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An Efficient Hop Count Routing Protocol for Wireless Ad Hoc Networks

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Abstract: An efficient hop count route finding approach for mobile ad hoc network is presented in this paper. It is an adaptive routing protocol that has a tradeoff between transmission power and hop count for wireless ad hoc networks. During the route finding process, the node can dynamically assign transmission power to nodes along the route. The node who has received route request message compares its power with the threshold power value, and then selects a reasonable route according to discriminating algorithms. This algorithm is an effective solution scheme to wireless ad hoc networks through reasonably selected path to reduce network consumption. Simulation results indicate that the proposed protocol can deliver better performances with respect to energy consumption and end-to-end delay.

Keywords: Wireless ad hoc networks, routing protocol, hop count, threshold, transmission power.

1 Introduction

In terms of wireless ad hoc networks, resources such as bandwidth, power, computing ability for nodes are limited by the environments and hardware. Furthermore, the varied wireless networks with different properties such as coverage, power and communication protocols make it difficult to establish and maintain the communications through the multiple intermediate nodes which are mobile devices. Transmission range of nodes will change over time in real wireless networks. In recent years, mobile ad hoc networks (MANETs) become an important research point in the wireless network field. In such networks, there is no regular infrastructure such as base stations or mobile switching centers, each node only has a limited radio propagation distance, limited power of battery, and nodes can move freely. Due to these characteristics in MANETs, routing protocols designing is a major challenge for mobile ad hoc networks. International engineering task force (IETF) has organized a wireless ad hoc networks working group to standardize routing protocols in wireless ad hoc networks. Mobile ad hoc networks are appropriate for mobile applications either in hostile environments where no infrastructure is available, or temporarily established mobile applications which are cost crucial[1]. In recent years, application domains of mobile ad hoc networks gain more and more importance in non-military public organizations and in commercial and industrial areas. The typical application scenarios include the rescue missions, the law enforcement operations, the cooperating industrial robots, the traffic management, and the educational operations in campus.

The existing variation in power levels in deployed wireless network cards strongly indicates that link asymmetry due to heterogeneity in power levels will occur commonly in ad hoc networks, and other types of heterogeneity such as computation power, storage space, and battery resource may occur across the nodes. In [2], Le et al. focus on link heterogeneity caused by variation in transmission power levels. Although the hop count shift problem can be eliminated if all nodes know their Cartesian coordinates through their respective GPS unit[3], equipping each node with a GPS is expensive. Many protocols are designed without the assumption of knowing the exact locations but based on hop count only. In fact, a lot of protocol designs do not consider the assumption to know the specific location, but simply are based on the number of hops. The Euclidean distance can be estimated if a node knows its distance in hop count from an anchor node. The hop count information has been widely used in the design of many network protocols, e.g., the DV-hop node localization protocol in [4], wireless sensor network localization algorithm based on geometry[5], hop ID greedy routing algorithm[6], routing protocol for heterogeneous wireless ad hoc networks[2, 7].

This paper presents an efficient route search approach for mobile ad hoc network. According to the discriminating algorithm, node will determine whether to forward packets or not. More nodes can communicate with each other through broadcasting node sending out multiple copies of the hop message. It is desirable that the routing protocol can assign transmission power to nodes such that the total overhead can be reduced.

The rest of the paper is organized as follows. In Section 2, we give an overview of the related works. In Section 3, we present the proposed protocol in this paper. Simulation results are presented and analyzed in Section 4. Finally, conclusions are discussed in Section 5.

2 Related works

Several algorithms have been proposed so far to obtain efficient routing over MANET. This section describes the research background of this article.

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Yang et al.[8] focus on developing a localization algorithm which provides both low-cost and accuracy. They have made a key assumption that the ratio of the Euclidean distance between a node and two anchor nodes is well approximated by the ratio of the corresponding hop distances. The hop-count-ratio based localization (HCRL) algorithm satisfies low-cost with a single flooding from a small number of anchor nodes, and subdivides one-hop into several sub-hops by transmission power control to improve localization accuracy. Zhao et al.[9] have designed efficient routing schemes for mobile ad hoc networks of various densities, topologies and obstacles. They proposed a new hop ID routing scheme, which is a virtual coordinate-based routing protocol and does not require any location information. Each node maintains a hop ID, which is a multidimensional coordinate based on the distance to some landmark nodes. It is insensitive to obstacles and voids and can be used in a wide variety of ad hoc environments. The authors proposed the hop distance based waving and routing protocol (WMC) in [10]. The density of the wireless sensor network (WSN) will affect the grouping structure. With increasing node density, the result of grouping would approach perfect circular strips if the channel fading and noise components in the network are homogeneous. The group ID can be used to estimate the hop distance from the node to the sink, and the packet forwarding can be guided towards the sink without precise location information.

In [11], authors proposed a protocol called "delay, jitter, bandwidth, cost, power and hop count constraints routing protocol with mobility prediction for mobile ad hoc network using self healing and optimizing routing technique (QPHMP-SHORT)". It is a multiple constraints routing protocol with self healing technique for route discovery to select a best routing path among multiple paths between a source and a destination to increase packet delivery ratio, reliability and efficiency of mobile communication. It considers the cost incurred in channel acquisition and the incremental cost proportional to the size of the packet. It collects the residual battery power of each node in each path, and selects multiple paths, which have nodes with good battery power for transmission to satisfy the power constraint. The contribution of [12] is a simulation based analysis of the network connectivity, hop count and lifetime of the routes determined for mobile ad hoc networks using the Gauss-Markov mobility model. The random waypoint mobility model is used as a benchmark in the simulation studies. Two kinds of routes are determined: routes with the longest lifetime (stable paths) and routes with the minimum hop count. In low-density network scenarios, the authors observe that the network connectivity under the Gauss-Markov model is significantly lower than that obtained under the random waypoint model. In moderate and high-density network scenarios, the network connectivity obtained under the two mobility models is almost equal. In [13], authors propose a new ad hoc on-demand distance vector routing (AODV) mechanism based on max hop count, adding an intelligent and real-time estimation function to original AODV protocol to get the information of the max hop of the networks. The dynamic-adjusting AODV (DA-AODV) based on max hop count first calculates the value of max hop of the networks and then intelligently and dynamically adjusts its parameters based on the value of max hop to enhance the network performance. The packet drop probability and the delay analysis have been discussed in [14]. Some routing algorithms[15−17] have been proposed for wireless networks. Authors propose a partially interconnected mesh network topology and a routing scheme for network on chip (NoC) topology[15]. An efficient multi-hop MCROB protocol for highway VANET is shown in [16], it adopts the concept of opportunistic routing.

3 Proposed hop-based routing protocol

3.1 Routing mechanisms for ad hoc networks

Routing is based on addresses that are unique in the network. The source node specifies the destination address, and the network routing service returns a route that contains multiple intermediate nodes between the source and the destination. Packets are routed through the intermediate nodes and every node forwards the packets according to the destination address. The routers in an MANET simply forward the data packet without checking its content. However, unlike traditional internet where computers and routers are separate and the network topology and hierarchy are static, in an MANET every computer is also a router and there is no static network topology or infrastructure. Although internet routing protocols also handle network topology changes, the changes are infrequent. In an MANET, the topology changes are so frequent that the traditional routing protocols may not even work. One of the biggest challenges in MANET routing is to design a proper routing protocol that handles node mobility and rapid topology change. During the past decade, numerous MANET routing protocols have been proposed, which fall into two broad classes: proactive and reactive. Proactive protocols compute routes between all nodes in the network in advance, whereas reactive protocols compute routes only when they are needed for communication.

The dynamic source routing protocol (DSR)[18, 19] is a simple and efficient routing protocol designed specifically for use in multi-hop wireless ad hoc networks of mobile nodes. DSR allows the network to be completely self-organizing and self-configuring without the need of any existing network infrastructure or administration. The protocol is consist of the two main mechanisms of "route discovery" and "route maintenance", which work together to allow nodes to discover and maintain routes to arbitrary destinations in the ad hoc network. Other advantages of the DSR protocol include easily guaranteed loop-free routing, operation in networks containing unidirectional links, use of only "soft state" in routing, and very rapid recovery when routes in the network change.

AODV is an on-demand routing protocol[20], every intermediate node decides where the routed packet should be forwarded next. Routing requests are generated at each hop by local broadcasting in case of path discovery. A simple flooding broadcast for route requests generates a considerable redundant packet overhead which is a major cause of inefficiency of MANET routing protocols. AODV discovers routes on an as needed basis via a similar route discovery process. However, AODV adopts a very different mechanism to maintain routing information. It uses traditional routing tables, one entry per destination. This can maintain multiple route cache entries for each destination. Without source routing, AODV relies on routing table entries to propagate an route reply (RREP) back to the source and subsequently, to route data packets to the destination. AODV uses sequence numbers maintained at each destination to determine freshness of routing information and to prevent routing loops. All routing packets carry these sequence numbers.

In on-demand protocols[21], nodes obtain routes on an as needed basis via a route discovery procedure. Route discovery works as follows. Whenever a traffic source needs a route to a destination, it initiates a route discovery by flooding a route request (RREQ) for the destination in the network and then waits for a route reply (RREP). When an intermediate node receives the first copy of RREQ packet, it sets up a reverse path to the source using the previous hop of the RREQ as the next hop on the reverse path. In addition, if there is a valid route available for the destination, it unicasts an RREP back to the source via the reverse path. Otherwise, it re-broadcasts the RREQ packet. Duplicate copies of the RREQ are immediately discarded upon reception at every node. Fig. 1 shows the discovery process of AODV routing protocol.

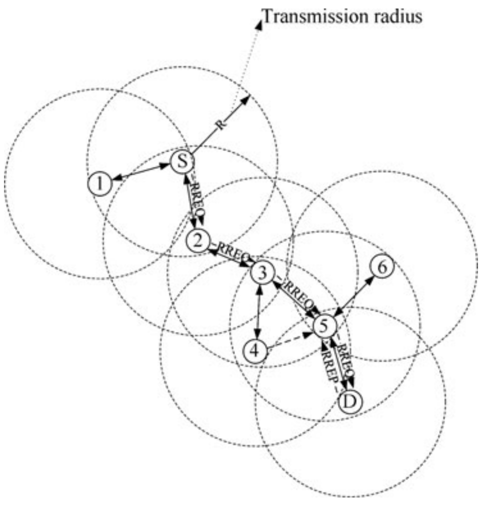

Fig. 1 Route discovery procedure

The destination on receiving the first copy of an RREQ packet forms a reverse path in the same way as the intermediate nodes. It also unicasts an RREP back to the source along the reverse path. As the RREP proceeds towards the source, it establishes a forward path to the destination at each hop. AODV also includes mechanisms for erasing broken routes following a link failure, and for expiring old and unused routes.

The main difference between DSR and AODV is the source routing feature. The DSR is based on source routing in which all the routing information is maintained at mobile nodes. DSR is truly based on source routing whereby all the routing information is maintained and updated at mobile nodes. All aspects of the protocol operate entirely on demand, allowing the routing packet overhead of DSR[19] to scale automatically to only what is needed to react to changes in the routes currently in use. The AODV uses a combination of a DSR and DSDV mechanism. It uses the route discovery and route maintenance from a DSR and uses hop-by-hop routing, periodic advertisements, sequence numbers from DSDV. The AODV easily overcomes the counting to infinity and Bellman Ford problems, and it also provides quick convergence whenever the ad hoc network topology is altered.

3.2 Hop count problem in ad hoc networks

Most of assumptions consider that all the nodes in the network are homogeneous, so there are no asymmetric links. However, they completely ignore the extra capabilities of the heterogeneous nodes.

As in [3], we also do not consider the transmission collision problem, and packet loss is solely caused by the lossy radio channel due to the multiple-path effects. Like [22], we make a general yet reasonable assumption on packet reception rate (PRR).

Assumption 1. Given a fixed transmission power, the channel PRR between a pair of sender and receiver is a non-increasing function of their Euclidean distance.

The most commonly used log-normal radio model[22] satisfies the assumption. In this model, the received power P_r (in dB) at the receiver with a distance d to the sender is given by

$$P_r(d) = P_t - PL(d_0) - 10\alpha \log_{10} \frac{d}{d_0} + N_\sigma \tag{1}$$

where P_t is the output power of the transmitter, α is the path loss exponent, $PL(d_0)$ is the power attenuation for a reference distance d_0, and N_σ is a Gaussian random variable with mean 0 and standard deviation σ (to model the shadowing effect). Here $\alpha \in [2, 6]$, $\sigma \in [1, 4]$. PRR is modeled as a random variable and given by $P_r(P_r \geqslant \gamma)$, where γ is the required signal-to-noise ratio (SNR). We also adopt the method proposed by Hekmat and Mieghem[23, 24] to normalize $pij(d)$ of this log-normal channel model with respect to a nominal transmission range R as follows, where $pij(d)$ means the PRR between a pair of sender i and receiver j. A reception is always successful if $P_r \geqslant \gamma$. Let R denote the distance where $P_r = \gamma$ without the shadowing effect.

$$P_r = P_t(R) - PL(d_0) - 10\alpha \log_{10} \frac{R}{d_0} = \gamma. \tag{2}$$

So the probability of a successful reception with shadowing is given by

$$\begin{aligned}\Pr(P_r \geqslant \gamma) = \ & \Pr(-10\alpha \log_{10}(\frac{d}{R}) + N_\sigma \geqslant 0) = \\ & \frac{1}{\sqrt{2\pi}\sigma} \int_{10\alpha \log_{10}(\frac{d}{R})}^{\infty} \mathrm{e}^{-\frac{x^2}{2\sigma^2}} \mathrm{d}x.\end{aligned} \tag{3}$$

Fig. 2 shows for different values of δ, the link probability calculated by (3), where $\delta = \frac{\alpha}{\sigma}$.

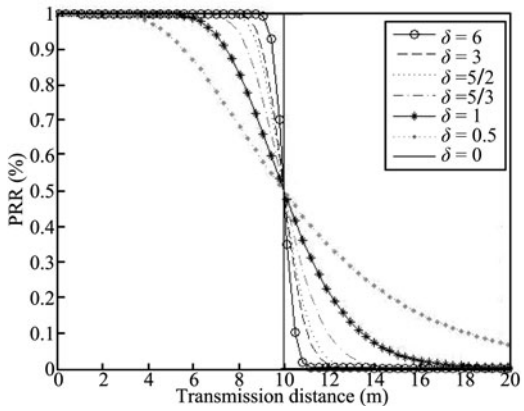

Fig. 2 PRR with log-normal shadowing radio model as function of the distance between two nodes

It is seen that the disk communication model is a special case of this log-normal channel model without shadowing. When the distance between two communicating nodes is larger than the transmission range of its ability, then the packet reception rate reduces rapidly.

3.3 Hop count optimized routing algorithm

As mentioned above, the wireless ad hoc networks may have nodes with different power. Their transmission range (the communications radius R) is not the same. Or due to the movement of nodes, it will lead to topology change between nodes, which further leads to the re-detect routing information, and results in increased system overhead and data latency issues. The proposed broadcast scheme in [3] is called consensus quota based broadcast strategy (CQBS). The approach of CQBS is to let a broadcasting node send out multiple copies of the hop message to increase the likelihood that only nodes with the Euclidean distance to the sender not larger than R need to update their hop count. The authors propose a tier-based routing framework (TRIF)[2] which tackles the asymmetric link problem while taking advantage of long-range transmissions by high-power nodes. We can find that these two methods are both reasonable solutions in wireless networks, they consider different ability of nodes in heterogeneous network. But the former method only considers that the two nodes′ Euclidean distance is smaller than the communication radius, which is based on the traditional ideal transmission range of programs. The latter method can be leveraged to compute the transmission power level over each link. Although it will reduce interference, it may also lead to all the data is mainly focused on the high-power nodes. Each link in Fig. 3 is representing the relation of transmission power and hop counts. We can see that the nodes with higher transmission power can reduce the total hop counts to establish the routes. And that is the reason why we are interested in this phenomenon.

In this paper, we will focus our attention on reactive protocols. Here we propose an efficient hop count routing protocol (EHCR) based on the number of hops. It is an on-demand routing protocol, which discovers routes only when there are packets needed to be sent to the destination. EHCR relies on periodic hello messages to allow nodes learn about neighbor′s information. It depends on the construction and maintenance of the hop count information. A source node initiates a route discovery and broadcasts the request packet between the source and destination. The route packet format is shown in Fig. 4, containing the IDs of the source and destination, a sequence number incremented each time the source sends out an RREQ.

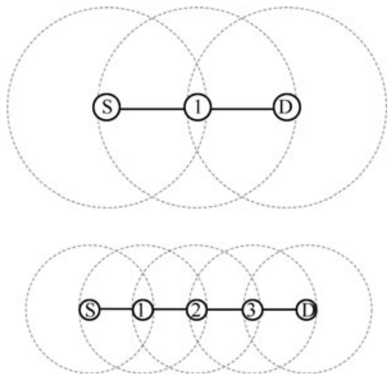

Fig. 3 Transmission power versus hop counts

Source	Destination	Sequence Number	Hop count	Power	Threshold

Fig. 4 Route packet format

The source ID and the sequence number uniquely identify a route request packet. When receiving RREQ packet, node i will discard the packet if it has seen it before. Otherwise, node i will record the previous hop information, and then rebroadcast the RREQ packet till it reach the destination node. The routing process mainly has the following steps:

1) Broadcasting node sends out multiple copies of the hop message.

2) The node receives the broadcast information, at the end of the receiving process, the nodes in the network will obtain the hop-count information through the broadcast packet.

3) Each node will make discrimination of hop count, and then determine which path will be chosen. We have set a power threshold ξ as in (4). When the power P_i is higher than ξ, it will select the minor hop count, which is node with higher power and shorter path. When the power P_i is lower than ξ, it will select the larger hop count, which is node with lower power and longer path.

$$h = \begin{cases} h_{\min} + 1, & P_i \geqslant \xi \\ h_{\max} + 1, & P_i \leqslant \xi. \end{cases} \tag{4}$$

4) If $h > h_i{+}1$, the node sets its own hop count to $h \leftarrow h_i{+}1$, and rebroadcasts a hop message with its new hop count. Otherwise, the node just ignores the message. The method can not only choose the shorter path to transmit data packets when it has sufficient energy, but also select a longer path to transmit data packets when the energy is not enough, which may cause increased latency, but can ensure connectivity and lifetime of the network at the same time.

4 Simulation and results

In this section, we compare the performance of our proposed EHCR protocol with the well-known traditional ad-hoc routing protocol AODV and DSR. We studied the performance of three protocols in the network simulator (NS2), the most used simulator for research on wireless ad hoc networks.

We choose three key performance metrics:

1) Packet delivery fraction: Ratio of the data packets delivered to the destination to those generated by the sources.

2) Normalized routing overhead: 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.

3) Average end-to-end delay of data packets: This includes all possible delays caused by buffering during route discovery, queuing delay at the interface, retransmission delays at the MAC, propagation and transfer times.

The mobility model uses the random waypoint model in a rectangular field. The field configurations used is: $1000\times1000\,\text{m}^2$ field with 100 nodes. The traffic sources used are constant bit rate (CBR). The source destination pairs are spread randomly over the network. Simulations are run for 1000 s. Here, each packet starts its journey from a random location to a random destination with a randomly chosen speed (uniformly distributed between 0–10 m/s). The simulation parameters are shown in Table 1.

Table 1 Simulation parameters

Parameters	Values
Simulation area	$1000\times1000\,\text{m}^2$
Traffic sources	Constant bit rate CBR
Packet size	512 bytes
Antenna type	Omni antenna
MAC protocol	802.11
Routing protocols	AODV, DSR & EHCR
Number of nodes	100
Speed of nodes	0–10 m/s
Simulation time	1000 s
Mobility model	Random waypoint

Fig. 5 shows the performance of the three protocols with different node speed. We change the node speed from 0 to 10. We can find that as the velocity increases to 10 m/s, the packet delivery fraction decreases rapidly in case of DSR whereas EHCR maintains at more than 80 % ratio. Thus with the increase in node velocity, EHCR gives more packet delivery fraction (PDF) thereby outperforming AODV. This is because the AODV and DSR protocols do not work well in the presence of hop count change links and do not take notice of the unidirectional links and they will repeatedly perform route discoveries. And after every route search fails, all packets buffered at the source are dropped. On the other hand, our EHCR protocol adaptive route mechanism, significantly reduces the number of packets dropped due to unpredictable link breaks.

Fig. 6 is the normalized overhead of the three protocols comparison, DSR and AODV protocol normalized routing overhead grows rapidly with the changes in the network topology, this is because the two routing needs to quickly initiate a new route discovery process when link fails, and therefore need to consume a large amount of routing overhead. DSR aggressively uses route caching. By virtue of source routing, it is possible to cache every overheard route without causing loops. So it will cause a lot of overhead. The normalized routing overhead (NRO) of EHCR is almost smaller than other two protocols. The worst performance of EHCR is still around 3. Our proposed protocol has the ability to use high-power nodes, which will not destroy the connectivity of the network due to node mobility. So the normalized overhead is smaller than AODV and DSR protocol.

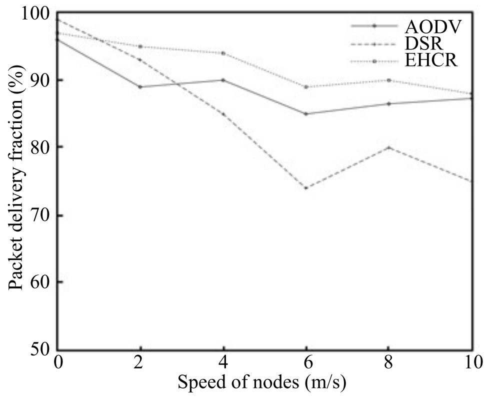

Fig. 5 Packet delivery fraction versus node speed

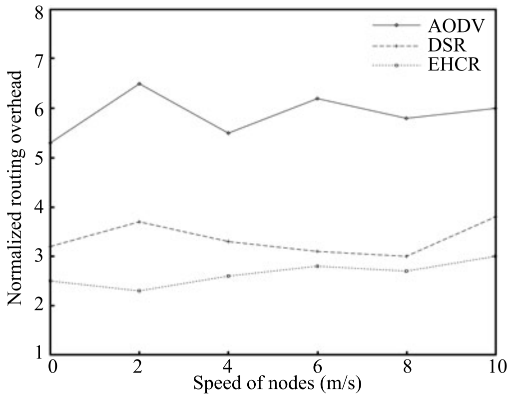

Fig. 6 Normalized routing overhead versus node speed

Fig. 7 shows the performance comparison of end-to-end average delay in the network. Under this condition, EHCR continues to outperform other protocols. This is obvious for the case of AODV and DSR, when the node moving speed is zero, performances of the three protocols are almost the same. And if the speed of node is faster than 2 m/s, we can find that the delay of EHCR almost does not change while delay of DSR increases obviously. Because EHCR utilizes a high power node to choose the shortest path to forward the data, this advantage continues to be maintained in the network when it changes to a dynamic network. And it can be seen that the performance of DSR is rapidly deteriorated, while the EHCR protocol remains to keep a lower average end-to-end delay than other two protocols.

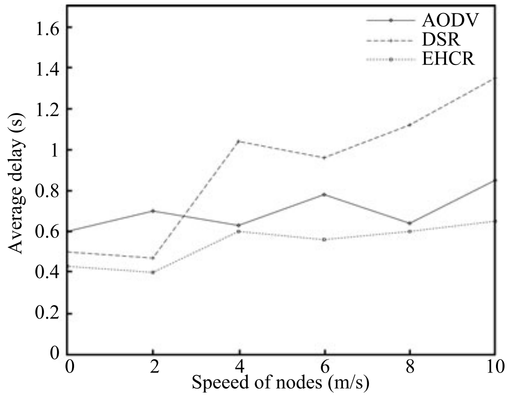

Fig. 7 Average end-to-end delay versus node speed

Finally, we did the simulations of the relationship between power costs and hop count, as shown in Fig. 8. We ran the simulations for 50 times, and the network topology is the same, and final power cost is averaged over these simulations. It can be seen that the average cost decreases when the hop counts increase. This is because with the lower transmission power and bigger hops, the total power consumption is reduced. If we select EHCR protocol, it can dynamically assign transmission power to nodes along the route, and the expected residual lifetime as well as hop count of a route are taken into account, so EHCR can maintain the network as long as possible.

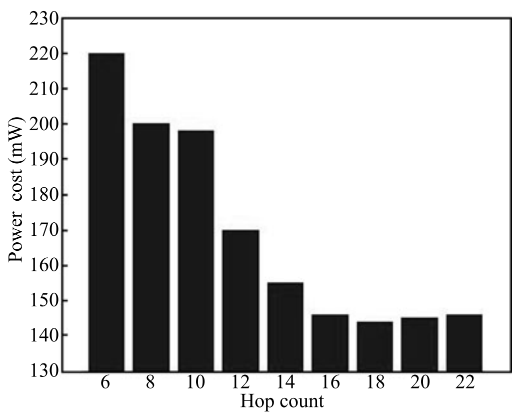

Fig. 8 Average power cost versus hop count

5 Conclusions

In this paper, we present the hop count problem in mobile ad hoc network, and propose an efficient hop count routing protocol on the basis of previous studies for mobile ad hoc network. We compare the performance of EHCR with existing protocols by using NS2. Simulation results show that the program can resolve the hop count problem and improve the network packet delivery ratio, reduce the network delay and overhead, and enhance the overall system performance of wireless ad hoc networks.

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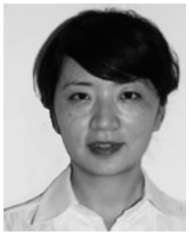

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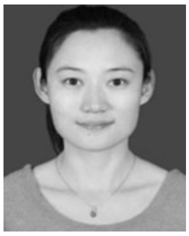

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