An Energy Aware Multi-path Routing Algorithm

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Abstract: In this paper we present an Energy Aware Multi-path Dynamic Source Routing protocol (EA-MPDSR). This protocol is based on the existing on-demand Dynamic Source Routing protocol (DSR). It is energy aware and uses a multi-path technique. EA-MPDSR reduces the energy consumed per received data bytes as well as prolongs the network lifetime which leads to improvement in the performance of the network. The simulation results show the EA-MPDSR protocol performs better than conventional DSR and Maximum of Minimum Energy DSR (MME-DSR) protocols.

Key words: Energy Aware Routing, Mobile Ad hoc network,, Multi-path routing, Wireless.

Introduction

A mobile ad hoc network (MANET) is a collection of wireless nodes that can dynamically be set up anywhere and anytime without using any pre-existing network infrastructure [1, 2]. It is an independent system in which mobile devices connected by wireless links are free to move randomly and often act as routers at the same time. These type of networks are useful in any situation where temporary network connectivity is needed, such as in disaster relief, rescue operations, automated battlefields, and many other applications.

Since mobile nodes in the ad hoc network are usually battery-based, energy conservation at nodes has been one of the main goals and the most challenging problem to keep the availability of ad hoc networks. A number of studies have been done on different network layers to achieve energy conservation such as MAC layer and application layer [3] or routing/network layer [3, 4].

Routing protocols in ad hoc network can be classified into two types: table-driven (proactive) protocols and on-demand (reactive) protocols. Routing protocols without consideration of energy consumption use the same paths for given traffic demands, which results in a quick energy exhaustion of nodes along those paths. This affects the performance of the networks, especially if those traffic demands are lasting for a long period of time and the amount of data being transferred is quite large, e.g., data related to voice or video stream (multimedia). Energy conservation issues are becoming more significant in ad hoc network environments where multimedia application can be used. Routing in ad hoc networks presents other challenges. These challenges come mainly from two aspects: node mobility causes frequent topological changes while limited network bandwidth restricts the timely topological updates at each router.

On-demand routing has been widely developed in mobile ad hoc networks in response to the bandwidth constraints because of its effectiveness and efficiency. The multipath routing technique is another promising technique to combat problems of the frequent topological changes and link instability since the use of multiple paths could diminish the effect of possible node/link failures. Multipath routing allows the establishment of multiple paths between a single source and single destination node. Multipath routing is typically proposed in order to increase the reliability of data transmission (i.e., fault tolerance) or to provide load balancing [5]. Load balancing is of especial importance in MANETs because of the limited bandwidth between the nodes [6].

Network simulator NS-2 has been used in simulating MANETs. Random way point mobility model is selected to describe the random movement of nodes with different speeds and pause times. There are three wireless channel models supported by NS-2: freespace, two ray ground, and shadowing. The effect of these three channel models on the performance of DSR was studied [7]. The freespace wireless channel model is chosen because it is found to have the least effect on the performance of the network.

We implemented one of the energy aware routing protocols that use only one route to deliver the data packets called MME-DSR. The result of simulation shows the EA-MPDSR protocol performs better than conventional DSR and MME-DSR protocols. In particular, it achieves a remarkable improvement over conventional DSR protocol in the energy efficiency by about 12% and improves the packet delivery fraction by about 8%. EA-MPDSR improves the end-to-end delay by about 35% when we have stress network environment (high mobility, high network load). It also reduces routing overhead by up to 17% by reducing the frequency of route discovery operations. It also reduces the total number of packets dropped by up 40% in average. The drawback of our proposed protocol is the average end-to-end delay when the mobility and the network loads are low.

Routing in Mobile Ad Hoc Networks.

The role of routing is to find, based on a specific metric, the most suitable route to forward data packets in a multi-hop network. The autonomy of the ad hoc nodes prevents the formation of a hierarchical structure, making it difficult to the routing protocol to be scalable. Routing protocols like Routing Information Protocol (RIP) [8], and Open Shortest Path First (OSPF) [9], work correctly on wired networks that have a nearly static topology but these protocols would have convergence problems in MANETs, because of its dynamic topology. Other problems such as the possibility of asymmetric links and the varying connectivity of wireless networks add to the complexity of dealing with such a network.. The ad hoc routing protocols are divided into two classes:

- *Table-Driven(Proactive) Protocols:* Each node in the network keeps information about other nodes in the network in a table. Destination Sequence Distance Vector routing protocol (DSDV) [10, 11], Fisheye State Routing (FSR)[12], and the Optimized Link State Routing (OLSR) [13] are some of the popular table-driven protocols for mobile ad-hoc networks.
- *On-Demand (Reactive) Protocols:* In on-demand protocols, if a source node requires a route to the destination for which it does not have route information, it initiates a route discovery process. The source node uses this route for data transmission to the destination node. Some of the best known on-demand protocols are Dynamic Source Routing (DSR) [14, 15, 16], Ad-hoc On-demand Distance Vector routing (AODV) [17, 18], and Temporary Ordered Routing Algorithm (TORA)[19].

Table-driven protocols might not be considered an effective routing solution for mobile ad-hoc network. Nodes in mobile ad-hoc networks operate with low battery power and with limited bandwidth. Presence of high mobility, large routing tables and low scalability result in consumption of bandwidth and battery life of the nodes. Moreover, continuous updates could create unnecessary network overhead. Comparing with on-demand protocols, table-driven protocols sustain significantly high routing overhead and hence lead to increase the energy consumption in the network. It is shown in [10] that on-demand routing protocols are more efficient in energy consumption as compared to table driven routing protocols. Table 2.1 shows the summary of the comparison.

	On-demand	***Table driven***
overhead	*Low*	*high*
Memory	*Low*	*High*
Cope with	*Good*	*Bad*
Sleep time	*High*	*Low*
purpose	*Relative high*	*Low mobility*

Table 2.1: On-demand (reactive) versus table-driven (proactive) protocols

A performance comparison [21] between the two most accepted on-demand routing protocols AODV and DSR has shown that DSR is better. We based our new protocol on DSR.

Energy Aware in Mobile Ad Hoc Networks.

Wireless mobile devices are useful if they can be used "anywhere and anytime". One of the limitations achieved this goal is finite power supplies. Therefore, power management is one of the most challenging problems in wireless communication. Several energy aware routing protocols have been developed: Minimum Battery Cost Routing (MBCR), Min-Max Battery Cost Routing (MMBCR) [22], Conditional Min-Max Battery Cost Routing (CMMBCR) [23], Request Delay Routing Protocol (RDRP), Max-Min Routing Protocol (MMRP) [24], Max-Min Energy DSR (MME-DSR) [23], Energy-Dependent DSR (ED-DSR) [25], and Minimum Drain Rate (MDR) [26]. In most of these routing protocols, the aim is to minimize the energy consumed per packet needed to deliver this packet to the destination. Some of the more sophisticated routing algorithms associate a cost with routing through a node with low power reserve. Other routing protocols are aimed to maximize the network lifetime, which is the time to network partition because of node failures. All previous protocols use single path to distribute data traffic through network. Some of these energy aware routing protocols are explained in the following sections.

Multipath Routing in Mobile Ad Hoc Networks

The routing protocols, described in the previous section, are based on the single path routing between a source and a destination, the single minimum-cost path tends to be selected although different cost metrics may yield different paths. However, in a reasonably well-connected network, there may exist several paths between a source-destination pair. The concept of multipath routing is to give the source node a choice at any given time of multiple paths to a particular destination by taking advantage of the connectivity redundancy of the underlying network. The multiple paths may be used alternately, namely, traffic taking one path at a time, or they may be used concurrently, namely, traffic flowing through multiple paths simultaneously.

Multipath routing aims to establish multiple paths between source-destination pairs and thus requires more hosts to be responsible for the routing tasks. Although a lot of benefits have been explored for multipath routing in wired networks [27, 28], the advantage of multipath routing is not obvious in MANETs because the traffic along different paths may interfere among each others due to the broadcast feature of radio transmission. In order to get the most benefits of multipath routing in MANETs, one should consider the following: how to efficiently search for multiple paths, how to choose proper multiple paths, and how to use them.

Multipath in MANET is used to improve the performance of the network such as reducing end-to-end delay [29], robustness of data delivery [30, 31], improve network security[32], balance the traffic load to alleviate congestion and bottlenecks, and balance the power consumption among nodes[20, 33]. A good survey on multipath issue in MANETs can be found in [34, 35].

Multipath routing consists of three components: route discovery, route maintenance, and traffic distribution among multiple paths (traffic allocation).

Route Discovery: It finds multiple routes between a source and destination nodes. Multipath routing protocols may be node disjoint (no common nodes), link disjoint (no common links), or non-disjoint routes. Non-disjoint routes may have lower aggregate resources than disjoint routes, because non-disjoint routes share links and/or nodes. Disjoint routes provide higher fault-tolerance.

Route Maintenance: It finds and repairs the broken paths.

Traffic Allocation: The traffic allocation strategy is used to deal with how the data is distributed amongst the paths.

EA-MPDSR Algorithm

The proposed protocol, EA-MPDSR, is based on the on-demand DSR routing protocol. It modifies DSR route discovery mechanism to collect the node-disjoint paths with nodes that contain higher energy. The source then selects *two* paths based on their length (the shortest) and their energy. The source node distributes the data traffic among these paths according to the minimum energy of their nodes. The higher the energy of the minimum energy node, the higher the traffic load will be sent through that path.

The source node in the proposed protocol, EA-MPDSR, will trigger route discovery when there is no route in its route cache. The source node will keep broadcasting periodic RREQ packet (to get routes to the destination) until it either receives the RREP packet from destination or the periodic number RREQ packet exceeds the number of times specified to find routes to the destination. Intermediate nodes are not allowed to respond to the RREQ packet from their route cache because they do not reflect the real state of the paths (specially the energy of the nodes). When the intermediate node receives the first RREQ packet, it adds its address as well as its energy to the RREQ packet and rebroadcasts it again. Intermediate nodes will not drop the later RREQ packets received with the same id and source. Instead, they will save all late RREQ packets (unless the RREQ packet includes its address) in temporary table called (*mpath_table*). This temporary table will be used in RREP packet to redirect the path back form destination to the source.

When destination node receives the first RREQ packet, it adds this RREQ packet to a temporary table called (*dpath_table*), and prepares RREP packet to be sent to the source by reversing the path included in the RREQ packet. Destination node will send RREP packet to the all RREQ received packets.

Each intermediate node rebroadcasts the first received RREQ packet and records the other RREQ packets (except RREQ packet which has the address of this intermediate node).

In our proposed protocol EA-MPDSR, each intermediate node rebroadcasts only one (the first) RREQ it receives and discards the others. In this case, two paths P1 $< S, v_1, v_2, \dots, v_m, N >$ and P2 $<S, u_1, u_2, \dots, u_n, N>$ received at node N are node-disjoint paths if their first hops v_1, u_1 are not equal ($v_1 \neq u_1$).

Destination node **D** sends RREP packet to all RREQ packets received. RREP packet in EA-MPDSR includes a Boolean field *isRedirection* to indicate whether the RREP packet should be redirected when traversing back to source node. To check whether two paths received by the destination are node-disjoint, it is enough to see if their first hops are the same. When the destination node **D** receives the RREQ packet, prepare the RREP packet by reversing the path of the RREQ packet and do the following: it checks if it is the first RREQ packet or if the path P included in this RREQ packet is node-disjoint with all paths included in the previously received RREQ packets (cached at *dpath_table*). If the condition is satisfied, the destination node will set *isRedirection* in the RREP to FALSE. Otherwise, it sets *isRedirection* to TRUE. The RREP packet is sent back to the source node **S**.

The destination node does not need to set timer when it receives RREQ packets, which may increase end-to-end delay, to find link/node-disjoint. Instead, it sends RREP packet as soon as it receives the RREQ packet. The intermediate nodes will help to find the link/node-disjoint with high energy if the field *isRedirection* of the RREP packet is set to TRUE. Otherwise, they forward the RREP packets to the next node without any change.

Route Discovery: the *isRedirection* flag in RREP packet is set to either TRUE or FALSE. This flag is used by intermediate nodes to decide whether to redirect RREP packets or not.

Load Balance Traffic Distribution (Traffic Allocation): The source node caches every path included with RREP packets and starts sending the data when the first RREP packet has been received. When the last RREP packet is received, EA-MPDSR distributes the traffic load over the *two* selected paths based on their energy and the following remarks:

- Source node extracts the node-disjoint paths and saves their indexes in special table called *balanceTable*.
- If there is more than one node-disjoint path, then filter the node-disjoint paths and sort them based on their length. When lengths are equal sort them descending based on their minimum energy.
- If no node-disjoint paths are found, then sort all paths based on their length. When lengths are equal sort them descending based on their minimum energy.
- Select the first *two* paths then balance the traffic data over these selected paths based on the minimum energy found in their nodes. Example, if P1 and P2 are the selected paths, and e1=40% and e2= 60% are their minimum energy respectively, then the load of P1 is (60% / (40%+60%)) = 60% of the data traffic and 40% for path P2.
- The source node will trigger new route discovery only when all paths in its route cache are dead.

We implemented our algorithm in Network Simulator version-2 (NS-2). NS-2 [36, 37] is a discrete event simulator used specially for simulating network for research purpose. NS-2 provides substantial support for simulation of Transmission Control Protocol/User Datagram Protocol (TCP/UDP), routing, and multicast protocols over wired and wireless networks.

Conceptual Data Structure of EA-MPDSR

In addition to the table that DSR uses, we added the following table:

- **Intermediate Multipath Table (*mpath_table*):** this table is used by the intermediate nodes to find the node-disjoint paths with high energy. The intermediate nodes rebroadcast the first RREQ packet only after they added node energy to the packet. It saves subsequent RREQ packets into *mpath_table*. Each entry of the table consists of Source Address "*src*", Destination Address "*dest*", Identification "*seq*", Redirection flag "*IsRedirection*", and the Path "*path*", which contain the addresses and the energies, from source node to the destination node. The <src,seq> fields are used to specify unique identification key to RREQ which belongs to the same route discovery. This identification key helps the intermediate node to recognize to which source and destination do a particular route belongs. Intermediate nodes use this table to change the path in the RREP, if the *isRedirection* flag is true, or just send the RREP packet to the next hop of the path included in the RREP, if the *isRedirection* flag is false.

- **Destination Multipath Table (*dpath_table*):** this table is used by the destination nodes to redirect the RREP packets to find node disjoint paths. *Dpath_table* has the same entry structure as *mpath_table*. The destination node stores the list of RREQs received in this table. It also uses this table to decide whether a RREP packet needs to be redirected (its path is not node-disjoint with other paths in destination multipath table that have the same identification key <*src,seq*>) or not.

- **Balance Traffic Table (*balanceTable*):** the source uses the information available in this table and the information available in the route cache table to select the best *two* paths and distribute the data traffic among these paths. The source node stores in this table all the selected paths to the destination nodes and their percentage data traffic load.Each entry of the table consists of Destination Address "*dest*", "*Index*", and "*Load*". Source selects tw*o* paths to the destination "*dest*" and saves their pointers in the "*index*" field. The source then computes the load percentage of each path based on their minimum energy and saves it in the "*load*" filed. The source distributes the data among these *two* paths using this table. When the source node delivers the data to multiple destinations at the same time, destination Address field *"dest"* used to help the source to recognize the routes of each destination.

Simulation Environment

A square area (1000m x 1000m) is used to compare the performance of our proposed protocol EA-MPDSR to MME-DSR and conventional DSR protocols. The environment contains 50 wireless nodes forming an ad hoc network, moving randomly in the simulation area. The simulation time is 900 seconds. The energy assigned to each node is uniformly distributed between 1 and 8 Joules. We considered high (speed is 20m/s or 72km/h) low (speed is 1m/s or 3.6km/h) and medium node velocity (speed is 10m/s or 36km/h). We used waypoint mobility to model how nodes move on a terrain. Nodes in the random waypoint regime move according to the following rules: (1) each node picks a destination randomly moves within the simulation area and also picks a speed *(v)* that is uniformly chosen between (*vmin)* and *(vmax)*. Each node then moves toward the destination over a straight line with speed (*v)*. (2) upon reaching the destination, a node pauses for a given pause-time; (3) the node then picks the next destination and the process re-starts. Typically, the values of *(vmin)*, *(vmax)*, and pause-time are parameters of the simulation and are selected according to the requirements and operating environment of the application at hand. The movement scenario files, we used for each simulation, were characterized by a pause time. Each node begins the simulation by remaining motionless for a given pause time. It then selects a random destination and proceeds to that destination at chosen speed. Upon reaching the destination, the node again stays stationary for the chosen pause time, selects another destination and moves there as previously described, repeating this behavior for the duration of the simulation. Each simulation ran for 900 seconds of simulated time. We ran our simulations with movement patterns generated for seven different pause times (0, 150, 300, 450, 600, 750 and 900 seconds). A pause time of 0 second corresponds to continuous motion, and a pause time of 900 seconds corresponds to almost no motion. In our simulation we used a set of five movement scenario files with different seeds for each pause time value to improve the accuracy of the results and to smooth out spikes due to extremely favorable or unfavorable movement scenarios.

For the traffic we used constant bit rate (CBR) sources over UDP. We created five different movements scenarios for each run.

Although a lot of benefits have been explored for multipath routing in wired networks, the advantage of multipath routing is not obvious in MANETs because the traffic along different paths may interfere with each other due to the broadcast feature of radio transmission. In order to get the most benefits of multipath routing in MANETs, the following should be considered: how to search for the best multiple paths based on certain criteria? How to select proper multiple paths? And how to use these selected multiple paths to distribute the data?

It is not enough to select the node-disjoint paths and distribute the data load among these paths. There are some other factors that may affect the performance of the network such as the length of the paths, the number of paths selected, and the correlation between the selected paths. If two node disjoint paths have different length, this will cause out of order problem (packets arrive out of order) in the destination node. It also affects the performance of the network. In [38], it is concluded that when the number of paths used in a multipath algorithm exceeds three, the overheads increase significantly. The correlation between paths also affect the end to end delay of the network because the increasing of traffic interference [20]. In our case, we observe from simulation results that the number of node-disjoint paths is often not exceeding two paths due to the number of nodes in our simulation study. In dense environments where the number of nodes is high (grater than 50), the chance to find more node-disjoint paths increases. For all previous reasons, we limit the number of the selected paths to two.

Routing Metrics

The following metrics are used to compare the protocol EA-MPDSR protocol to the conventional DSR protocol:

- **Energy Efficiency (EE):** Total data received measured in *Bytes/Joule* at the end of simulation. *EE = (Total received data)/(Total consumed energy).*
- **Packet Delivery Fraction (PDF):** the ratio of the number of packets generated by sources to the number of packets received by the destinations. This metric reflects the throughput a network can support. One of our goals is to design an energy-efficiency network protocol which can improve energy consumption without a significant loss of capacity. Thus, this metric is useful to measure any degradation in the network throughput.

*PDF = (# packets received / # packets sent) * 100.*

- **Average End-to-End Delay of data packets:** the delay of data propagation and transfer, and the delays caused by buffering, queuing and retransmitting data packets. The delay of each packet is computed as: (the time of received data packets – the time of sent this data packet). The average end to end delay is then computed as :

Average delay = Total Delay of each data packets / total data packets received.

- **Normalized Routing Load (NRL):** The metric is also called routing overhead; it is equal to the number of routing packets transmitted per data packet delivered at the destination. Each hop-wise transmission of a routing packet is counted as one transmission.

NRL = (number of routing packets / number of received packets).

- **Total number of dropped packets:** The total packets dropped during simulation time. It includes all types of dropped packets such as TOUT which means time out (i.e. packet has expired), and NRTE which means no route is available.

Performance Evaluation

We compared the performance of our proposed protocol EA-MPDSR, conventional DSR protocol, and MME-DSR protocol. The results show that our proposed protocol EA-MPDSR outperforms the MME-DSR protocol in EE, PDF, NRL, and Total packets dropped. MME-DSR outperforms EA-MPDSR in average end to end delay.

Conclusion

In this paper we designed an energy aware multi-path routing protocol based on the conventional DSR protocol. We compared this protocol to DSR and MME-DSR. The metrics considered for the comparison are energy efficiency, packet delivery fraction (PDF), average end-to-end delay, normalized routing load (NRL), and number of dropped packets during simulation time. The simulation results show that the proposed protocol perform better than these two protocols for most of these metrics.

EA-MPDSR protocol outperforms the conventional DSR and MME-DSR for all situation, with widening performance gaps with increasing stress (e.g. more load, higher mobility). In low network stress (low mobility, less load) EA-MPDSR still performs better except the average end to end delay metric due to correlation between nodes. In all cases, MME-DSR has the shortest delay than both EA-MPDSR and conventional DSR protocols. EA-MPDSR has shorter delay than conventional DSR in high network stress only.

References

[1] E. Royer and C-K Toh, "A Review of Current Routing Protocols for Ad-Hoc Mobile Wireless Networks", IEEE PCM, pp. 46-55, April 1999.

[2] S. Bhandare , "Energy Aware Implementation of an Ad Hoc Routing Protocol", *ITD Masters Thesis* University of Colorado, 2003.

[3] C. Jones, K. Sivalingam, P. Agrawal, J. Chen "A Survey of Energy Efficient Network Protocols for Wireless networks", Wireless Networks, 7(4):343--358, July 2001.

[4] Christopher N. Ververidis, George C. Polyzos. "Routing Layer Support for Service Discovery in Mobile Ad Hoc Networks," *percomw*, Third IEEE International Conference on Pervasive Computing and Communications Workshops (PERCOMW'05), pp. 258-262, 2005.

[5] S. Vutukury, "Multipath routing mechanisms for traffic engineering and quality of service in the Internet," PhD Thesis, March 2001. http://citeseer.ist.psu. edu/vutukury01multipath.html.

[6] S. Mueller, R. P. Tsang, D. Ghosal, "Multipath Routing in Mobile Ad Hoc Networks: Issues and Challenges", in LNCS Volume 2965. pp. 209-234, 2004.

[7] Q.Nasir,, M. Al-Dubai and S. Harous , "A Performance Study of DSR under Different Wireless Channel Models", The third Int. Conference on Advances in Mobile Multimedia (MoMM2005), pp. 283-289,sep. 19-21, 2005.

[8] G. Malkin, RIP Version 2. RFC 2453, Nov. 1998.

[9] J. Moy, OSPF version 2. RFC 2328, Apr. 1998.

[10] G. He, "Destination-Sequenced Distance Vector (DSDV) Protocol", http//www.citeseer.ist.psu.edu/531710.html, 2003.

[11] J. Broch, D. Maltz, D. Johnson, Y-C. Hu, J. Jetcheva, "A performance comparison of multi-hop wireless ad hoc network routing protocol", 4th Annual ACM/IEEE Int. Conf. on Mobile Computing and Networking (MobiCom'98), pp. 85-97, Dallas, TX, October 1998.

[12] A., C.-C. Chiang, Iwata, G. Pei, M. Gerla and T.-W. Chen, "Scalable Routing Strategies for Ad Hoc Wireless Networks", JSAC99, IEEE Journal

on Selected Areas in Communications, Vol. 17, No. 8, pp. 1369-1379, August 1999.

[13] T. Clausen, P. Jacquet, A. Laouiti, P. Muhlethaler, A. Qayyum and L. Viennot, "Optimized link state routing protocol for ad hoc networks", IEEE INMIC 2001, pp. 62 – 68, Dec. 2001.

[14] D. B. Johnson and D. A. Maltz. "Dynamic source routing in ad hoc wireless networks". In Mobile Computing, edited by Tomasz Imielinski and Hank Korth, chapter 5, pp. 153–181. Kluwer Academic Publishers, 1996.

[15] S. Bhandare, S. Doshi, T. X Brown, S. Sanghani, "Comparison of two wireless ad hoc Routing protocols on a hardware test-bed", IEEE WCNC, vol.2, pp.1168 – 1173, 2003.

[16] A. Mathur, "Performance Analysis and Enhancement of Dynamic Source Routing for Mobile Ad Hoc Networks", *Master Thesis*, University of Texas at San Antonio, 2005.

[17] C.E. Perkins, and E.M. Royer, "Ad-hoc On Demand Distance Vector Routing," Proceedings of the 2nd IEEE Workshop on Mobile Computing Systems and Applications", New Orleans, LA, February 1999, pp. 90-100.

[18] C. E. Perkins, E. M. Royer, S. R. Das, "Ad hoc On-Demand Distance Vector (AODV) Routing *Mob. Comput. Commun. Rev.* 6, 3, pp. 92-93 , Jun. 2002.

[19] V.D. Park, and M. S. Corson, "A Highly Adaptive Distributed Routing Algorithm for Mobile Wireless Networks", Proceedings of IEEE INFOCOM '97, pp. 1405 - 1413 vol.3, April 1997.

[20] K. Wu, J. Harms, "Performance study of a multipath routing method for wireless mobile ad hoc networks", 9th international symposium on modeling, analysis and simulation of computer and telecommunication system (MASCOTS' 01), Cincinnati, Ohio ,pp. 99 - 107, August 2001

[21] R. Krishnan, J.A. Silvester, "Choice of Allocation Granularity in Multipath Source Routing Schemes". INFOCOM '93. Proc. Twelfth Annual Joint Conf. of the IEEE Computer and Comm. Societies. Networking: Foundation for the Future. IEEE, vol.1, pp. 322 – 329, 1993.

[22] C.-K. Toh, "Maximum Battery Life Routing to Support Ubiquitous Mobile Computing in Wireless Ad Hoc Networks," IEEE Communications Magazine, 39(6), pp. 138–147, June 2001

[23] W. Yu and J. Lee, "DSR-based energy-aware routing protocols in ad hoc networks," Proceedings of the Int. Conf. on Wireless Networks (ICWN), Las Vegas, Nevada, June 2002

[24] V. Venugopal, R. Bartoš, M.J. Carter, and S.S. Mupparapu, "Improvement of Robustness for Ad Hoc Networks through Energy-Aware Routing," Proc. of the Fifteenth IASTED International Conference on Parallel and Distributed Computing and Systems (PDCS), Marina del Rey, CA, (T. Gonzales ed.), November 2003.

[25] J.-E. Garcia, A. Kallel, K. Kyamakya, K. Jobmann, J.-C. Cano, P. Manzoni: "A Novel DSR-based Energy-efficient Routing Algorithm for Mobile Ad-Hoc Networks", IEEE Vehicular Technology Conference, VTC Fall, Orlando, USA, Vol. 5, pp. 2849 – 2854, 6-9 Oct. 2003.

[26] D. Kim, J.J. Garcia-Luna-Aceves, K. Obraczka, J, Cano, and P. Manzoni. "Power-aware routing based on the energy drain rate for mobile ad hoc networks." 11th IEEE International Conference on Computer Communication and Networks. pp. 565- 569, 2002.

[27] .A. Sriniva, E. Modiano, "Minimum Energy Disjoint Path Routing in wireless ad-hoc Networks", San Diego, California, USA, MobiCom'03, pp. 122--133 , Sept. 2003.

[28] S.K. Das, A. Mukherjee, et al, "An adaptive framework for QoS routing through multiple paths in ad hoc wireless newtorks", J. Parallel Distributed Computing,pp. 141-153, 2003.

[29] Z. Ye, S. V. Krishnamurthy, S. K. Tripathi, "A framework for reliable routing in mobile ad hoc networks", IEEE INFOCOM 2003, Sanfrancisco CA, Vol.1, pp. 270–280, Mar/Apr 2003.

[30] A. Tsirigos, Z. J. Haas, "Multipath routing in the presence of frequent topological changes", IEEE Comm. Magazine, 39(11):132-138, Nov. 2001.

[31] W. Lou, W. Liu, Y. Fang, "SPREAD: Enhancing data confidentiality in mobile ad hoc networks", IEEE INFOCOM 2004, Vol.4, pp. 2404–2413, Mar 2004.

[32] D. Ganesan, R. Govindan, S. Shenker, D. Estrin, "Highly-resilient, energy efficient multipath routing in wireless sensor networks", Mobile Computing and Communication Review, 5(4):10-24, Oct 2001.

[33] W. Lou, W. Liu, Y. Zhang, "Performance Optimization using Multipath Routing in Mobile Ad Hoc and Wireless Sensor Networks", book *Combinatorial Optimization in Communication Networks*, edited by M. Cheng, Y. Li, and D-Z. Du, Kluwer, 2006.

[34] S. Mueller1, R. P. Tsang2, and D. Ghosal1, "Multipath Routing in Mobile Ad Hoc Networks: Issues and Challenges", Invited paper in Lecture Notes in Computer Science, Edited by Maria Carla Calzarossa and Erol Gelenbe 2004.

[35] K. Fall and K. Varadhan, "ns Notes and Documents," The VINT Project. UC Berkeley, LBL, USC/ISI, and Xerox PARC, February 2000, Available at http://www.isi.edu/ nsnam/ns/NS-documentation.html.

[36] Fast NS-2 simulator website, http://lst.inf.ethz.ch/fast-ns2/.

[37] P. P. Pham, S.Perreau, "Performance Analysis of Reactive Shortest Path and Multi-path Routing Mechanism with Load Balance", in Proceedings of IEEE INFOCOM, vol. 1, pp. 251-259, 2003.