This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the WCNC 2007 proceedings.

Ad hoc Network State Aware Routing Protocol

Jie Xiang*, Samba Sesay†, Yiming Wang‡ and Jianhua He§
* ANDA Networks (Wuhan) Inc, Wuhan, 430071, P.R.China. Email: jxiang@andanetworks.com
† Huawei Technologies Company Limited, Shenzhen, 518129, P.R.China. Email: samba_sesay@huawei.com
‡Centre for Communications Research, University of Bristol, Bristol, BS8 1UB, UK. Email:Yiming.Wang@bristol.ac.uk
§Department of Electronic Systems Engineering,University of Essex, Essex, CO4 3SQ, UK. Email: Jianhua@essex.ac.uk

Abstract— **The environment of a mobile ad hoc network may vary greatly depending on nodes' mobility, traffic load and resource conditions. In this paper we categorize the environment of an ad hoc network into three main states: an ideal state, wherein the network is relatively stable with sufficient resources; a congested state, wherein some nodes, regions or the network is experiencing congestion; and an energy critical state, wherein the energy capacity of nodes in the network is critically low. Each of these states requires unique routing schemes, but existing ad hoc routing protocols are only effective in one of these states. This implies that when the network enters into any other states, these protocols run into a sub optimal mode, degrading the performance of the network. We propose an Ad hoc Network State Aware Routing Protocol (ANSAR) which conditionally switches between earliest arrival scheme and a joint Load-Energy aware scheme depending on the current state of the network. Comparing to existing schemes, it yields higher efficiency and reliability as shown in our simulation results.**

I. INTRODUCTION

A mobile ad hoc network (MANET)[1] is a collection of mobile nodes connected by wireless links to form a temporary network without any existing network infrastructure or centralized administration. Nodes in the network can act as routers forwarding packets, and they are free to move randomly and organize themselves arbitrarily.

The environment of an ad hoc network is characterized by unpredictable connectivity changes, unreliable wireless medium, resource-constrained nodes, and dynamic topology. These features make a MANET prone to numerous types of failures including: transmission errors, node failures, link failures, route breakages, and congestions. The environment of ad hoc network can be categorized into three main states: an ideal state, wherein the network is relatively stable with sufficient resources; a congested state, wherein some nodes, regions or the whole network is experiencing congestion; and an energy critical state, wherein the energy capacity of nodes in the network is critically low. Under these conditions, designing an efficient and reliable routing protocol that adapts to the current state of the network is an important and challenging task. To our knowledge none of the current routing protocols designed and evaluated for ad hoc networks in literatures has demonstrated effective operation in a wide range of network dynamics or states.

In this paper, we propose a network state aware routing protocol (ANSAR) that adopts route selection metrics based on the current state of the network. In particular, ANSAR conditionally switches between earliest arrival scheme and a Joint Load-Energy aware scheme to efficiently utilize network resources, keep the network robust and maintain a high network performance.

II. RELATED WORKS

Typical route selection metrics used by exiting ad hoc routing protocols are: shortest hop, load aware, and energy aware. In this section, we discuss these related routing metrics, and analyze their drawbacks that motivates this research work.

A. Shortest-Hop Routing Metric

This is the most commonly used routing metric wherein a destination or source node chooses the route with the minimum number of hops for data transfer. Some examples of ad hoc routing protocols that adopt shortest path metric are: Destination-Sequenced Distance Vector(DSDV)[2], Ad hoc On-Demand Distance Vector Routing(AODV)[3], Dynamic source routing(DSR)[4], and Wireless Routing Protocol(WRP)[5].

The main draw back of shortest path routing metric is that it can easily concentrate traffic on centrally located nodes, leading to congestion, contention and resource exhaustion on those nodes. This may in turn result in packet delay and loss, and faster energy depletion, degrading the overall performance of the network.

B. Load Aware Metric

Load Aware routing protocols such as dynamic load aware routing protocol DLAR[6], aim at evenly distributing network traffic load[7][8][9][10]. In DLAR, nodes use their load information (the number of packets buffered in the interface) as the primary route selection metric. The destination node compares the total traffic load on each path and selects the least loaded path.

The main disadvantages of load aware routing protocols are that they are unaware of the energy status of nodes, and may divert load to low energy capacity nodes causing them to deplete of energy. This may in turn cause high node failures, packet loss, high overhead and network partitioning.

C. Energy Aware Metric

Energy or power aware ad hoc routing metrics[11] aims to either minimize the total power needed to route packets across the network or maximize the lifetime of all nodes in the network. To minimize the total energy consumed to send packets, energy aware protocols like 'Minimum Total Transmission Power Routing(MTPR)'[12] compare the total power consumption of transporting packets along each path from source to destination and choose the path which consumes the least power. To maximize the lifetime of nodes in the network, energy aware protocols such as 'Minimum Battery Cost Routing (MBCR)'[13] and 'Min-Max Battery Cost Routing (MMBCR)'[13] can be employed. These two protocols determine the willingness of a node to forward packets based on its remaining battery capacity.

The main disadvantage of energy aware protocols is that they tend to concentrate traffic load on nodes with high battery capacity. This tendency can cause congestion, and induce high packet delay and low throughput.

To guarantee the requirements of various ad hoc network states, we are proposing a network state aware routing protocol ANSAR, that switches between shortest-hop route selection metric (earliest arrival) for ideal case and a joint load-energy aware metric for congested and energy critical states as described in the next section.

III. PROTOCOL DESCRIPTION

In this section, we will deduce ANSAR route selection metric, specify the generation model of this route selection metric, and give a detail description of implementation based on DSR routing protocol.

A. Route Selection Metric

As mentioned in the previous sections, our proposed ad hoc network state aware routing protocol ANSAR combines earliest arrival route selection metric with a joint load energy aware route selection metric to select routes according to the current state of the network. The earliest arrival scheme is quite simple, while the joint load energy aware metric is a bit demanding. In analyzing the joint load energy route selection metric, we made the following assumptions:

I Energy consumed due to computation related activities is negligible compared to communication related activities.

II All data packets are of the same size.

III The energy consumed per unit transmission, reception and overhearing of a packet are constant, denoted by e_{i_x}, e_{i_r} and e_{i_o} respectively for node i.

Assumption I means that a node's battery power is consumed only due to active communication related activities i.e transmission, reception and listening[14]. Thus the total energy consumed at node i over a time interval T at time t is equal to the energy drain $ED_i(t)$:

$$\begin{aligned} ED_i(t) &= \int_t^{t-T} P_i(t)dt \\ &= \int\limits_{T_{i_x}(t)} P_{i_x}dt + \int\limits_{T_{i_r}(t)} P_{i_r}dt + \int\limits_{T_{i_o}(t)} P_{i_o}dt \\ &= RBC_i(t-T) - RBC_i(t) \end{aligned} \tag{1}$$

Where $T_{i_x}(t), T_{i_r}(t), T_{i_o}(t)$ are respectively the proportion of the time interval during which the node is in the state of transmission, reception and overhearing. P_{it}, P_{ir} and P_{io} are the power required of node i in the transmission, reception and overhearing state respectively. $RBC_i(t)$ and $RBC_i(t-T)$ are the remaining battery capacity of node i at time t and $t-T$ respectively.

Even though the number of packets buffered in a node's interface queue can be used to measure the traffic load, it is complex to devise an efficient cost function that combines the buffer information with the remaining battery power. Therefore, at node i and time t, we define the traffic load $L_i(t)$ as the amount of activity at that node, with the number of packet transmitted $n_{i_x}(t)$, received $n_{i_r}(t)$ and overheard $n_{i_o}(t)$ during an observe time.

$$L_i(t) = n_{i_x}(t) + n_{i_r}(t) + n_{i_o}(t) \tag{2}$$

From assumption II and III, the total energy consumed by these load at node i during an observed time can be estimated as:

$$EL_i(t) = n_{i_x}(t) \times e_{i_x} + n_{i_r}(t) \times e_{i_r} + n_{i_o}(t) \times e_{i_o} \tag{3}$$

Eq.(3) is equivalent to Eq.(1): $EL_i(t) = ED_i(t)$, and the energy drain rate $EDR_i(t)$ is :

$$\begin{aligned} EDR_i(t) &= \tfrac{ED_i(t)}{T} = \tfrac{EL_i(t)}{T} \\ &= \tfrac{n_{i_x}(t)\times e_{i_x} + n_{i_r}(t)\times e_{i_r} + n_{i_o}(t)\times e_{i_o}}{T} \end{aligned} \tag{4}$$

At time t, the ratio of the remaining battery capacity $RBC_i(t)$ to the energy drain rate $EDR_i(t)$ gives an approximate lifetime $NL_i(t)$ of the node:

$$\begin{aligned} NL_i(t) &= \tfrac{RBC_i(t)}{EDR_i(t)} \\ &= \tfrac{RBC_i(t)\times T}{n_{i_x}(t)\times e_{i_x} + n_{i_r}(t)\times e_{i_r} + n_{i_o}(t)\times e_{i_o}} \end{aligned} \tag{5}$$

For fixed time interval T and $e_{i_x} = e_{i_r} = e_{i_o} = K_i$, Eq.(5) could be simplified to the following expression:

$$NL_i(t) = \frac{T}{K_i} \cdot \frac{RBC_i(t)}{L_i(t)} = K\frac{RBC_i(t)}{L_i(t)} \tag{6}$$

Where K is an overall constant. Eq.(6) above shows that node lifetime NL_i is a direct function of the remaining battery capacity and an inverse function of the traffic load. Since node lifetime NL_i is expressed as a function of both the energy status and the traffic load condition at a node. It is therefore used as our route selection metric that is both energy and load aware.

For all nodes i in path p, path lifetime PL_p is defined as the lifetime of the nodes with the least lifetime:

$$PL_p = \min\{NL_i|\forall i \in P\} \tag{7}$$

Best path p_b selected by the destination node is the path with the maximum path lifetime. Given A is the set of path p, p_b can be expressed:

$$p_b = p|\max_{\forall p\in A} PL_p = p|\max_{\forall p\in A}\min_{\forall i\in p} NL_i \tag{8}$$

A reserve path p_r, with second best path lifetime, is also selected by the destination node, defined as:

$$p_r = p|\max\{PL_p|\forall p \in A, \& \ p \neq p_b\} \tag{9}$$

ANSAR route selection metric M is a combination of the joint load energy aware metric and earliest arrival metric defined by:

$$M = \begin{cases} \partial P & forE > \gamma \\ \max\{PL_p | \forall p \in A\} & forE \leq \gamma \end{cases} \tag{10}$$

Where ∂P is an earliest arrived route path to the destination node, for which all nodes that are members of that path have battery energy capacity above the threshold value γ.

B. Generation Model of Protocol

A block diagram representation of the protocol generation model is given in fig1.

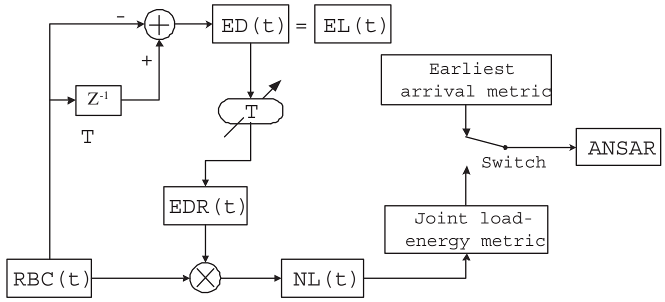

Fig. 1. ANSAR generation model

Every node monitors its battery capacity. Let the remaining battery capacity at time t be $RBC(t)$. $ED(t)$ (the energy drained during a interval T) is equal to $EL(t)$ (the energy consumed by the load). The ratio of present battery energy status $RBC(t)$ to that of the energy drain rate $EDR(t)$ gives the node life time $NL(t)$, used as the joint load energy aware route section metric. This joint load energy aware route section metric when combined with earliest arrival scheme gives the network state aware protocol ANSAR.

C. Implementation

Our proposed route selection metric can be implemented onto conventional ad hoc routing protocols, such as AODV, DSR, etc. Take DSR as an example. We build ANSAR upon DSR with the following main modifications:

- Intermediate nodes are prevented from replying to route requests RREQs, so the destination node can receive all routes and select the best path according to the gathered network state information.
- Two additional fields are added in DSR route request RREQ. One carries path lifetime(PL)information, and another sets an energy threshold flag (ETF) when a RREQ traverses any intermediate node with critically low energy capacity.
- We create a field in DSR route reply RREP for inclusion of a reserve path in addition to the best selected route.

The rest of this section describes the operations and pseudo codes of this protocol.

1) Route Discovery: ANSAR finds routes on-demand. Whenever a source node needs to communicate with a destination node for which it does not have a known route, the source node will broadcast a route request RREQ packet specifying the destination address for which the route is requested, set the path lifetime(PL) entry to a very big value and the energy threshold flag (ETF) off. Intermediate nodes receiving a non-duplicate RREQ will perform the following two check operations before rebroadcasting it.

- If the received RREQ path lifetime entry value is greater than the intermediate node's lifetime value, it will update the path lifetime value with its node lifetime value.
- If the intermediate nodes' energy capacity is below a predefined threshold level, it will set the energy threshold flag on.

When a destination node receives the first RREQ packet, it will check the energy threshold flag. If it's off, it implies that the incoming path is ideal, and the destination node will immediately send a route reply to the source (earliest arrival scheme) and ignore all later arrived RREQs from the same source. Otherwise, the destination node caches the RREQ and triggers a route selection wait timer. During the route selection wait time if any other RREQ is received without the energy threshold flag set, the destination node cancels the route selection wait timer and replies to that RREQ. However, if route selection wait time expires, and the entire source RREQs received up to the time have their energy threshold flag set, the destination node uses the joint load-energy route selection metrics to choose the best path and send a reply to the source. The reply sent from destination node to source node embeds one reserve path, which is a candidate to the best selected path. In the case when only one RREQ is received by the destination node during the path-selection wait time the reserve path is NULL. When the source node receives a RREP, it places the selected best path into the primary cache and the reserve path into the secondary cache, and then starts transmission using the primary route.

2) Route Maintenance: Whenever a broken link is detected, the upstream node will generate a route error RERR message sent to all sources using the broken link. The RERR message erases all routes using the link along the way. Upon receiving notification of a broken link, a source node deletes the broken path from its primary route cache and looks up its secondary route cache for any reserve route to the destination. If it finds one, it immediately sends a route status probe packet RSP through that path to confirm the status of the route. The destination on receiving RSP responds with a Route acknowledgement probe RAP. These probe messages help to maintain the reliability of data delivery. Upon receipt of a reply probe the source then promote the reserve path to the primary cache and starts data communication with the destination. However if the source fails to receive reply probe during a short probe reply wait time, it initiates a new route discovery process. Routes are deleted from a cache if they are not used for a certain amount of time.

3) Pseudo Codes: Following part are the pseudo codes for three different nodes in communication.

```
(a) For a source node
Case 1: When source node S has data packets to send and no route is known to the targeted destination.
    Step 1 S broadcasts a RREQ message to its neighbor nodes, setting an included path lifetime field PL to an very big value.
    Step 2 If S does not receive acknowledgement from destination within a route-discovery waiting period, it repeats step 1.
    Step 3 Else, S inserts the best path $p_b$ and reserve path $p_r$ to the primary and secondary route cache respectively.
    Step 4 S sends out data packets using $p_b$.
Case 2: When S receives route error RERR notification while sending packets, it then removes paths containing the broken link, and lookup the secondary cache for any reserve path.
    Step 1 If no reserved path $p_r$ exists in the secondary cache, go to Case 1.
    Step 2 Else, send a route status probe RSP to the destination.
    Step 3 If a route status acknowledgement RSA is received from the destination within a route wait time, it continues to send data using $p_r$, and adds $p_r$ to primary cache.
    Step 4 Else, go to Case 1.
(b) For an intermediate node
Case 1: When IN receives a no duplicate RREQ
    Step 1 IN compares its node lifetime NL to the path lifetime entry PL.
    Step 2 If NL<PL, it sets path lifetime PL to NL.
    Step 3 Rebroadcast.
Case 2: When IN receives a RREP, it forwards the RREP to the upstream node in the backward path.
Case 3: When IN receives route error RERR notification, it removes paths containing the broken link and forwards it to the source.
Case 4: When IN receives RSP, it forwards it to the destination.
Case 5: When IN receives RSA, it forwards it to the source.
Case 6: If IN is upstream to a detected link break, it sends RERR to all sources having active route through the broken link.
(c) For a destination node
Case 1: When a destination node D receives a RREQ.
    Step 1 If the RREQ energy threshold flag $EF$ is off, it sends RREP and ignores all later replies.
    Step 2 Else it caches the route and triggers a route select wait timer.
    Step 3 If during route-select wait time, D receive any source destination RREQ with energy threshold flag off, it cancel the route-selection wait timer and send a RREP.
    Step 4 Else after route-selection timer expires, D selects the best and reserve path as in equation 8 and 9, and sends a route reply RREP.
Case 2: When D receives RSP, it acknowledges source node S with a RSA.
```

IV. PERFORMANCE EVALUATION

A. Simulation Environment

We use network simulator NS-2 (Version 2.28)[15] and simulate 50 ad hoc nodes in a virtual environment of $1500m \times 300m$ for $900s$ of simulation time. The channel data rate and transmission range are set to $1Mbps$ and $250m$ respectively. The network nodes move according to the random waypoint mobility model with a speed uniformly distributed between 0 and $20m/s$ maximum. Traffic sources are constant bit rate (CBR), with sending rates of $1, 2, 3, 4, 5, 6, 7, 8pkts/s$, and packet size of $512bytes$. The rest of the simulation parameters are given in tableI below.

TABLE I

SIMULATION PARAMETERS

Parameter	Value
Number of connection	15
Interface Queue Size	50
Node's Initial Energy	80J
Energy drain per data transmission P_{tx}	0.4J
Energy drain per data reception P_{rx}	0.2J
Energy threshold	16J
Route Select wait time	0.02sec

B. Performance Metrics

The following performance metrics were used in evaluating our proposed ad hoc network state aware protocol in comparison to other related protocols:

Average end-to-end delay: this implies the delay which a packet suffers between leaving from sender and arriving at the receiver. This includes all possible delays caused by queuing for transmission at the node, retransmission delays at the MAC, propagation delay and transmission time. It represents the quality of the routing protocol.

Throughput: the ratio between the number of packets sent out by source nodes to the number of packets correctly received by the corresponding destination nodes. This reflects the degree of reliability of the routing protocol

Control packet overhead: the ratio between total number of control packets sent out and number of data packets correctly received during the simulation. This evaluates the efficiency of the routing protocol in terms of extra load introduced into the network.

Average energy consumption per packet: defined as the ratio of the average energy consumed to the number of data packets successfully received by all destination nodes in the network during simulation time. This represents the energy efficiency of the routing protocol.

C. Simulation Results and Analysis

In our experimentation, the proposed ad hoc network state aware routing protocol ANSAR was evaluated in relation to ideal state, congested state and energy critical state aware routing protocols using the performance metrics defined above. MBCR, MMBCR, and DLAR were implemented based on DSR protocols. In particular MBCR and MMBCR represent energy aware routing protocols, DLAR represents load aware routing protocols, and DSR represents ideal shortest hop routing protocol.

1) Average end-to-end delay: Figure2 shows the average end-to-end delay for varying sending rates. At low sending rates of one to two packets per second, all the routing protocols approximates shortest path algorithm. Therefore we can see that the graphs cluster together at low sending rate, with DSR under such ideal situation slightly better. At moderate rate of two to four packets per second some regions in the network becomes congested, whilst other regions remain light in the amount of load they carry. This brings the need for load balancing, thus DLAR the pure load balancing protocol performs the best. However its advantage in terms of delay is really minimal due to the additional delay it incurs using longer routes. At high sending rate the network is congested and queuing, back-off and retransmission delays are high. DSR with shortest path algorithm suffers from long queues and back-off delays therefore performs the worst. Also at high sending rate energy consumption is high and most of the network nodes are in energy critical state. Balancing load without energy awareness results in high node failure rate that leads to high retransmission delay. This makes pure load balancing protocol DLAR not to perform well at very high sending rates. Our propose ANSAR protocol performs the best since it is capable of balancing for both load and energy.

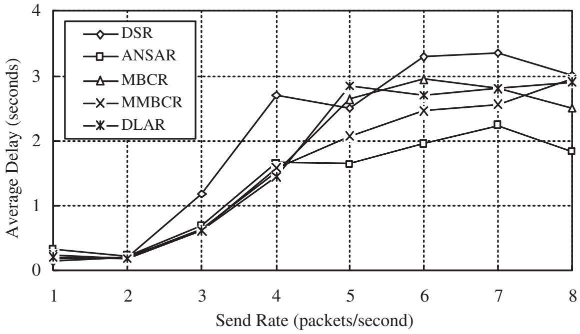

Fig. 2. Average end-to-end delay for varying sending rates

2) Throughput: Figure3 shows the throughput graphs for varying sending rates. From the graph, we can see that throughput decreases as sending rate increases. The throughput values are closely related to the number of packets dropped. In all cases DSR has the worst throughput. At low to moderate sending rate, DLAR, MBCR, MMBCR, and ANSAR yield an almost equal amount of throughput. But at high sending rate the performance graph of the pure load and energy aware schemes lags behind ANSAR and falls close to DSR.

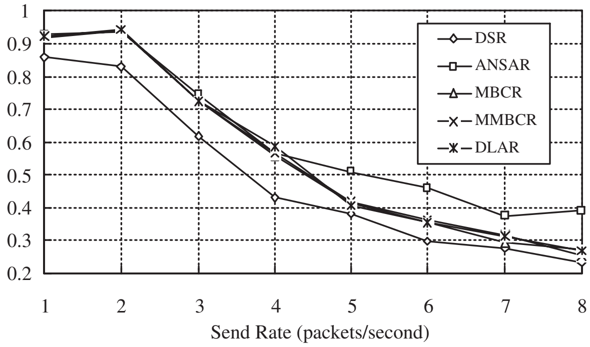

Fig. 3. Throughput for varying sending rates

3) Control packet overhead: Figure4 shows the graphs of control packet overhead for varying sending rate. Since all the protocols use the same scene and traffic files, the difference in their amount of control packets is proportion to the number of route errors. DSR performs worst, because it's shortest hop metric induces node congestion and link failures. There is no big difference between DLAR, MBCR, and MMBCR, because they can alleviate the route errors using load or energy balance schemes. But our proposed ANSAR protocol yields the least amount of control packets, since it joint load and energy balance schemes to prevent the case of both load congestion and energy exhaustion.

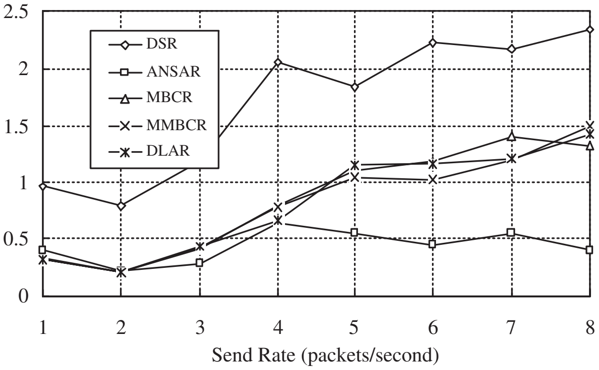

Fig. 4. Control packet overhead for varying sending rate

4) Average energy consumption per packet: Fig.5 shows the graphs of the average energy consumed per packet for varying send rate. In this graph, DSR compared to all the other schemes consumes more energy per packet delivered for all cases, because of its ignorance of node's energy and load state. DLAR, MBCR, MMBCR are only better than ANSAR at low sending rate. In higher sending rates, when the network suffers from more congestions and energy depletions, ANSAR performs best. This implies using load or energy aware schemes alone can not lead to high efficiency of energy consumption.

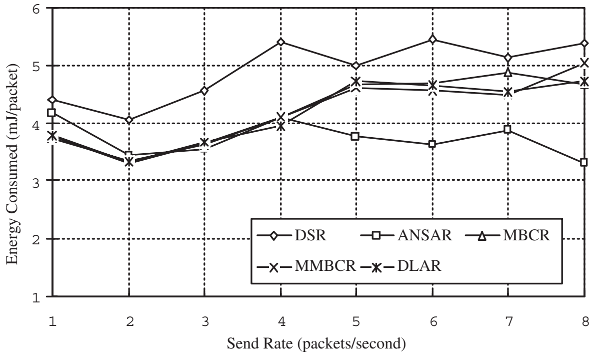

Fig. 5. Average Energy Consumption for varying send rates

The simulation experimentation and analysis of ANSAR in comparison to related ideal shortest-hop state (DSR), congested state (DLAR), and energy critical state (MBCR and MMBCR) protocols shows that balancing for energy and traffic load alone can not yield good performance. An ad hoc routing protocol should be able to run in ideal state when the network resource is sufficient; balance the network traffic load when congestion is experienced and prolong the lifetime of nodes when the energy capacity is critically low. These qualities are realized by our proposed ANSAR protocol and for most of the experimental cases perform better than other related schemes.

ANSAR has the following advantages:

1) Effective for operation in a wide range of network dynamics, traffic conditions and scale.
2) ANSAR is very flexible and can be implemented in part or whole on any standard ad hoc routing protocols.
3) Additional reserve routes embedded in ANSAR route replies reduced the number of route discoveries and can allow for multi-path routing.
4) ANSAR can implement QOS by adopting the joint load energy balancing scheme for common data packets and earliest arrival scheme for priority data packets.

With all these, ANSAR proves to be a suitable routing protocol for ad hoc networks in terms of reliability and efficiency.

V. CONCLUSIONS AND FUTURE WORK

In this paper, we categorize ad hoc network environment into three main states: an ideal state, congested state, and energy critical state. In order to adapt to the current state of the network, we have proposed a routing protocol ANSAR that is aware of the network states and utilizes combined state metrics. The simulation results show that ANSAR has some advantages to other related routing protocols for energy-constrained mobile ad hoc networks.

However, we made some assumptions for ANSAR. So, ANSAR may not be the most optimizing solution to the various states of ad hoc networks. Moreover, the energy threshold used to determine the state of a network is selected by our experimentation without precise optimization from mathematics. And using of the energy threshold alone to determine the state of an ad hoc network may not be sufficient. How to find a more effective metric to estimate the state is still a problem needs to be solved. In the near future, we will commence on the mathematic modeling of this problem, and eager to find a optimizing solution based on mathematic analyzing and experiments.

ACKNOWLEDGMENT

The authors would like to thank the editors and anonymous reviewers for their valuable comments.

REFERENCES

[1] S. Corson and J. Macker. "Mobile Ad hoc Networking (MANET): Routing Protocol Performance Issues and Evaluation Considerations," IETF RFC2501, Jan. 1999

[2] Perkins CE, Bhagwat P. "Highly dynamic destination-sequenced distance-vector routing (DSDV) for mobile computers," Proceedings of SIGCOMM'94. New York: ACM Press, 1994. pp. 234-244.

[3] C. Perkins, E. Belding-Royer, S. Das. "Ad hoc On-Demand Distance Vector (AODV) Routing," IETF RFC3561, July 2003

[4] David B. Johnson, David A. Maltz, Yih-Chun Hu. "The Dynamic Source Routing Protocol for Mobile Ad Hoc Networks (DSR)," IETF Draft, July 2004

[5] Murthy S, Barcia-Luna-Aceves JJ. "An efficient routing protocol for wireless networks," ACM Mobile Networks and Applications Journal, Specail issue on Routing in Mobile Communication Networks, 1996,1(2):183-193.

[6] S. Lee and M. Gerla, "DLAR: Dynamic load aware routing in ad hoc networks," In: Proceedings of IEEE International Conference on Communications 2001(ICC 2001), Helsinki, Finland. June 2001.

[7] K. Wu and J. Harms. "Load-sensitive routing for mobile ad hoc networks," In: Proceedings of 10th IEEE International Conference on Computer Communications and Networks (ICCCN 2001), Phoenix, Arizona. October 2001. pp. 540-546.

[8] H. Hassanein and A. Zhou, "LBAR: Routing with load balancing in wireless ad hoc networks," In: Proceedings of the Fourth ACM International Workshop on Modeling, Analysis and Simulation of Wireless and Mobile Systems(MSWiM 2001), Rome, Italy. July 21 2001. pp.89-96.

[9] H. Hassanein and A. Zhou. "Load-aware destination-controlled routing for MANETs," Elservier Computer Communications, Vol. 26, Issue 14, September 2003. pp. 1551-1559(9).

[10] A. Argyriou and V. Madisetti. "Realizing Load-Balancing in Ad hoc Network with a Transport layer protocol," In: Proceedings of IEEE Wireless Communications and Networking Conference 2004(WCNC 2004), 1897-1902. Atlanta, USA. March, 2004.

[11] J.-H Chang and L. Tassiulas, "Energy conserving routing in wireless ad-hoc networks," In: Proceedings of IEEE INFOCOM 2000, Tel-Aviv, Israel, March 2000. pp. 22-31.

[12] I. Stojmenovic and X. Lin, "Power-aware localized routing in wireless networks," In: Proceedings of the IEEE International Parallel and Distributed Processing Symposium 2000, Cancun, Mexico. May 2000. pp. 371-376.

[13] C.-K. Toh, "Maximum Battery Life Routing to Support Ubiquitous Mobile Computing in Wireless Ad Hoc Networks," IEEE Communications Magazine, June 2001.

[14] M. Carvalho, C. Margi, et,al. "Modeling Energy Consumption in Single-Hop IEEE 802.11 Ad Hoc Networks," Thirteenth International Conference On Computer Communications And Networks(ICCCN 2004), Chicago, USA. October 2004.

[15] NS-2, http://www.isi.edu/nsnam/ns/