

# A High Survivability Route Selection Method in Wireless Ad Hoc Networks

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**Abstract**—Energy limitation is a critical issue in wireless ad hoc networks. Researchers have developed some power-aware mechanisms in routing area to prolong the lifetime of connections in networks. The existed power-aware routing protocols often use residual energy, transmission power, or link distance as the metrics to select an optimal path. The investigation in this paper indicates that these route selections will cause rapid energy exhaustion in parts of the network, thus degrade the survivability of whole network. To average the energy consumption over the network with higher energy efficiency, a novel route selection mechanism, based on novel metrics, the relay capacity and the relay efficiency, is proposed. Simulation results show that this method saves energy with significantly more robust connectivity.

**Keywords**- ad hoc network, route selection

## I. INTRODUCTION

With the rapidly increasing drive for wireless-capability of portable devices, a lot of research has been done in wireless network technologies. To provide more flexibility and convenience than traditional infrastructure networks, wireless ad hoc networks are being developed and under examination by industries and academics. In wireless ad hoc networks, various communication devices may form a temporary wireless network that has neither fixed infrastructure nor any centralized administration. These devices are not only the means of data interchanging but also the managers for the routes to data and access to services [1].

Prolonging network lifetime is one of the critical issues in wireless ad hoc networks, widely discussed in the literature, due to the limited energy stored in battery operated mobile equipments. To improve the link survivability and the stability of the topology through power saving, research has been done in each aspect of ad hoc network communications, such as routing protocols in network layer, and media access schemes in MAC layer. Current MAC designs for power saving in wireless ad hoc networks mainly concentrate on using various methods to put the communication unit of a node to sleep and minimize the time in transmission, reception and idle states [2-4], or to avoid overhearing neighbouring nodes [5]. Power-aware routing is another central means to make the connections more reliable and long lived. Generally, there will be many possible communication paths between source and destination node. Most of the proposed protocols try to find the minimum energy path to

improve the energy usage of a node. An optimal route is always determined by the relay cost,  $C_{(i,j)}$ , which is calculated by total transmission power [6], path distance [7-8], or residual battery energy [9]. Normally, the cost of a path is the sum of the cost of its links,  $C_{Path} = \sum_{(i,j) \in Path} C_{(i,j)}$ . However,

this is not a best choice from the sense of survivability of an entire network. Frequently selecting a low energy path will easily lead to energy exhaustion of the nodes along the selected path, thus resulting in network partition and topology instability [10].

In this paper, the focus is on a route selection method with novel metrics to increase path survivability of wireless ad hoc networks. The proposed novel metrics result in stable network connectivity and less additional route discovery operations. Comparing against other proposed routing metrics and selection methods, the simulation results show that the proposed metrics and route selection mechanism can support continuous services with high power efficiency.

The rest of this paper is organized as follows. Section 2 reviews the existed metrics and ad hoc route selection methods. In section 3, a novel metric, named relay capacity (RC) is formulated. Then, a new route selection method, named conditional maximum relay capacity route selection (CMRCRS), which is based on RC and the constraint metric, relay efficiency (RE), is introduced in detail. The simulation model and the results, comparing against other route selection methods, are presented and discussed in section 4. Finally, conclusions can be found in section 5.

## II. BACKGROUND

According to the triggering mechanism and the style of route discovery, existing routing protocols can be divided into two categories, proactive routing, and reactive routing protocols [1, 11-12]. When using proactive routing, each node periodically exchanges route information, and maintains a routing table, which covers all paths. Each node can use a route extracted from its routing table immediately, thus minimising latency. However, proactive routing does not scale well to the highly dynamic topology, as periodic routing maintenance becomes expensive. In wireless ad hoc networks, another drawback is that a portable device may not afford storage space and extra energy to maintain a large routing table. Reactive routing protocols do not need to maintain information on the whole topology in each node. They try to discover routes when a node needs to transmit data packets. The discovered routes are only part of the

whole topology. Reactive routing protocols save resources and can adapt to sudden topology change [12]. The drawback of reactive protocols is a bigger latency than proactive routing protocols. However, as end-to-end delay performance is not primary consideration in wireless ad hoc networks, reactive routing protocols are more attractive than proactive routing protocols.

When some alternative paths with same source and destination are co-existed in a wireless ad hoc network, routing metrics are important for the route selection mechanism. Depending on the type of metric, power-aware route selection methods can be classified into three categories, maximum residual energy (MRE) [13-14], minimum transmission power (MTP) [6-7], and hybrid type [15].

A typical MRE route selection adopts the reciprocal of the residual battery energy of a node as the relay cost for routing, which can be described as:

$$f_{\text{cost}}|_i = 1/E_i(t) \quad (1)$$

where  $E_i(t)$  is the residual battery energy of a node  $i$  at time  $t$ . Then the route cost,  $R_{\text{cost}}(r_j)$ , is defined as the maximum value  $f_{\text{cost}}|_i$  along the route,  $r_j$ . The optimal route  $r_{\text{opt}}$  satisfies the following equation:

$$R_{\text{cost}}(r_{\text{opt}}) = \min_{\forall r_j \in r^*} R(r_j) \quad (2)$$

where  $r^*$  is the set of all possible routes with the same source and destination node. This route selection method avoids using paths, with a link that will become energy-exhausted. The drawback of this selection method is that the nodes with higher residual energy will have higher probability of supporting data-relay tasks, so these nodes will face high actual energy consumption, which may induce unstable connectivity. On the other hand, the so-called optimal route is not the route with better energy efficiency.

The transmission power over the hop ( $n_i, n_{i+1}$ ) is proportional to  $d^\lambda(i, i+1)$ , where  $d(i, i+1)$  is the distance between node  $n_i$  and  $n_{i+1}$ , and  $\lambda$  is the constant between 2 and 4 [16]. Essentially, the shortest distance routing [15, 18] protocol, in which the location information is used to select an optimal path, can be classified in the MTP category. For instance, authors in [6] proposes a typical MTP protocol, in which the relay cost of the route,  $r_j$ , is defined as following:

$$R_{\text{cost}}(r_j) = \sum_{i=0}^{d-1} T(n_i, n_{i+1}) \quad (3)$$

where  $T(n_i, n_{i+1})$  is the transmission power over the hop ( $n_i, n_{i+1}$ ),  $n_0$  is the source node, and  $n_d$  is the destination node.

The optimal route,  $r_{\text{opt}}$ , is selected based on the condition:

$$R_{\text{cost}}(r_{\text{opt}}) = \min_{\forall r_j \in r^*} R_{\text{cost}}(r_j) \quad (4)$$

Using the link distance or the transmission power as the routing metric can improve the quality of the receiving signal. However, to save energy, an accurate transmission power control mechanism should be applied, which will introduce redundant computation. Moreover, it is impractical for normal portable devices to obtain an accurate value of the distance. On the other hand, the nodes with short link distance will face more traffic load.

A hybrid scheme, which integrates the residual-energy metric and the transmission-power metric, was proposed by C.-K. Toh [15]. In this mechanism, a set of routes  $r^{**}$  was selected firstly by the MRE with the condition:  $R_{\text{cost}}(r_j) \leq R_{th}$ , where  $R_{th}$  is the threshold of the route cost. Then MTP is applied to the  $r^{**}$  to find an optimal route,  $r_{\text{opt}}$ . However, the performance of this mechanism depends on the uncontrollable value  $R_{th}$  and  $d(i, i+1)$ . Otherwise, like forenamed methods, more traffic load will put on the node with higher residual battery energy or short link distance.

### III. A NEW ROUTE SELECTION METHOD IN WIRELESS AD HOC NETWORKS

In wireless ad hoc networks, the connections are easily broken due to the energy exhaustion. As discussed in the last session, some existing route selection methods will result in higher energy consumption in parts of the network, which shortens the time to network partitioning. In this session, some metrics and the corresponding route selection method are proposed to make the nodes expend energy more equitably and efficiently.

The proposed metrics has the following desirable characteristics:

- It averages the energy consumption across a whole network, thus postponing the time to network partition, and improving the survivability of the paths, therefore avoids unnecessary energy wastage through frequent route re-discovery.
- The energy efficiency is also considered into the route selection through using the constrained condition, relay efficiency.
- The nodes do not need to know their locations for routing.

### A. A Novel Metric and Its Constrained Condition

In this session, a novel metric RC, which is constrained by relay efficiency (RE), is formulated to specify the node's capability to transmit and its energy efficiency.

Firstly, the lifetime of the node  $i$ ,  $L_i$ , is defined as:

$$L_i = E_i(t) / \overline{R_i(t)} \quad (5)$$

where  $E_i(t)$  is the node's residual energy.

$R_i(t) = \frac{\partial E_i(t)}{\partial t}$  is defined to indicate how much energy is used per second at node  $i$ .

To avoid rapid changes in  $R_i(t)$ , and obtain the average trend, an  $\alpha$  low-pass filter is applied to  $R_i(t)$ , to give:

$$\overline{R_i(t)} = \alpha \cdot R_i(t-T) + (1-\alpha) \cdot R_i(t) \quad (6)$$

where  $T$  is the sample period of  $R_i(t)$ .  $\alpha$  and  $T$  have to be chosen carefully to accurately reflect the energy-consumption trend of a node.

The transmission capability of a resource-limited node relates to not only the residual energy but also the data rate. When the nodes support multi-rates, the data rate should be considered in the routing metric to exactly reflect the traffic capacity that a node can support. So the relay capacity of a node,  $RC_i$ , can be described as:

$$RC_i = L_i D_i \quad (7)$$

where  $D_i$  is the current data rate of the node  $i$ . The unit of  $RC_i$  is the bit.

Another important parameter to denote the node energy feature is  $RE_i$ , which describes the efficiency of the energy consumption in node  $i$ .  $RE_i$  is specified as:

$$RE_i = D_i / \overline{R_i(t)} \quad (8)$$

The unit of  $RE_i$  is bits/Joule. It can be used as a constraint condition to select a more energy efficient path.

### B. Details of the CMRCRS

The new conditional maximum relay capacity route selection (CMRCRS) mechanism is based on  $RC_i$  and  $RE_i$ .

In CMRCRS, the relay-efficiency function of the route  $r_j$  is defined by the equation:

$$\eta(r_j) = \min_{\forall n_i \in r_j} RE_i \quad (r_j \in r^*) \quad (9)$$

where  $r^*$  is the set of all possible routes with the same source node  $n_0$  and the destination node  $n_d$ .  $n_i$  is one of the nodes in route  $r_j$ .

The allowable worst-case value of the  $RE_i$  is defined by  $Th_{RE}$ . When the RE of a node is less than  $Th_{RE}$ , it means that this node has low energy efficiency, and will expend more energy on a packet exchange. For example, when a node increases its transmission power to overcome interference, or is bearing more relay tasks, this node will suffer poor energy efficiency. In this case, the route selection method should avoid loading more relay tasks onto such nodes. So the route set,  $r^{**}$  is selected by the condition:

$$\eta(r_j) \geq Th_{RE} \quad (\forall r_j \in r^{**} \in r^*) \quad (10)$$

Moreover, the relay-capacity function of the route  $r_j$  is:

$$\phi(r_j) = \min_{\forall n_i \in r_j} RC_i \quad (\forall r_j \in r^{**} \in r^*) \quad (11)$$

The optimal route  $r_{opt}$  is the one, which satisfies the following condition:

$$\phi(r_{opt}) = \max_{\forall r_j \in r^{**}} \phi(r_j) \quad (12)$$

If  $r^{**} = \emptyset$ , then select the route, which satisfies the condition:

$$\phi(r_{opt}) = \max_{\forall r_j \in r^*} \phi(r_j) \quad (13)$$

## IV. SIMULATION

### A. Simulation Configuration

An 40-node wireless ad hoc network simulation environment in Network Simulator 2 (NS2) [18] was developed to compare the performance of CMRCRS against MRE and MTP. The nodes are randomly located in a  $600m \times 600m$  area.

The energy consumption is estimated by the "first order radio" model discussed in [16]. This energy model can be described as follows:

$$E_{i\_tx} = E_{tx} \times P_{tx} + \varepsilon_{amp} \times P_{tx} \times d_{i-j}^2 \quad (\text{Joules}) \quad (14)$$

$$E_{i\_rx} = E_{rx} \times P_{rx}$$

where  $E_{i\_tx}$  is the energy consumed in transmission, and  $E_{i\_rx}$  the energy consumed in reception for node  $i$ .  $E_{tx}$  and  $E_{rx}$  are the radio transmitter and receiver operation energy dissipation per bit. We assume the node has some form of power control to achieve an acceptable signal-to-noise ratio.  $\varepsilon_{amp}$  is set to obtain the desired signal strength for transmissions to  $j$ .  $P_{tx}$

and  $P_{rx}$  is the transmitted packet size and the received packet size.  $d_{i,j}$  is the distance between the source node  $i$  and the destination node  $j$ . In the simulation,  $E_{tx}=E_{rx}=50nJ/bit$ ,  $E_{amp}=100nJ/bit/m^2$ . Each node is given an initial energy, calculated from a uniform probability distribution function (PDF) with the range [1500J,2000J].

Since the goal of our simulation is to compare the performance of route selection methods, not whole routing protocols, we simply modify dynamic source routing (DSR) [11], a typical reactive routing method, to act as the underlying route discovery and maintenance protocol. Figure 1 shows the modified procedure of the route discovery. The source node broadcasts the route request packets (RRP) to find all the possible routes. The neighbour nodes, B and F, receive RRP, and record their own node information, including the node relay capacity, node relay efficiency and other features, into the RRP and relay this to their neighbours. The destination node E will receive two distinct RRP, in which the whole routing information is recorded. Finally, node E uses the route selection method to choose the optimal route and replies with a route ACK packet (RACKP), in which the selected route information is enclosed, following the reverse direction of the selected route to the source node A. Then the source node uses this route, indicated in the RACKP, to send the data packets to E.

The CSMA/CA strategy is used for MAC layer. The relay-efficiency threshold,  $Th_{RE}$ , is set to  $2kbits/Joule$ , T is 2s, and  $\alpha$  is 0.25. The data rate is fixed at  $2Mbits/s$ .

### B. Simulation Results

#### 1) Energy consumption distribution over the network:

Fig. 2 shows the total energy consumption during one-hour period of the network with MRE route selection method. This result is compared against the energy cost with MPT route selection mechanism (fig. 3) and CMRCRS (fig. 4). The energy cost is normalized by the maximum value of the consumption. The warm colour area means much more energy was consumed. Using MRE or MPT, the energy consumption is concentrated in small parts of the network. The reason for this phenomenon is that more traffic was put

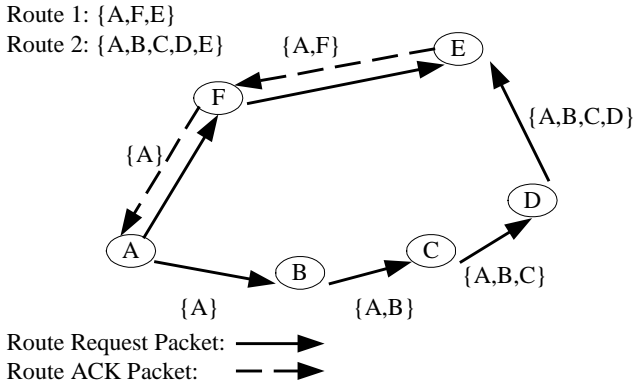


Figure 1. The procedure of the route discovery

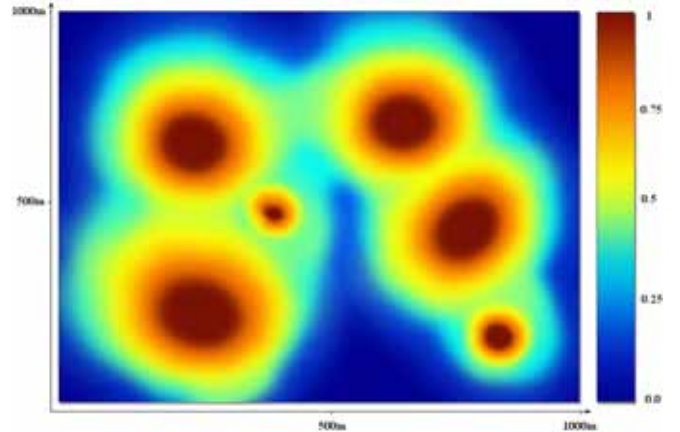


Figure 2. Normalized energy consumption in MRE

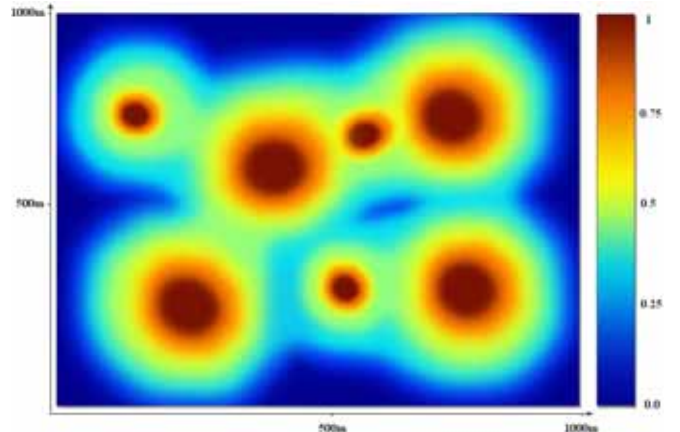


Figure 3. Normalized energy consumption in MPT

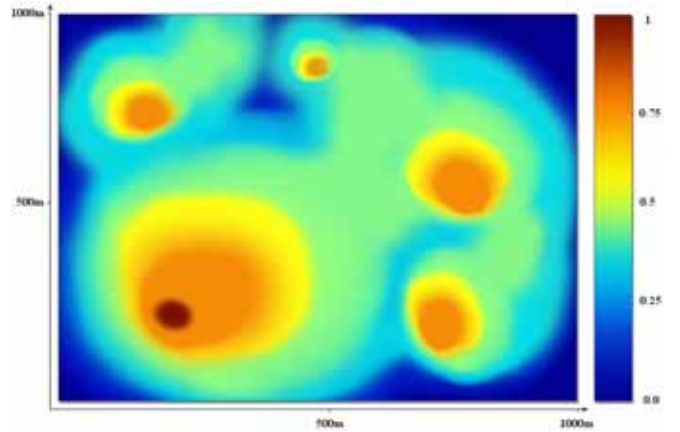


Figure 4. Normalized energy consumption in CMRCRS

into the nodes with higher residual energy or shorter link distances. These nodes will face higher energy consumption, thus become readily exhausted, which will induce the network partitioning. After a period, many nodes will lost intermediate nodes for relaying their packets. So the survivability of a whole network will be degraded. In fig. 4, though most of the network area faces a 50% normalized

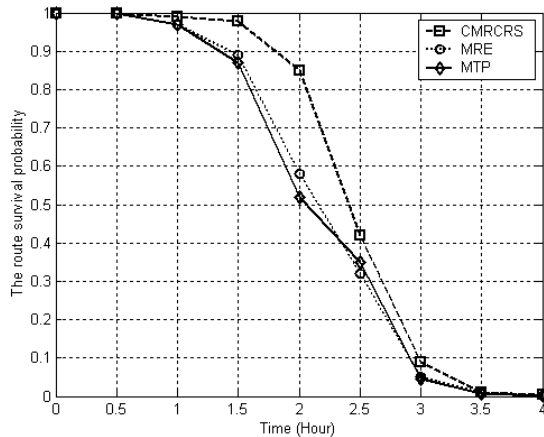


Figure 5. The route survival probability

energy consumption, the CMRCRS equalizes the energy use over the entire network. That means most of the nodes will maintain residual energy at an average level. So the lifetime of paths can be extended.

### 2) Route survival probability:

To describe the characteristic of the network survivability under different route selection methods, a statistical value, named the route survival probability (RSP), was calculated in the simulation. After each half-hour period, the sum of survival paths,  $N_{surv}$ , is computed. Then the RSP can be expressed by  $N_{surv}/N_{total}$ . If the route is broken, a new route discovery operation must be executed to finish the data exchange, or the transmission should be abandoned, thus energy will be wasted. So the RSP means not only robustness of connection, but also energy efficiency. This is plot for each routing selection method in fig. 5. The CMRCRS evidently increases the RSP, since it prolongs the time to network partitioning.

### 3) Average residual energy:

The average residual energy,  $E_{ARE}$ , can be expressed as:

$$E_{NARE}(t) = \frac{1}{N} \sum_{i=0}^{N-1} E_i(t) \quad (14)$$

where N is the number of nodes in the simulation scenario.

The  $E_{ARE}$  of the simulation is plot in fig. 6, which shows that the CMRCRS can prolong the nodes' lifetime. For instance, the nodes employing CMRCRS maintain energy above a 30% level for 1 hour longer than other nodes. The reason is that this mechanism decreases the time spent on route discovery and selects the path with lower energy consumption.

## V. CONCLUSIONS

Since energy limitation is one of the critical problems in wireless ad hoc networks, many researchers are developing methods to improve the lifetime of the paths. Routing is a

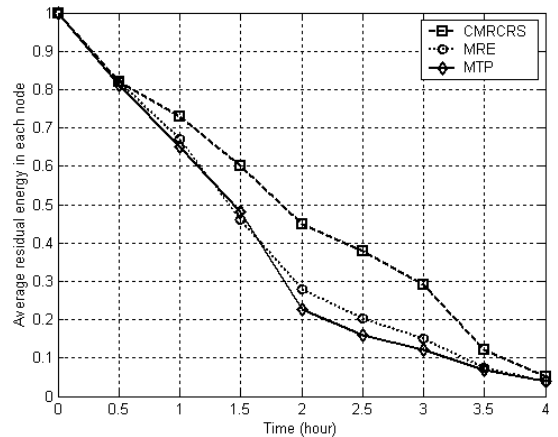


Figure 6. The average residual energy in each node

primary way to tackle the network survivability issue. A number of routing protocols use residual energy, transmission power, or link distance to decide the optimal route among the multiple paths between the source node and the destination node. The simulations in this paper show that using these metrics may result in network partitioning, and unnecessary energy wastage by frequent route discovery operations. To improve the survivability of an entire network, some new metrics are formulated in this paper. Based on these metrics, a novel route selection method, named CMRCRS, is described in detail. The simulation results show that this method can equalize the energy consumption across the whole network, decrease the probability of network partitioning, and improve the lifetime of the routes with higher energy efficiency.

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