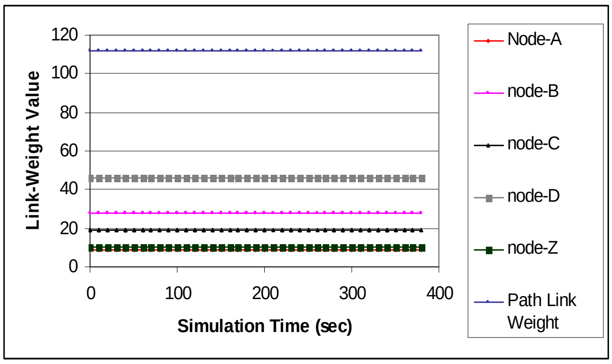

Fig.9: Path link-weight for route selected by ALW

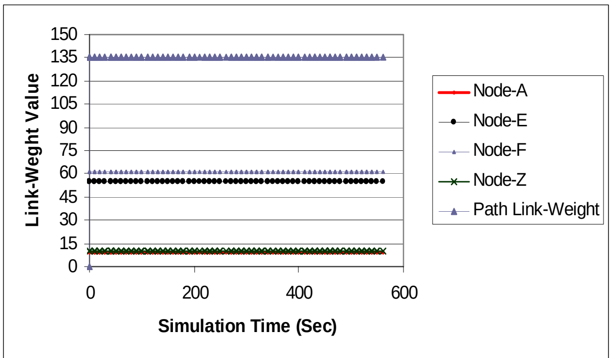

Fig.10: Path link-weight for route selected by AODV

5 Conclusion

This paper presented a novel approach for routing in MANETs. Keeping in view the dynamic nature of wireless medium, the proposed routing protocol is adaptive and minimizes the routing overhead. ALW considers link weight parameters during route discovery and select an optimum path which meets the required QoS level. ALW provides flexibility and the default route selection parameters can be overridden with custom parameters specified according to the application requirements. The protocol deviates from previous approaches by using new cross layer interfaces to communicate PHY layer information to the network layer. Comparison of ALW and AODV clearly highlights the improvement in performance in terms of lower route discovery time, reliability of selected routes, meeting the requested bandwidth parameter and minimizing the network load.

References:

[1] C.S.R. Murthy, B.S. Manoj, *Ad Hoc Wireless Networks Architectures and Protocols*, Prentice Hall PTR, 2004.

[2] E. M. Royer, C.K. Toh, A review of current routing protocols for ad hoc mobile wireless networks, *IEEE Personal Communications Magazine*, Vol.6, No.2,1999, pp. 46-55.

[3] C.E. Perkins, P. Bhagwat, Highly Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) for Mobile Computers, *SIGCOMM*, 1994, pp. 212-225.

[4] C.E. Perkins, E.M. Royer, Ad-hoc on-demand distance vector routing, *WMCSA 2nd IEEE Workshop*, 1999, pp. 90-100.

[5] B.D. Johnson, D.A. Maltz, Y.C. Hu, The dynamic source routing protocol for mobile ad hoc networks (DSR), *draft-ietf-manet-dsr-09.txt (work in progress), Internet Draft, IETF MANET Working Group*, 2003.

[6] Z.J. Haas, M.R. Pearlman, The Performance of Query Control Schemes for the Zone Routing Protocol, *ACM/IEEE Trans. Networking*, Vol. 9, No. 4, 2001, pp. 427-438.

[7] L. Wang, S. Olariu, A Two-Zone Hybrid Routing Protocol for Mobile Ad Hoc Networks, *IEEE Trans. on Parallel and Distributed Systems*, Vol.15, No.12, 2004, pp. 1105-1116.

[8] S.G. Chen, K. Nahrstedt, Distributed quality-of-service routing in ad hoc networks, *IEEE Journal Selected Areas in Communications*, Vol.17, No.8, 1999, pp.1488-1505.

[9] T.W. Chen, J.T. Tsai, M. Gerla, QoS routing performance in multihop, multimedia, wireless networks, *6th IEEE Int. Conf. on Universal Personal Communications*,Vol.2, 1997, pp. 557-561.

[10] C.R. Lin, J.-S. Liu, QoS routing in ad hoc wireless networks, *IEEE Journal Selected Areas in Communications*, Vol.17, No.8, 1999, pp. 1426-1438

[11] C.R. Lin, J.-S. Liu, An on-demand QoS routing protocol for mobile ad hoc networks, *Proc. IEEE Global Telecommunications Conf.*, Vol.3, 2000, pp. 1783-1787.
[12] Y.-K Ho, R.-S Liu, On-demand QoS-based routing protocol for ad hoc mobile wireless networks, *5th IEEE Symp. on Computer and Communications*, 2000, pp. 560-565.
[13] A.M.Z. Alam, A. Rahman, M.A. Hassan, M.L. Rahman, High Performance Routing Protocol for Mobile Ad Hoc Network Based on Cost Effective Lifetime Prediction, *WSEAS Trans. on Communications*, Issue 9, Vol.4, Sept. 2005, pp. 881-887.
[14] Y.-L. Kuo, H.-K. Wu, G.-H. Chen, HQR: Hidden Route Aware QoS Routing Protocol for Mobile Ad Hoc Networks, *WSEAS Trans. on Communications*, Issue 4, Vol.5, Apr. 2006, pp. 634.
[15] I. Zagli, M. Song, TUQR: A Topology Unaware QoS Routing Protocol for MANETs, *Proceedings of the 5th WSEAS Int. Conf. on Telecommunications and Informatics*, Turkey, May 2006, pp. 207-212.
[16] Q. Xue, A. Ganz, Ad hoc QoS on-demand routing (AQOR) in mobile ad hoc networks, *Journal of Parallel and Distributed Computing*, 2003. vol. 63, pp. 54-165.
[17] www.opnet.com