Power and Channel Aware Routing in Wireless Mobile Ad Hoc Networks

Dr. Merlinda Drini, Queensborough Community College of the City University of New York

Dr. Merlinda Drini joined the Queensborough Community College in September 2011 and currently holds an Associate Professor position in the Engineering Technology department. She earned her Ph.D. in Electrical Engineering, June 2009, from The Graduate School and University Center of the City University of New York. She is a recipient of the awards in mentoring various students on undergraduate research projects. Her research areas are computer networking, wireless communications and information security.Her research areas are computer networking, wireless communications and information security.

Power and Channel Aware Routing in Wireless Mobile Ad Hoc Networks

Mobile Ad Hoc Networks (MANETs) consist of peer to peer networking architecture, where each node performs the role of a router, providing the services and routing decisions to the network. They should be adapting to the topology changes, reflecting these changes to their routing tables, as well. Movement of the nodes, results in a frequent connectivity failures between nodes. Therefore an important role in a wireless ah-hoc network routing protocol design should be the likelihood of stable path selection.

In order to improve the end-to-end performance of an ad-hoc network, we propose a routing algorithm that uses the multiple layer information of the network protocol stack, in making the routing decisions. In our previous work we have developed a network layer model to adapt dynamically to changing channel characteristics. Since, the devices that participate in MANETs are battery operated with limited capacity and they all suffer from severe battery consumption, we extend our algorithm with power management control. We demonstrate our model by applying it to the Dynamic Source Routing protocol (DSR). In the proposed modified DSR, both the route discovery and route selection are based on physical layer parameter, such as Signal to Noise Ratio (SNR), and the residual Power of each participating node.

The simulation results of the modified protocol using the various metrics (such as throughput, end-to-end delay, routing overhead etc.), indicate significant performance improvement in comparison to the network when the existing routing protocol is used.

Introduction

Mobile Ad-Hoc Networks (MANETs) consist of mobile nodes that have a freedom to move in any direction by self-maintaining and self-organizing without any fixed infrastructure. The dynamic topology of the MANETs with frequent path failures has as a consequence a challenging routing issue. This means if link breakages occur the network has to stay operational by building new routes. This can generate undesirable delays and network collision, increasing the routing overhead.

Routes in MANETs are selected using the shortest path metric, which is not a sufficient condition to construct the best paths. Since the reliable data transmission is limited by destructions due to physical properties of the channel: noise, path loss, multipath effect, interference, mobility, and limited transmission power, certain QoS will be required, to maintain the routing.

Related Work

In [1], Novatnack at al. describe and analyze how the existing ad-hoc routing protocols, reactive and proactive, differ in the mechanisms they use to select paths, detect broken links, and buffer messages during periods of link outage. But current routing protocols favor routing traffic based on shortest path, thus causing a bottleneck, because minimum hop count routing often chooses routes that have significantly less capacity than the best paths that exist in the network. [2]

In MANETs, there are many other metrics to be considered: power, packet loss, maximum available bandwidth, etc. These metrics should come from a cross-layer approach in order to make the routing layer aware of the local issues of the underling layers. Authors in [3] explored three primitive physical layer parameters: interference, packet success rate, and data rate to determine the best path.

In [4] Wisitpongphan at al. suggests that routing should take into account physical layer characteristics. In particular, the bit error rate (BER) at the end of a multi-hop route may, under certain conditions, represent a good pointer of the physical layer status. However, the performance evaluation of any routing protocol was not presented.

In [5], we implemented the SNR aware routing metric by modifying the dynamic source routing (DSR) protocol. We demonstrated the benefits of inter layer interactions in low mobility scenarios, applying the routing metric to route discovery and the route maintenance. However, the nodes in MANET have limited battery power, thus they should not participate in the routing decision if their residual power level drops to the minimum.

In [6] Upadhyay at al.make a literature survey on power aware routing protocols based on transmission power control approach, load distribution approach and sleep/power down approach.

In [7] paper describes a survey on some of energy aware routing protocols for Mobile Ad-Hoc networks. The first category of power aware protocol schemes minimizes the total transmission power and the second category of schemes tries to increase the remaining battery level of every individual node to increase the lifetime of the entire network.

Ghandera and Shaabanb in [8] introduced a Power Aware Cooperation Enforcement (PACE) distributed mechanism to help nodes make intelligent routing and forwarding decisions. Adding a “residual Energy” parameter to original existing “Path”, the protocol can find more energy efficient routes. However the channel characteristics were not considered.

In our approach, the objective is to design optimal communication algorithm which is based on a probabilistic approach for route selection and maintenance: both SNR and the residual Power level are propagated from the physical layer up to the routing layer to improve the performance of the existing protocol.

Channel Modeling

The link reliability is the most important factor to be considered when transmitting information over a wireless channel. Wireless channels have limited bandwidth, and high bit error rate, which degrade the network performance. Their quality vary continually due to the pathlos, multipath fading, and shadowing. Path loss model predicts the mean received power at distance *d*, and can be demonstrated using log-normal shadowing model. [9].

$$\left[\frac{P_r(d_0)}{P_r(d)}\right]_{dB} = -10\beta\, log\left(\frac{d}{d_0}\right) + \varphi_{dB} \dots\dots\dots\dots\dots (1)$$

$P_r(d)$ is mean received power at distance d, and is computed relative to $P_r(d_0)$, where d_0 is a reference distance, β is the path loss exponent and, φ_{dB} is a Gaussian random variable with zero mean and standard deviation σ_{dB} obtained by measurement.

On the other hand, the node's movement over long distances causes large scale fading, which as a consequence has a gradual decrease of the average signal strength. If the nodes move over short distances, the received signal strength will rapidly change. Generally the signal propagation is modeled using both: large scale and small scale fading. [9]. With line of sight, small scale fading can be modeled using Ricean fading. However, the more realistic model is that of Rayleigh fading, when the effects of various obstacles are considered.

In our work we adopt the Rayleigh fading channel model, where the received SNR can be expressed with the probability density function:

$$p(\sigma) = \frac{1}{\bar{\sigma}} exp\left(\frac{\sigma}{\bar{\sigma}}\right) \dots \dots \dots \dots \dots (2)$$

Where $\bar{\sigma}$ is the average SNR, and is physical layer dependent. [10]

In a wireless network, since nodes share a common channel, the interference usually has a larger impact than noise. [11] Therefore to measure the signal quality, we will consider the SINR. However, for simplicity we will refer to it as SNR, where the noise will be the addition of the background noise and the interference of neighboring transmissions.

Our study is based on a Finite State Markov Chain (FSMC) Model, where the channel switches between different states. Each state corresponds the probability that a packet sent by the transmitter will be received by receiver or will be lost. Mathematical modeling of Rayleigh fading channel using Markov Chains has been used from many researchers in previous years. Zhang and Kassam in [12], partition the received SNR into finite number of states in such a way, that each state will produce the same steady state probabilities.

We consider the situation in which the success of a packet transmission in a given state is determined by comparing the received SNR, to the thresholds in each state, each of which has certain packet error probability. Each state can have a different threshold level, and depending on a given threshold, we associate an error probability with that state. In our approach we use three state Markov chain model, where there are two good states, E (Excellent) and F (Fair), and a single bad state, B. This gives us an insight for modeling wireless channels more accurately.

Assuming that probability of transition from state E to state B and vice versa is very low, we can represent this with the diagram in **Figure 1**.

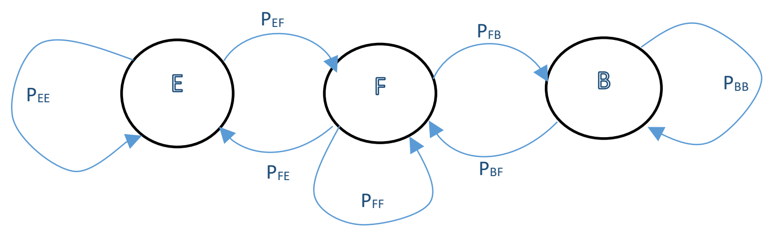

Figure 1 Three State Markov Chain

Hence the transition probabilities from state *k* to state *k+1*, can be expressed as a ratio of the level crossing rate at threshold of state *k+1*, and the average number of signal segments per second staying in state *k*. [10], and in the matrix form is shown below:

$$P = \begin{bmatrix} P_{11} & P_{12} & P_{13} \\ P_{21} & P_{22} & P_{23} \\ P_{31} & P_{32} & P_{33} \end{bmatrix} = \begin{bmatrix} P_{EE} & 1 - P_{EE} & 0 \\ P_{FE} & P_{FF} & 1 - P_{FE} - P_{EF} \\ 0 & 1 - P_{BB} & P_{BB} \end{bmatrix} \dots\dots\dots\dots\dots\dots (3)$$

Power Aware Routing

SNR value of a link is a function of distance between the nodes, therefore the direction of the movement of the sending and receiving node can be determined by comparison of the previous SNR value and the new received value: if the existing value is lower than the received one we say that the nodes are approaching each other. However, the nodes in the network have limited battery and stop transmitting or receiving if the power is drained. Thus, we extend our work including the Residual Power (RP) of the nodes, for route selection and maintenance. The channel can be in an excellent state, yet, if RP is very low, the link would not be selected, since that node is dying. Our three state Markov model, with the new metric, RP added, could be given with the following diagram in **Figure 2**:

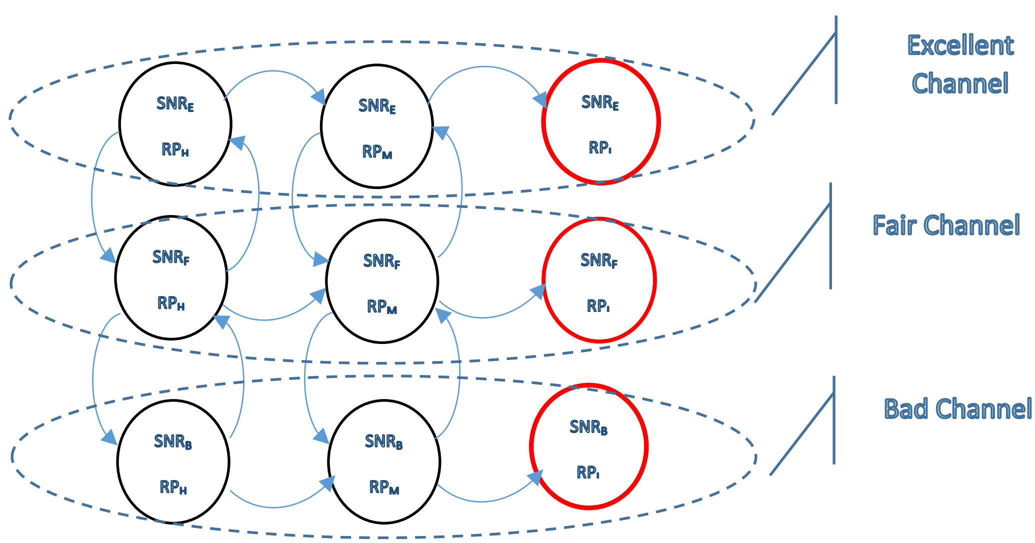

Figure 2 Three State Markov Diagram with SNR and RP

Where RP_L is the threshold, below which, a node cannot participate in the communication. Nodes represented with *red* circles are dead nodes.

The variations of Received SNR in a particular link with selected thresholds can be seen from the **Figure 3** below:

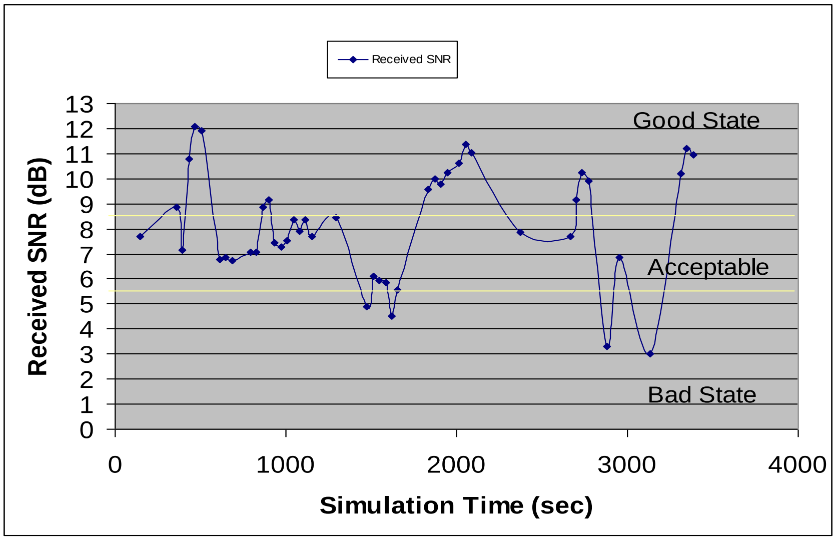

Figure 3 Received SNR for a link vs. Simulation Time
(SNR thresholds between three states are given with solid yellow lines)

Route Discovery of SP-DSR (SNR and Residual Power aware DSR)

We will implement the new routing metric by modifying the dynamic source routing (DSR) protocol, and demonstrate the benefits of inter layer interactions to both: route discovery and the route maintenance of this protocol.

The Dynamic Source Routing (DSR) protocol was designed especially for MANET applications. Its main feature is that every data packet follows the source route stored in its header. This route gives the address of each node through which the packet should be forwarded in order to reach its final destination. Each node on the path has a routing role and must transmit the packet to the next hop identified in the source route. [13]

If a source node doesn't find a suitable route to the destination in its cache, it originates a route discovery with broadcasting a RREQ (Route Request) packet. RREQ contains a unique identifier, the addresses of the initiator and the target, and the listing of all intermediate nodes which forward the copy to the neighbors currently within the wireless transmission range. However, to implement our algorithm, in the header of the RREQ packet is added a new field (SP), to indicate the quality of the path.

Here, as a new parameter, we are using cost of the link, which is based on SNR and the residual power, as a routing metric. We will call this parameter as SP (SNR and Residual Power dependent).
The cost of the link is based on Three State Markov Model and calculated this way:

- SNR and the Residual Power (RP) of the devices are based on two thresholds. The level between two thresholds is considered as “Fair”, while the level below the second threshold is considered as “Bad”, and above the first threshold as “Excellent”.
- The links with high SNR and RP have the lowest cost “0”
- The cost of the links will be considered “1” if the SNR of the node is high
- If any of these metrics (SNR or RP) is in “Fair” state, the cost of the link will be marked as “2”
- Nevertheless, if SNR or RP is in a “Bad” state, the cost will be the highest. We assign value “3” to this state, which means, that either the link is so poor, or the energy level of the node is very low, and the node is dying.

Each intermediate node will append its address as a hop sequence only if it did not detect a duplicate RREQ and the value of the SP is lower than “3”.

This is given in the flowchart below, **Figure 4**:

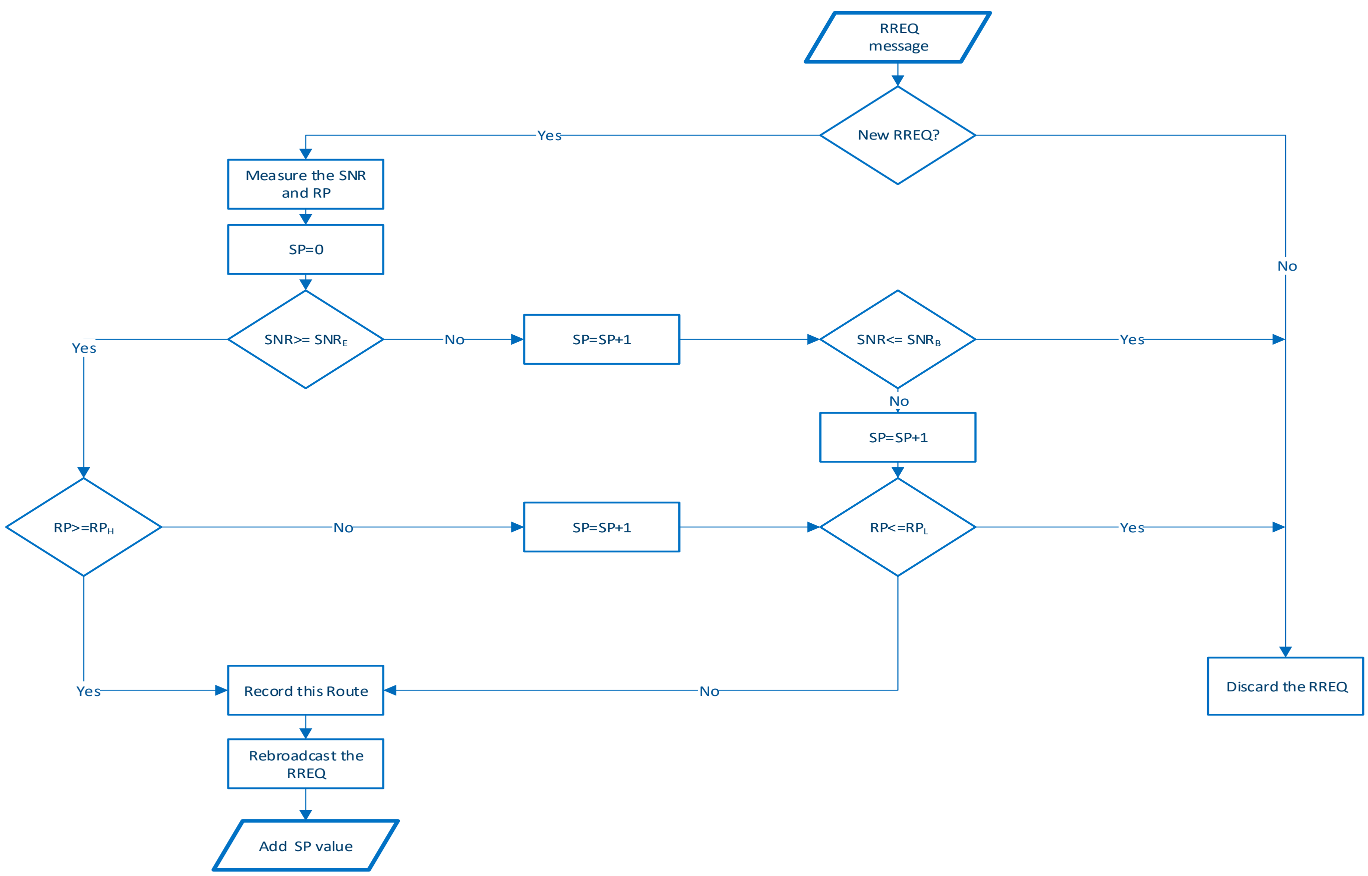

Figure 4 SP-DSR Route Discovery Process

Hence, whenever a node receives a RREQ packet, the cost parameter - SP is determined and if the value of SP is “3”, then the RREQ packet is discarded. Therefore, it does not propagate the RREQ any further and will not be a potential transit node in the path.
When the RREQ packet reaches its destination, the node generates a Route Reply (RREP) back to the source node.

However, before transmitting a RREP packet, the destination will make an informed decision regarding selection of a communication path. It replies to that RREQ, which has the lowest cost, SP, to the destination, determined with:

$$SP = min\sum_{1}^{N} SP_i \ldots\ldots\ldots\ldots\ldots (4)$$

SP_i is the cost of the link *i* between nodes *j* and *j+1*, *N* number of nodes from source to destination.

Intermediate nodes are not allowed to return Route Replies (RREP) to the initiator with the information from their Cache. When the RREP reaches its destination, the source node begins using this route for delivery of the packet, which at the same time meets the QoS criteria set by the SP metric.

Since SP is used as criteria in the selection of the routes, we have to ensure that during the route maintenance phase, all existing routes meet the criteria of not exceeding link SP threshold (SP<3), otherwise such route is invalid.

Route Maintenance of SP-DSR

Route maintenance is DSR's standard operation mode. Any node listed in the source route, unicast packets to the next hop. If the link is broken, a node sends a route error (RERR) packet to the sender. Nodes overhearing the RERR, update their caches, erasing the upstream route. Upon receiving the route error packet, the sender attempts to find a new route to the destination node in its cache, and if none is found, switches to the route discovery mode.

Though DSR has the maintenance mechanism, it is applied only during the packet transmission. To maintain the active routes, in this approach during the route reply, each node will keep track of its first neighbor from which it has received the RREP message for the first time, and send some kind of HELLO messages periodically. This node replies with ACK but only when the link status is "Excellent", which is determined by the SNR threshold1and the residual Power (SP = 0, or SP = 1).

On the other hand if SNR value is between two thresholds (SP = 2), the node replies with WARN message. When a node receives a WARN message, implies that the link is going down, or the node is dying due to the low power level. Therefore the source within a certain period of time could switch to an alternate route, if it exists or to start a new route discovery process.

If the SP of the link does not improve for a period of time determined with TIME_EXPIRY, then the link layer realizes that this degradation may be due to a change of the topology, so it informs the network layer about the unavailability of the link, by sending RRER message to its first neighbor in the upstream link. When RRER message reaches the source node, it updates its cache and deletes the existing path with the broken link. TIME_EXPIRY is determined as the mean waiting time that the channel remains in either of the two good states: "Excellent" or "Fair".

The same part of the code which determines the SP value as in the Route Discovery process, is inserted to the Route Maintenance part of the original DSR code. This can be seen from the following flowchart, **Figures 5** and **6**:

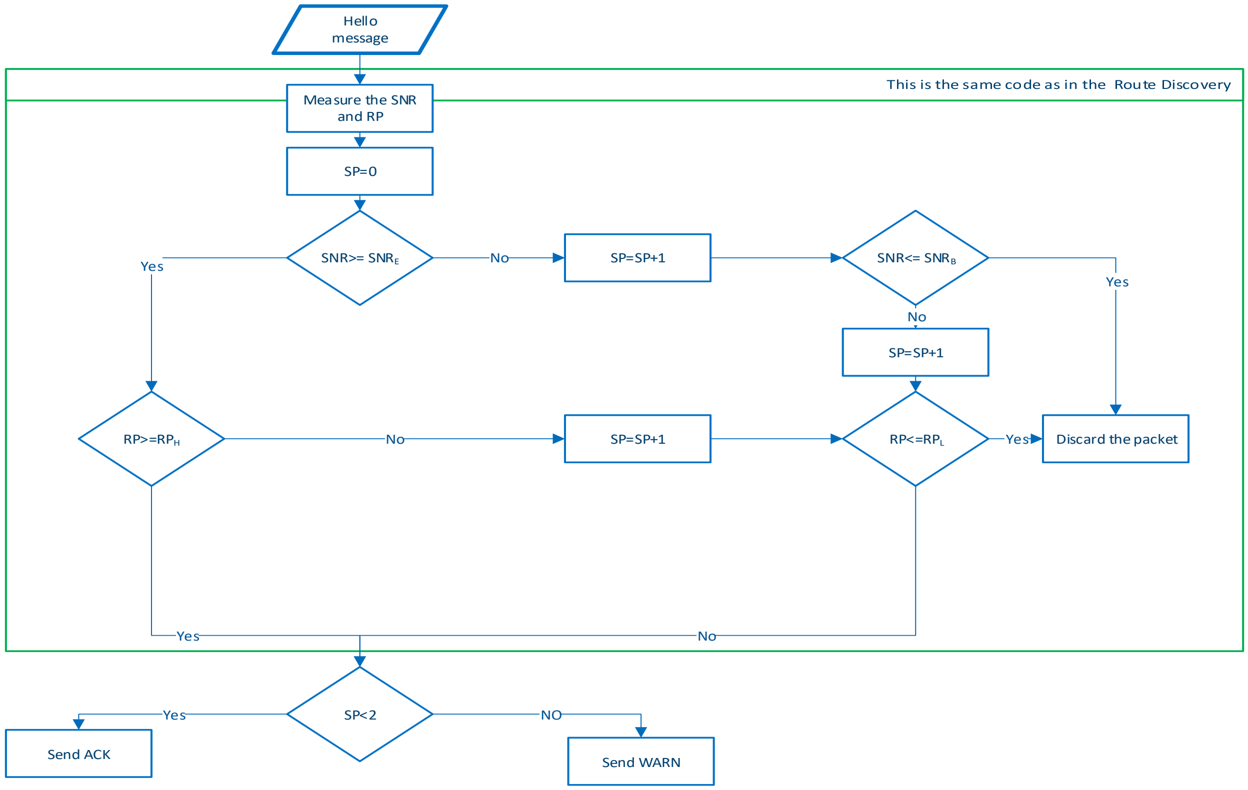

Figure 5 Route Maintenance in SP-DSR (Hello Messages)

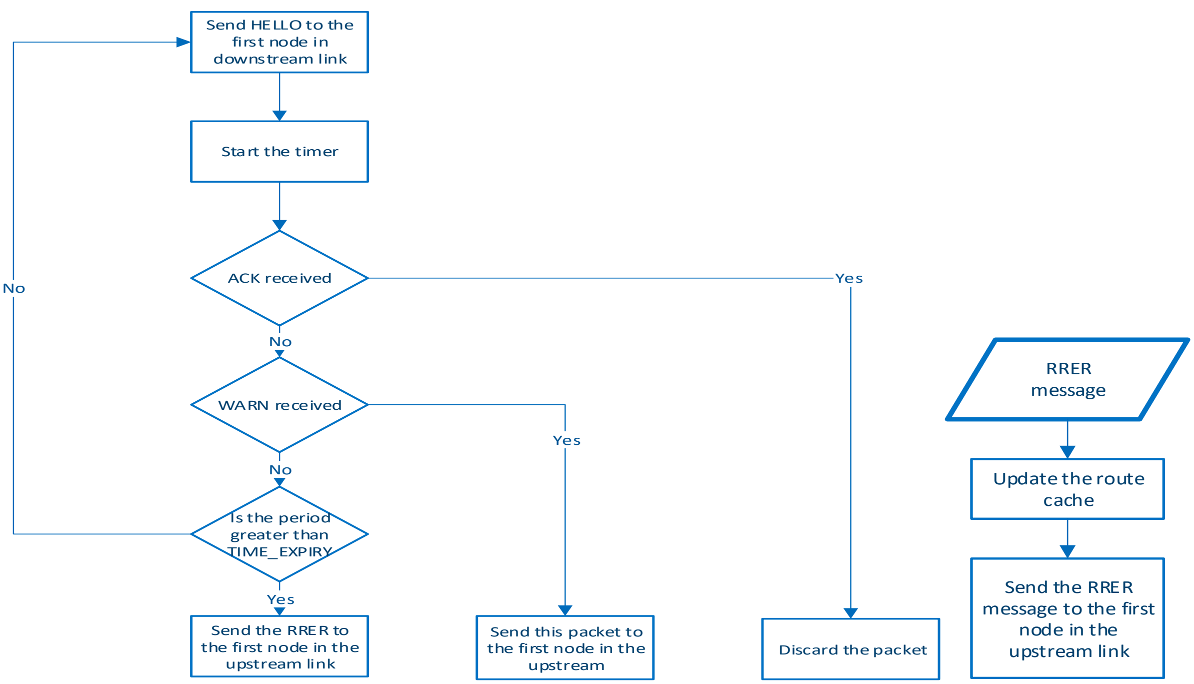

Figure 6 Route Maintenance of SP-DSR (ACK and WARN)

Simulation Results and Discussion

Our algorithm described above was implemented and evaluated using NS-2 [14] discrete event simulator. We set up a network in 1000m x 1000m terrain consisting of 60 mobile nodes. The radio propagation model is Rayleigh fading and the mobility is Random-Waypoint. The rest of the parameters are given in **Table 1**.

Figures 7-9 illustrate the performance comparison between the traditional DSR and its modified versions:

Table 1 Simulation Parameters

Parameters	Value	Parameter	Value
Terrain dimensions	1000mx1000m	Traffic rate	1 Mbps
Simulation time	1 hr	Radio Tx Power	0.005 W
Nodes number	60	Mobility model	Random-Waypoint
Routing protocol	DSR	Propagation model	Rayleigh fading
MAC protocol	802.11	Carrier Frequency	2.4 GHz
Packet size	512 bytes	Speed	1-20 m/s

- Only when channel quality was considered
- When both, the channel quality and the residual power of the nodes were considered. (SP-DSR).

The average end-to-end delay is the cumulative of all possible delays in the links and the nodes. Traditional DSR has higher delays, due to the buffering delays of route recoveries and the retransmission delays at the link layer. SP-DSR has the best end-to-end delay performance, because the nodes obtain sufficient information from physical layer to construct more reliable paths. The paths built from these links reduce the probability of failure, especially when the nodes with low battery level are eliminated from the communication path.

One of the primary objectives of an ad-hoc routing protocol is to maximize energy efficiency which can be measured by parameters such as routing overhead. Obviously, SP-DSR performs better than the DSR, since it is looking for more reliable paths. The nodes discard the RREQ messages if the SP is not less than 3. Though the route maintenance of the modified protocols sends periodically HELLO messages, these control packets do not increase the routing overhead compared to the retransmitted data packets, which have significant larger packet size, since they carry the entire route in the header.

Figure 9 presents the visible improvement of average throughput of SP-DSR, which outperforms traditional DSR. Retransmissions result in higher delays and this leads to reduced throughput. Exchanging the information between physical layer and network layer, and considering the battery level of the nodes, the network layer may adapt itself, selecting the most reliable paths, and thus achieving higher throughput.

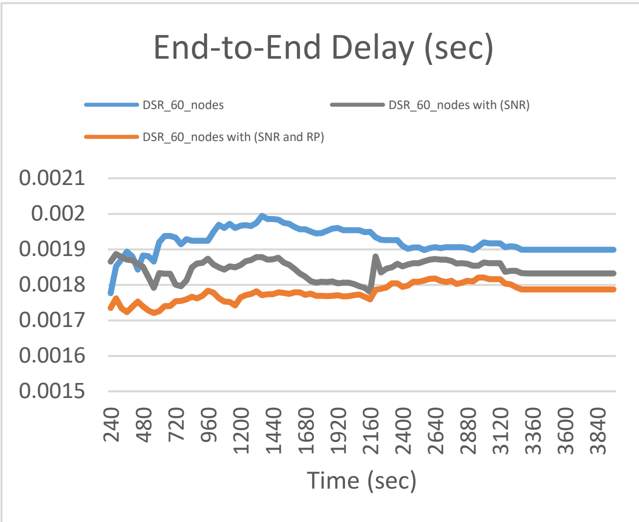

Figure 8 End-to-End Delay vs. Simulation Time

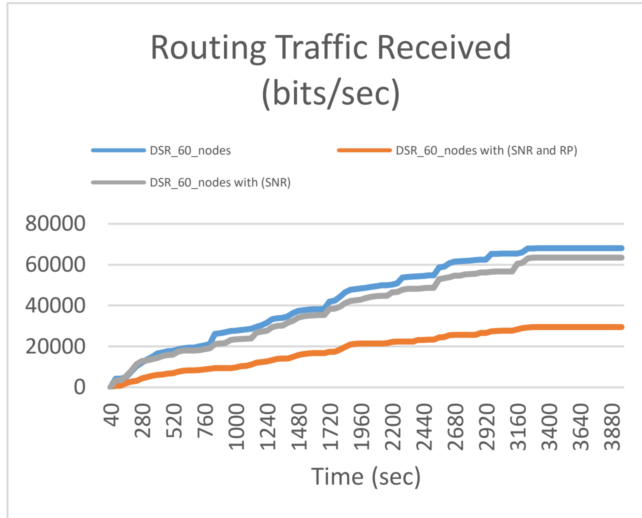

Figure 9 Routing Overhead vs. Simulation Time

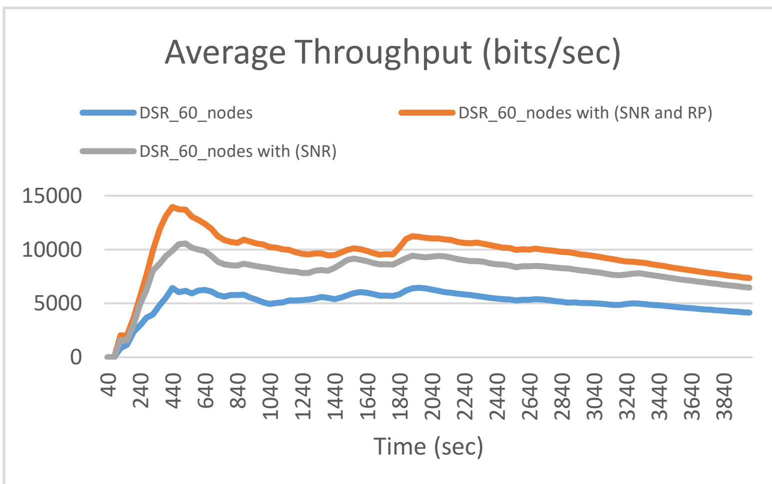

Figure 7 Average Throughput vs. Simulation Time

Conclusion

This paper proposes a network architecture that supports QoS in wireless ad hoc networks using probabilistic algorithm which monitors both SNR and the residual Power level. These parameters are propagated from the physical layer up to the routing layer to improve the performance of the existing protocol. We applied this technique to the DSR protocols, modifying both route discovery and route maintenance. DSR like other conventional MANET protocols, cannot stand against various constraints of ad-hoc networks, until it is combined with some other techniques to address power consumption. Introducing a proactive feature on the route maintenance mechanism of DSR (using HELLO messages), yielded in less link breakages with the significant improvements in the various routing protocol performance parameters.

Acknowledgements

This work is based on the research sponsored by PSC-CUNY under the agreement of TRADA-49-447.

References

[1] J. Novatnack, L. Greenwald, and H. Arora, "Evaluating ad hoc routing protocols with respect to quality of service," in *Wireless And Mobile Computing, (WiMob'2005), IEEE International Conference* , 2005, pp. 205-212.

[2] D.S.J. De Couto, D. Aguayo, B.A. Chambers, and R. Morris, "Performance of multi-hop wireless networks: Shortest path is not enough," in *Proceedings of First Workshop on Hot Topics in Networks (HotNets-I)*, 2002.

[3] L. Iannone, Khalili R., Salamatian K., and S. Fdida, "Cross layer routing in wireless mesh networks," in *Wireless Communication Systems, 1st International Symposium*, 2004.

[4] N. Wisitpongphan, G. Ferrari, S. Panichpapiboon, J.S. Parikh, and and O.K. Tonguz, "QoS Provisioning using BER-Based Routing in Ad Hoc Wireless Networks," in *IEEE 61st Vehicular Technology Conference*, 2005.

[5] Merlinda Drini and Tarek Saadawi, "Performance of Ad Hoc Routing Protocols with Link State," in *In the Proceedings of 10th WSEAS Int. Conf. on Automation & Information*, 2009, pp. 52-57.

[6] Navin Mani Upadhyay, Kumari Soni, and Arvind Kumar, "Power Aware Routing in Mobile Ad Hoc Networks by using Power Aware Matrices," *International Journal of Computer Applications*, vol. 166, no. 11, pp. 24-29, May 2017.

[7] Sarkar S. and Majumder K., "A Survey on Power Aware Routing Protocols for Mobile Ad-Hoc Network.," in *Proceedings of the International Conference on Frontiers of Intelligent Computing: Theory and Applications (FICTA)*, 2013, pp. 313-320.

[8] Abeer Ghandera and Eman Shaabanb, "Power Aware Cooperation Enforcement MANET Routing Protocols," in *The International Conference on Advanced Wireless, Information, and Communication*, 2015, pp. Volume 73, 2015, Pages 162-171.

[9] T. S Rappaport, *Wireless Communications: Principles and Practice*.: Prentice Hall , 2002.

[10] Merlinda Drini and Tarek Saadawi, "Modeling Wireless Channel for Ad-Hoc Network Routing Protocol," in *ISCC Marakech Marocco*, 2008, pp. 549-555.

[11] Amir Salman Avestimehr, Suhas N. Diggavi, and David N C. Tse, "A Deterministic Model for Wireless Relay Networks and its Capacity," in *IEEE Information Theory Workshop on Information Theory for Wireless Networks*, 2007.

[12] Q. Zhang, A. Kassam, and S.A, "Finite-State Markov Model for Rayleigh Fading Channels," *IEEE transactions on communications*, vol. 47, no. 11, pp. 1688-1692, 1999.

[13] D. B. Maltz and Johnson and D. A., "Dynamic source routing in ad hoc wireless networks," in *Mobile Computing*, 1996, pp. 153-181.

[14] NS2 Network Simulator. [Online]. www.isi.edu/nsnam/ns

[15] Marco Fotino et al., "Evaluating Energy-aware Behavior of Proactive and Reactive Routing Protocols for Mobile Ad Hoc Networks. ," in *1st Int. Conf. On Wireless Sensor and Actor Networks*, 2007, pp. 119-130.

[16] Baisakh Nileshkumar, R Patel, and Shishir Kumar, "Energy Conscious DSR in MANET," in *2nd IEEE International Conference on Parallel, Distributed and Grid Computing*, 2012, pp. 784-789.

[17] Z Cheng and W.B. Heinzelman, "Exploring Long Lifetime Routing (LLR) in Ad Hoc Networks," in *, 7th ACM International Symposium on Modeling, Analysis and Simulation of Wireless and Mobile Systems*, 2004, pp. 203-210.

[18] Fuad Alnajjar and Yahao Chen, "SNR/RP Aware Routing Algorithm: Cross-Layer Design for MANETs," *International Journal of Wireless & Mobile Networks (IJWMN), Vol 1, No 2, November 2009*, vol. 1, no. 2, 2009.

[19] J. P. Singh, N. Bambos, B. Srinivasan, and D. Clawin, "Cross-layer Multi-hop Wireless Routing for Inter-Vehicle Communication," in *2nd International Conference on Testbeds & Research Infrastructures for the Development of Networks & Communities*, 2006, pp. 100-110.