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一种移动Ad Hoc网络综合选路基准*

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Integrated Routing Metric for Mobile Ad Hoc Networks

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Abstract: Routing quality is affected by several factors altogether in mobile ad hoc networks (MANET). Most of current MANET routing protocols utilize hop count or other metric as their route creation criteria, which makes it hard to improve the overall protocol performance. This paper proposes an integrated routing metric which takes energy, communication interference, drop rate and mobility of a node (EIDM) into consideration. With an adaptive weight, this metric can adjust its stress on different items according to the network condition. Simulation results show that the EIDM does well in mitigating the hotspot effect.
Key words: drop rate; energy; interference; mobility; mobile ad hoc network

摘 要: 移动Ad hoc网络路由质量受到很多因素的影响.目前,多数移动Ad hoc网络路由协议利用单一跳数或其他基准作为路由产生的判据,使得协议整体性能的改善比较困难.提出一种考虑节点能量、通信干扰、丢失率和移动性(energy, interference, communication drop rate and mobility,简称EIDM)的综合选路基准.使用自适应权重,该基准能够根据网络状态调节各因子的作用.模拟实验结果显示,EIDM很好地减缓了热点效应.
关键词: 丢失率;能量;干扰;移动性;移动ad hoc网络
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1 Introduction

Mobile Ad hoc Networks (MANETs) are fully organized in a distributed mode, wherein nodes corporate with each other coequally as end host or intermediate relay to transmit, forward and receive packets. Independent of existing networking infrastructure like base stations, MANETs outperform their wired counterparts in disaster relief, battlefield communication and other tough areas. Despite their ability of self-configuration, fast deployment, topological flexibility and other advantages, MANETs still have a lot to suffer in terms of routing due to their nature

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characteristics. Mobile nodes which lay inside each other's communication radius make an active link. And consecutive active links bridge a routing path from the source node to the destination. Therefore, the node condition such as energy, communication interference, drop rate and mobility etc., to a considerable extent, decides the path quality. Mobility extends the communication coverage of each node, yet it also makes the network topology highly dynamic. Thus, when one mobile node becomes unreachable for its paired one the link breaks accordingly, which also makes all the paths enclosing this link temporarily (or even permanently) out of use. In some applications, energy is the precious resource for MANET hosts since recharge may be costly and time-consuming for these battery-driven units. Since both packets reception and forwarding cost energy, any intermediate relay node consumes energy, which may cause energy depletion. To make things worse, such exhausted nodes may kill all the routing paths that go through it. Wireless channels are shared by nodes in MANET, which means that there will be a fierce competition when too many nodes compete for data transmission at the same time. Without proper control some nodes may become overused while others are still at leisure. Besides this, since signals are transmitted through wireless radio, the normal data may be corrupted because of the hidden terminal problem and the node may fail to decode the needed signal correctly when the environmental interference is not trivial. Hotspot appears when data flows converge and intersect with each other. Nodes in such areas often consume more resources in a shorter time. It is a complex symptom caused by several factors mentioned above.

Many MANET routing protocols select the "optimal route" according to a single metric. For example, Dynamic Source Routing (DSR)[1] and Ad hoc On Demand Distance Vector (AODV)[2] pursue the shortest path in hop. However, in most cases, the path quality is affected by more than one factor. As discussed above, the node mobility, energy drainage etc. all contribute to degrade the routing performance. So it is reasonable to incorporate these affecting factors and form a complex routing criterion.

In this paper, we propose a novel routing metric EIDM, which takes into account the energy efficiency, surrounding interference, drop rate and the node mobility for evaluating node condition. With separate weight factors, EIDM can stress its focus on different sub-items adapting to real-time network condition automatically. Hotspot is a severe network symptom caused by several factors altogether. Also in this paper, we prove the validity of EIDM by mitigating hotspot.

The rest of this paper is organized as follows. Section 2 gives the related research and our previous work. Section 3 puts forward the EIDM, the experimental results are given in Section 4 and the final section concludes the paper.

2 Related Work

Current MANET routing protocols generally fall into two categories: proactive and reactive. The former asks each node to exchange messages periodically and maintain an up-to-date table about all possible paths towards the other nodes. So the path originator can easily seek a path towards the destination with no delay, which cuts down the end to end latency. However, such type of protocols cannot operate without central control and global information, and thus they do not seem so good for MANET environment. The reactive protocols operate in distributed mode and they establish routes on demand. Although more time is consumed in finding proper paths, yet global information is no longer a must. Nodes do not exchange messages for a global view of the network topology saving time and energy. However, most of the reactive protocols take one single metric as its sole path select criterion.

DSR and AODV are typical reactive protocols, and they both pursue the shortest path. Although this can cut down the end to end latency, it may cause traffic loads to concentrate at certain nodes because of unrestricted reply to route query from intermediate nodes. Signal Stability-based Adaptive routing (SSA)[3] always chooses the link with stronger signals to establish paths, but the mechanism to tell the wanted signal from the noise is needed. Reference [4] proposes a routing strategy based on power control, which tries to stretch the lifetime of the operational network. It incorporates the remaining energy level and the drain rate to construct a metric for optimal energy-efficient path. Reference [5] proposes an extension of AODV by considering the energy consumption as part of the routing metric. It chooses the optimal route that can reduce the node energy consumption. References [6,7] propose a routing metric named “leisure degree”, and a leisure node is picked by comparing the transmission condition based on transmision and reception rate. Leisure nodes are asked to replace overused ones for load-balancing. Reference [8] proposes a route maintenance mechanism Link Reliability-aware Route Maintenance (LRRM). Besides the number of forwarded and received packets, it also incorporates the node speed to evaluate node and link condition.

Hotspot[9] is a complex symptom resulting from several factors. In reactive routing protocols, nodes can react to any Route Request (RREQ) without considering its condition like congestion, energy level and so on. That can easily make the local node a convergence point in the future. Reference [10] defines hotspot as a transient but highly congested regions in wireless ad hoc networks that result in increased packets loss, end-to-end delay and out-of-order packets delivery. A node is declared as a hotspot if it suffers severely from Medium Access Control (MAC) delay, packet loss during the RTS-CTS-DATA-ACK cycle, buffer overflow and unreasonable energy drainage. And Ref.[10] proposes a Hotspot Mitigation Protocol (HMP) to solve this problem by suppressing the RREQ. Reference [11] proposes a routing metric Load_Energy Balance+Hotspot Mitigation (LEB+HM) which incorporates the power consumption and traffic load of each node for load balancing and hotspot mitigation. However, their algorithm forbids the intermediate nodes from replying any RREQ. This is overkill to mitigate hotspot and in some cases route cannot be established. Reference [12] proposes an efficient heuristic gossiping mechanism for ad hoc routing. This algorithm restricts the node to answer RREQ with a certain probability which is proportional to its energy level and local neighbor number.

3 EIDM

In this section, we’ll give the detail of EIDM to find an optimal path between the source node and the destination node. Firstly, the node credit, which evaluates the condition of the intermediate node, is given as follows. It is determined by the node energy, communication interference, drop rate and mobility.

3.1 Node credit

3.1.1 Energy

The major task of intermediate node is to forward packets from the source node towards the destination, and the overall traffic in MAC layer for an intermediate node can be formulized as

$$T_{mac} = N_t + N_r + N_f + N_o \tag{1}$$

where N_r, N_f, and N_o stand for the number of packets that has been received, transmitted and overheard by the local node. And N_t is the number of packets originated from the local node itself. Apparently, the local node is also a path originator when $N_t \neq 0$. The overheard packets are discarded and the received packets will go to the queue of the local node waiting to be forwarded.

To handle all these packets, an intermediate node should pay for such energy consumption as is shown in Eq.(2):

$$E_{cost} = (N_t + N_f) \times E_t + N_r \times E_r + \sum_{i=1}^{N_o} E_{o_i} \tag{2}$$

here, E_t and E_r stand for the energy threshold to transmit and receive a packet. As for overheard packets, they are not for the local node or the signal is too low for recognition. E_{o_i} is the sensed energy of the *i*th overheard packet.

If the initial energy of a node is E_{total}, then the residual energy for the local node is

$$E_{res} = E_{total} - E_{cost} \tag{3}$$

In Ref.[8], the relation between N_f and N_r can work as a sign of congestion: when N_f=N_r, the node enjoys an empty buffer and can proceed to receive more incoming packets given enough residual energy, and thus we consider it is in a leisure status; On condition that N_f is less than N_r, it follows that there are queued packets pending for future transmission. In such cases, node may fall in congestion when it fails to handle these queued packets while there are still continuous incoming data.

Consider such a situation: when E_{res}=E_r and N_r>N_f, which means the local node can receive only one more packet while there are still pending packet waiting for transmission in its queue. The node will certainly fail to handle all these packets if it spends the remaining energy inreceiving packets.

So we put forward a cautious energy baseline:

$$E_{base} = \max\{E_t, E_r\} + N_{queue} \times E_t \tag{4}$$

here, E_{base} is a lower energy bound with congestion protection. N_{queue} is the maximum number of packets that the queue can hold. When E_{res}>E_{base}, the node has enough energy to deal with the queued packets while receiving or transmitting at least one packet. So we have the definition of the “available energy”:

$$E_{avl}=E_{res}-(1-\lfloor N_f/N_r \rfloor)\times E_{base} \tag{5}$$

E_{avl} is the energy available for handling packets while preventing congestion safely.

Since the major task of the intermediate nodes is to deliver packets, we can define the energy contribution ratio (*ECR*) as follows:

$$ECR=(N_t+N_f)\times E_t/E_{cost} \tag{6}$$

And based on Eq.(6), we can predict the energy available in further delivering:

$$E_{fd}=E_{avl}\times ECR^{\alpha} \tag{7-1}$$

where α is an adaptive weight factor.

Or more specifically,

$$E_{fd}=[E_{res}-(1-\lfloor N_f/N_r \rfloor)\times E_{base}]\times[(N_t+N_f)\times E_t/E_{cost}]^{\alpha} \tag{7-2}$$

From Eq.(7-2), we see that E_{fd} is a predicted value based on the historical performance of the node.

Here, we define α as $(N_t+N_f)/N_o$ that reflects the MAC contention: if the MAC contention is fierce, the probability of the local node to use E_{avl} for delivering packets is low. Thus, we have

$$E_{fd} = E_{avl} \times ECR^{(N_t+N_f)/N_o} \tag{7-3}$$

Eq.(7-3) denotes the efficiency in packet delivering, including transmitting the original packets and forwarding the relayed packets.

3.1.2 Communication interference and drop rate

Now we will formalize the efficiency of a node to receive a packet, as we mentioned before, we have N_o for overheard packets which are filtered at MAC layer and we have N_r-N_f as the discarded packets in routing layer. The filtered packets in MAC layer can be seen as interference since they are not for the local node or their signals are not strong enough for a smooth reception. Considering that the interference is energy-related, we use Eq.(8) to denote the signal-interference ratio:

$$SIR = N_r \times E_r / \sum_{i=1}^{N_o} E_{o_i} \tag{8}$$

A small *SIR* value indicates that the local node is suffering from heavy interference, which jeopardizes the normal data reception. *SIR* is actually affected by the environment and it is defined as an accumulative variable which represents the historical effect of noise.

Also we define the drop ratio in routing layer as follows:

$$DR=(N_r-N_f)/N_r=1-N_f/N_r \tag{9-1}$$

DR in Eq.(9-1) reflects the congestion condition of the node itself. To represent the current drop ratio, we decide to compute the *DR* periodically every Δ seconds, so we have

$$DR = SIR \times DR_{old} + (1-SIR) \times DR_{now} \tag{9-2}$$

here, *SIR* is a weight to reflect the historical effect of DR_{old}. We argue that when the surrounding noise is large, there can be a lot of neighbors around the local node which may result in a convergence of traffic load or a hotspot area nearby. A high *DR* value indicates that the local node has been dropping packets recently, which represents a low packet receiving efficiency and is commonly seen in a congested area.

3.1.3 Mobility

In ad hoc networks, node mobility makes the network topology highly dynamic, and thus a node with high speed will cause the network topology less unstable, so node credit which evaluates the condition of the intermediate node also takes the node mobility into account as follows:

$$NC = (E_{fd}/DR)/(spd+1)^{\beta} \tag{10-1}$$

here, *spd* denotes the current speed of the node. Note the mobility of a node can be beneficial when the node comes near to its partner. To decide whether the node mobility jeopardizes the link communication or contributes to it, we define the β as $1-DR_{now}$, so we have

$$NC = (E_{fd}/DR)/(spd+1)^{(1-DR_{now})} \tag{10-2}$$

When the node gets away from its partner, it is likely that the node has to dump the packets in its queue due to lack of proper path to handle them. In such cases, $1/(spd+1)^{1-DR_{now}}$ becomes smaller as DR_{now} increases. E_{fd} denotes the energy efficiency in packet delivering. The node with comparatively higher efficiency and enough residual energy surely has the potential to contribute more in the future than those nearly drained or low-efficient ones. As we can see in Eq.(9-2), *DR* describes node's performance in receiving packet. It is actually a complex notion of drop rate and noise which represent the congestion condition of the node itself and the toughness of the environment. A lower *DR* indicates that the local node is located in a comparatively good working environment. To sum up, a bigger *NC* indicates that the local node is comparatively more steady and works more properly and efficiently.

3.2 Path credit

The routing path in MANETs consists of multi-hop of nodes. After we define the node credit for each node on the path we now give the formula of the path credit, which indicates the quality of the route.

For a path of *N* hops, path credit is defined as the minimal *NC* value of the intermediate nodes on this path.

$$PC = \min\{NC_i\},\quad 1 \le i \le n-1 \tag{11}$$

NC_i denotes the *i*th node on this path.

3.3 Hotspot mitigation

Hotspot occurs frequently where the traffic load converges. In most cases, hotspots are congested nodes which are the crossing point of several route paths. They are overburdened and cannot handle the incoming packets timely. So hotspot nodes always experience fast energy drainage and packet loss. Unrestricted response to RREQ is a major factor that can result in hotspot, for example in Fig.1, after node *D* responses the RREQ from B_1 and C_1, it becomes the cross point of route B_1-*D*-*E*-B_2 and C_1-*D*-C_2, when the traffic on these two paths becomes too heavy for *D* to burden, it becomes congested.

In Ref.[11], the author proposes to forbid the intermediate nodes from replying any RREQ to solve this problem. We argue that is problematic and overkill. Firstly, it takes comparatively longer time to establish a routing path to leave all the RREQs for the destination. Secondly, if the congested node happens to be a bottleneck which connects two groups of node, rejecting the RREQ will make it impossible to find a path between these two groups. Node D in Fig.1 illustrates such a case. If D denies any RREQ, A_1 will fail to find a path to A_2.

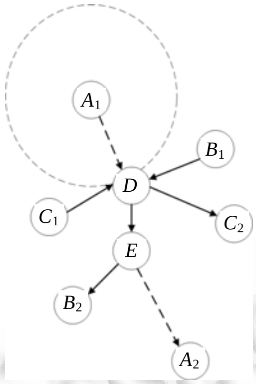

Fig.1 Improper control of the RREQs

In view of this, we propose a RREQ mechanism for hotspot node and for normal node respectively. This RREQ mechanism helps them to reduce their possibility to answer a RREQ. Like Ref.[10], we use interference severity, drop rate and energy level to decide hotspot. Specifically, a node is deemed as hotspot if it satisfies the following restrictions:

$$\begin{cases} SIR < T_1 \\ E_{avl} / E_{total} < T_2 \\ DR > T_3 \end{cases} \tag{12}$$

here, T_1, T_2 and T_3 are three thresholds.

The hotspot node will forward or answer the RREQ with a certain probability $P_{hotspot}$.

$P_{hotspot}$ is defined to restrict the possibility to answer a RREQ as follows,

$$P_{hotspot} = (E_{avl} / E_{total}) / (SIR / SIR\_\mathrm{MAX}) \tag{13}$$

SIR is given in Eq.(8), and a high SIR can guarantee that the surrounding area's interference is comparatively less intense. So hopefully, broadcasting RREQ in this area will bring less malicious effect. E_{avl}/E_{total} is the ratio of the current available energy against the overall energy when the node is initiated. SIR_MAX is a big number to make SIR/SIR_MAX fall between 0 and 1. The hotspot node is refrained from replying RREQs by $P_{hotspot}$ even if it has cached proper path to destinations.

Considering unrestricted reply to different RREQ can result in hotspot, we also restrict the reply of normal intermediate node. The probability of replying RREQ is revised as

$$P_{common} = (E_{avl} / E_{total}) \times (N_r / (N_o + N_r)) / \delta \tag{14}$$

For the term $N_r/(N_o+N_r)$ in Eq.(14), a smaller value means that the local node can sense more neighbor nodes. In such cases, one single RREQ is well enough to cover all these neighbors. So the node should restrict its possibility to forward the RREQ.

δ is the number of active paths which run through this node. The local node can check the packets it has forwarded to compute δ. A bigger δ value indicates that the local node is the crossing point of several paths, which may become the converge point of traffic if the load becomes heavy. So according to Eq.(13), a less converged node that also has fewer neighbors and more left energy is more likely to forward or answer the RREQ.

4 Experiment Result

4.1 Implementation

We implement our protocols EIDM based on DSR. The main difference between EIDM and DSR is that EIDM uses path credit as the route selection metric and it is determined by the node with minimum node credit on a route. EIDM computes all of nodes' node credit based on their own status, this mechanism only increases the computation-related complexity which is much smaller than communication-related complexity[11] in MANET, so the whole complexity brought by EIDM can almost be ignored. In route discovery phase, when RREQ is forwarded for the destination node in route discovery procedure, the 1st intermediate node will fill in a reserved entry of the packet header with its own *NC* value. While the following intermediate nodes receive this RREQ, they will compare their *NC* value with the one stored in RREQ and replace the original one if their *NC* is smaller. Route Reply (RREP) replied by the destination node will carry the minimal value of *NC*. The source node will record all these paths information and their *PC* value in its route cache and choose the one with the maximal *PC* value from all these candidate paths. And the shorter path is given higher priority if they are equal in *PC* value.

Beside that, each node will start a timer once initiated. Every η second, the node will flush its cache. All those paths which are unused in the past η seconds get deleted. This is to keep the cache information up-to-date. Intermediate node will react to RREQs with RREP according to information in the fresh cache.

4.2 Experiment setup

To evaluate the performance of EIDM, we compare EIDM with LEB+HM in Ref.[11] and the DSR protocol in terms of end to end latency, control packets overhead, packet delivery ratio and the network lifetime. *End to end latency* is the average time consumed in delivering a packet from the source node to its destination. *Packet delivery ratio* is the ratio of the total number of the packets successfully received by destinations against the number of packets transmitted by the sources. This reflects the reliability of the routing protocol. *Control packets overhead* refers to the total number of control packets. If one protocol can provide equal or even bigger packet delivery ratio while consuming less control packets, it follows that this protocol is effective and efficient in maintaining the robustness of the end to end communication. *The network lifetime* is the time span starting from network initialization till the first "dead node" comes up. The dead node refers to the exhausted node without enough energy to transmit or receive packets. Links on the dead node will break down and corresponding routes will also fail.

Our simulation tool is NS2[13]. We have 5 runs for every simulation scene and the topology is given in Table 1.

Table 1 Topology setup

Topology size	Square 1500m×300m
Running time	900s
Node number	50
Max speed	20 m/s
Mobility model	Random way-point (RWP)
Pause interval	0 second
Initial power	100 J
Traffic type	Constant bit rate (CBR)
Packets size	512 Bytes
Sending rate *N*	*N*=1,2,3,4,5 pkts/s

Note that EIDM introduces several undecided parameters like T_1, T_2, T_3 and η. For the sake of simplicity, we set them fixed values in our simulation. Yet in our future work, we'll make them dynamic and adaptive to reflect the variation of network condition. T_1, T_2, and T_3 are set as 0.5, 0.05, and 0.2. η is set as 6 seconds.

4.3 Simulation result

Figures 2~5 give the detailed results of the experiment. In Fig.2, we see that when the traffic load is not heavy, DSR outperforms LEB+HM since the latter asks intermediate nodes to ignore any RREQs. Thus, routes won't be established until the RREQ gets replied by the destination node, which certainly increases the latency. As the load goes up, the latency for DSR becomes bigger than LEB+HM, which means that route reestablishment due to node energy drainage and packet retransmission due to packet loss frequently occur, which enlarges the average delay. Yet in different scenarios, EIDM outperforms the other two with lower end to end latency. This is because EIDM partly allows node to answer the RREQ while considering the possible congestion issue. EIDM decreases the latency by 10.2% against DSR and 8.27% against LEB+HM.

Figure 3 highlights that EIDM achieves a larger packet delivery ratio than DSR and LEB+HM. LEB+HM may benefit from restricted response to RREQ mechanism in comparatively lower traffic load and it does better than EIDM when CBR is 0.4Mbps. As the traffic load becomes heavy, the RREQ mechanism in EIDM can indicate the hotspot node effectively and EIDM seeks an average 3.37% rise against LEB+HM.

Figure 4 illustrates that EIDM performs LEB+HM and DSR by consuming less control packets. An 8.72% and 15.51% decrease is sought against LEB+HM and DSR.

In Fig.5, we can see that EIDM extends the network lifetime longer than LEB+HM and DSR. The average extension reaches against LEB+HM and against DSR.

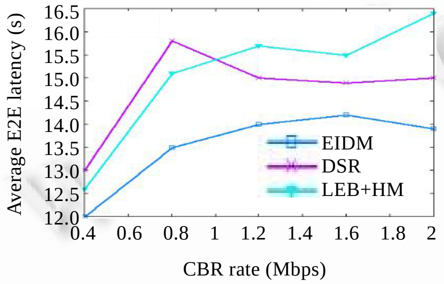

Fig.2 Comparison of the end to end latency

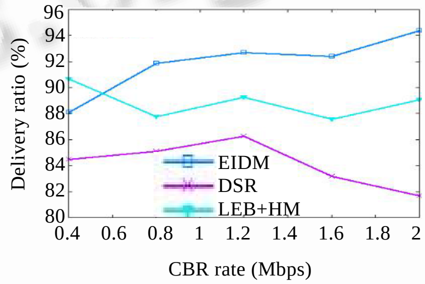

Fig.3 Comparison of the delivery ratio

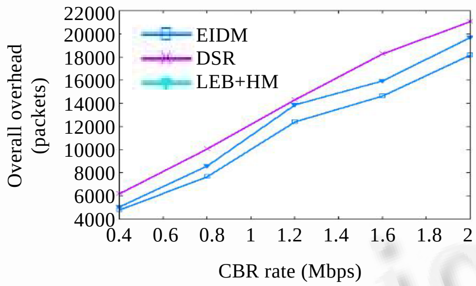

Fig.4 Comparison of the overall overhead

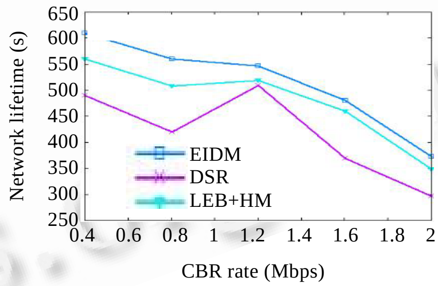

Fig.5 Comparison of the network lifetime

Seen from Figs.4 and 5, we find that EIDM and LEB+HM both outperform DSR in some degree. That is because both EIDM and LEB+HM take the energy issue into account trying to employ healthy or leisure node for load balancing. Yet the parameter in *NC* (Eq.(10-2)) uses dynamic parameters which can represent the real-time network condition that entitles our EIDM to a more accurate evaluation of node condition, and accordingly more precise selection of optimal route. So EIDM does better than LEB+HM in control packets consumption and network life extension.

5 Conclusions

In this paper, we analyze several major factors that can degrade the network performance and we try to formulize them with the number of handled packets and corresponding energy consumption. We put forward a new metric to evaluate the node condition which comes as a complex of energy, communication interference, drop rate and mobility of a node. Also, we propose a new path selection criterion based on this new metric. With dynamic and adaptive weight, our EIDM can adjust its stress on different sub-metrics. Simulation results also prove EIDM's validity in mitigating the hotspot symptom in the mobile ad hoc networks. We will continue to verify the EIDM's performance using testbed in our future work.

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