A High-Performance Routing Protocol Based on Mobile Agent for Mobile Ad Hoc Networks

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Abstract—In recent years, Mobile Ad Hoc Networks (MANETs) have been focused on research and applied in many domains such as healthcare, traffics, military, entertainment, and smart cities. However, the performance of MANETs is rather quite. Due to the mobile characteristic of network nodes, the routing is the main issue to improve network performance. In this study, we propose a routing protocol, called IWCETT (Improve Weighted Cumulative Expected Transmission Time) protocol. This protocol is a modification of a well-known routing protocol, is Ad hoc On-demand Distance Vector, as a solution to improve the performance of MANETs. We adapted the mobile agent technology and a novel metric for routing in these networks. The metric is a function of the loss rate, the bandwidth and the end-to-end delay of the link. Indeed, we established a new tunable parameter to obtain a tradeoff between throughput and delay when computing the new metric. As a result, any routing protocol using this metric can always choose a high throughput and low delay path between a source and a destination. Hence, the achievable performance of the MANETs has been improved remarkably with our modified routing protocol.

Keywords—High-Performance, Routing Protocol, IWCETT, MANETs

1 Introduction

According to the Cisco Internet Report, it is expected that, by 2023, there will be over 29.3 billion networked global devices and the number of global mobile devices will grow over 13 billion. Over 70% of the global population will have mobile connectivity. Each capita will have an average of 3.6 networked devices. Business users expect high-performance connectivity anywhere, anytime, on any devices [1].

The Next Generation Networks (NGN) such as the 5th, 6th generation networks are being shaped and expected to become the leading communication technology of the

Internet in the future. With NGN, the architecture and components of the mobile network will undergo a radical change. Here, the network architecture considers the device as the centre will replace the network architecture based on base stations in order to improve packet distribution. Mobile devices also are improved to adapt to the new role - being a central component of the network and must to be smarter to support effective communication technologies such as massive MIMO, Device-to-Device. Moreover, mobile devices will also be equipped with M2M modules, which capable of setting up M2M connections, is the principle of forming MANETs [2-3].

MANETs was born since the 1970s, have always been considered a very convenient communication tool. Despite being limited in ability and capacity, MANETs have proven to be outstanding advantages in communicating with flexible infrastructure. They are applied in very many domains such as smart cities [7], healthcare [8] smart traffic [9], military [10], emergency and disaster recovery [11-12], as well as promising a vital contribution to the future development of the Internet [13].

However, when the scale expands, MANETs face problems such as quite low performance, quality of service guarantees, energy efficiency. In MANETs, since mobility characteristics of the network nodes leading to network topology are changed continuously. Besides, network nodes must also cooperate to transmit data packets. Routing protocols are particularly important in improving network performance. Moreover, the performance of MANETs is generally quite low and depends on its size, communication model and radio communication environment [2, 5-6, 14]. Therefore, designing high-performance routing protocols for MANETs is a significant challenge and is an urgent research direction. Survey researches in [2, 4-6] also show that the throughput and end-to-end delay are typical criteria reflecting network performance.

In this study, we set up a new routing protocol, called IWCETT (Improve Weighted Cumulative Expected Transmission Time), based on extending known routing protocols for MANETs. Our main idea is to rely on mobile agents to obtain reliable routing information. First of all, we analyze the existing routing protocols to determine which routing protocols best suit the characteristics of MANETs. Then we expand to improve MANETs performance.

2 Routing Issues in MANETs

In MANETs, two typical routing protocols standardized by IETF (The Internet Engineering Task Force) are AODV (Ad hoc On-demand Distance Vector) [15] and DSR (Dynamic Source Routing) [16]. These are on-demand routing protocols that work on the principle that whenever a data is needed to transfer, the source node will discover and find a route to the destination node.

The route discovery process starts with the source node sending broadcast the RREQ (Route Request) packets. Then, these packets are forwarded through intermediate nodes to reach the destination node (Fig. 2, the red line). The destination node or intermediate node (the node knows the route to the destination) will respond by sending unicast RREP (Route Reply) packet back to the source node (Fig. 2, the green line). Beside the route discovery procedure, IWCETT also has route maintenance procedures that use

RERR (Route Error) packets (Fig. 2, the yellow line). In this way, the source node receives all candidate routes. Although both are designed to fit with the characteristics of MANETs, there are still differences between AODV and DSR protocols. AODV does not establish a route in advance to transmit data from source to destination. The route will be determined by each network node when data arrives, based on the system status information obtained by the node. In addition, AODV uses the sequence numbers to determine the latest route and avoid loop routing. Meanwhile, DSR determines the route at the source node. The source node will identify all hops from the source node to the destination node. Therefore, the header of RREQ and RREP packets must be expanded to store the address information of intermediate nodes. Besides, unlike AODV, DSR maintains a temporary memory to save routes and use them until they are no longer valid.

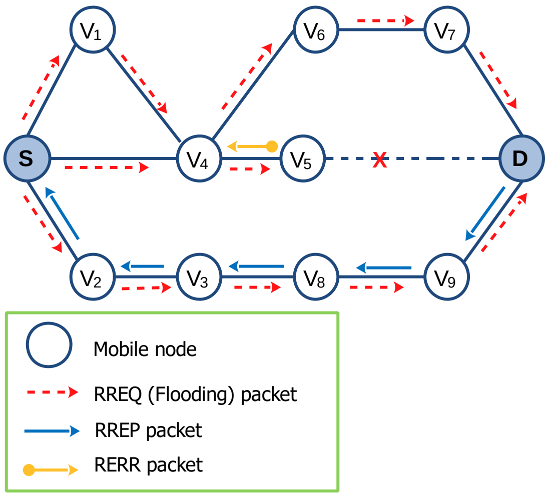

Fig. 1. The route discovery process in the AODV protocol

Both AODV and DSR protocols use less resource, save energy and support the architecture/organization features of mobile ad hoc networks such as self-organizing, self-configuring and mobile. In some performance comparisons [17-19], AODV has the packet delivery ratio over 90%, while DSR performance is best in the networks with small hop numbers. However, using AODV for MANETs in NGN will have more advantages than DSR. The main reason is the large scale and high mobility nature of MANETs in NGN. Meanwhile, the route discovery process of DSR can lead to the unpredictable length of control packets and data packets.

3 Mobile Agents

In computer science, a mobile agent is an entity (software/data/packet) capable of operating in the environment, interacting with other agents or performing a specific goal. A mobile agent used in the MANETs environment is small packets (probing packets) that are sent periodically between neighbouring nodes to collect information. In recent time, the solutions use mobile agents to control routing protocols more and more popular, indicated in several studies [20-23]:

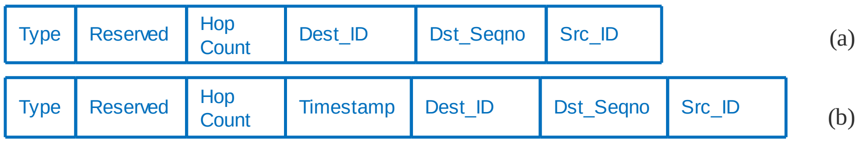

Fig. 2. The proposed mobile agent structure: a) $I - Request$; b) $I - Reply$.

According to [21], the authors proposed an intelligent route planning based on mobile agents for ad hoc networks in IoT systems to make the best decision for selecting the next node in different moments. This study used the Markov Decision Process (MDP) as the underlying optimization model, which is well-known for its effectiveness to optimize decision making under uncertainty. In the proposed model, authors considered the distance between the nodes, the distance between a node and the sink node, residual energy of the node and the priority of them as the MDP parameters. The experience results show that the proposed solution improves the energy consumption of IoT nodes and the lifetime of the system, as well as maximizes the reliability of the network and reduce data transmission delay.

Also, in this direction, in [22], the authors proposed a load balancing technique using mobile agents for MANETs aims to utilize maximum resources of the neighbour nodes and protect mobile agents from the malicious host using a hash function. Besides, this study also considers the impact of frequent network disconnection on agent movement. The simulation result shows that the proposed scheme improves robust against modification attacks on mobile agents.

In [23], to improve the intelligence of the mobile agent for ad hoc networks, authors proposed a conceptual, theoretical framework named $iAgent$, where i means intelligent, and the agent refers to the mobile agent. This study shows details of four designs of $iAgent$. Compared with the old mobile agent, the $iAgent$ has a learning ability, which means that it can dynamically plan the path according to the network environment in order to reduce energy consumption. Based on $iAgent$, authors also proposed a method to determine the number of the $iAgents$ and their visiting areas in the ad hoc network environment. The simulation results show that $multi - iAgent$ algorithm significantly improves the network performance, saving energy and load balancing.

Fig. 2 shows our mobile agent structure. In particular, the $Timestamp$ field is used to determine the period a probe packet needs to be transmitted between two neighbouring nodes. The meaning of the remaining fields is similar to what was described in [20]. There are two types of agents, respectively named *I-Request* and *I-Reply*, which correspond to two tasks: requesting information and responding to information. We set up every 20 (*ms*), a network node sends *I-Request* probe packets to neighbouring nodes. Upon receiving the *I-Request* packet, neighbouring nodes are responsible for sending back the *I-Reply* packet to provide information for the requesting node. Based on the information gathered, each node will decide to choose the most appropriate route.

4 Proposed Protocol

The routing metric used in MANETs must reflect the quality, the stability of the connections and, the hop numbers. In this section, we propose a routing protocol that uses the Weighted Cumulative Expected Transmission Time (WCETT) metric to find the route with high throughput. First of all, the protocol proceeds to assign a weight to each hop based on the quality of each connection; these weights then combined to select the most appropriate route. The detail of our proposed protocol will be provided in the following subsections.

4.1 Route selection algorithm

According to IETF, the route cost of AODV protocol is calculated by the total hop numbers that a packet must across from source to destination. However, choosing a route only based on this cost is not optimal. In order to improve the performance of MANETs, Couto *et al.* [24] proposed a new routing parameter to calculate the cost of the route, which is Expected Transmission Count (ETX). To determine the ETX value, each node sends probing packets to neighbouring nodes. Then, based on the probe packet numbers and the acknowledge packet number received, each node identified the successful transmission probability. Symbol d_f and d_r, respectively, are the probability of sending and receiving a packet successfully. The probability of an expected successful transmission/reception event on a hop is $d_f \times d_r$. The ETX on link L (a connection between two adjacent nodes) is determined by the following formula:

$$ETX_{(L)} = \frac{1}{d_f \times d_r} \tag{1}$$

ETX of the route P, is the sum of the $ETXs$ on each hop L, with $L \in P$.

$$ETX_{(P)} = \sum_{L \in P} ETX_{(L)} \tag{2}$$

With this method, the protocol will choose the route based on the packet delivery ratio. The simulation results in [24] show that MANETs performance is significantly improved when using the ETX metric instead of using hop numbers. However, the ETX metric is limited when only considering the packet delivery ratio without considering the data transmission speed. To solve this issue, Expected Transmission Time (ETT) metric was proposed in [25]. ETT is determined by integrating the throughput of the link and the ETX value. In other words, the ETT metric is determined by multiplying the ETT value by the bandwidth to obtain the period time needed for transmitting a packet on a hop. The symbol S is the size of the packet and B is the bandwidth on the link. The ETT value of link L is determined, as follows:

$$ETT_{(L)} = ETX_{(L)} \times \frac{S}{B} \tag{3}$$

By putting the bandwidth into calculating the path cost, ETT metric not only binds physical interventions but also influenced by the quality of each link.

When using the ETT metric, the cost of the route is the total cost of links. However, the real cost is different from the expected cost because this solution not take the co-channel interference into account when the nodes use the same channel. Therefore, authors in [25] proposed the WCETT metric with the particular purpose of reducing co-channel interference. The solution is to try to minimize the number of nodes using the same channel throughout the route. This technique uses an average weight β to balance between the total cost of the route with the effects of the bottleneck channel. In detail, [25] does not provide a way of determining the value of β, but based on the experimental results, this research determines that $\beta = 0.5$ is appropriate.

Consider the route with *P* hops, the total transmission time uses same channel *j* (assuming the system has a maximum of *k* channels) determined as follows:

$$X_j = \sum_{Link\ i\ \text{on}\ j\ channel} \text{ETT}(i),\ 1 \le j \le k \tag{4}$$

Due to the bottleneck channel will dominate route throughput (channel *j* has the highest X_j value). We proposal use an average weight β between the highest X_j value and the total ETTs on the route. Setting IWCETT is the improved cost function; we have obtained the formula:

$$\begin{cases} \beta = \dfrac{\sum_{i=1}^{D} \text{ETT}_{(i)}}{\max\limits_{1\le j\le k} X_j} \\ \text{IWCETT} = \left(\dfrac{\beta}{1+\beta}\right) \sum_{i=1}^{D} \text{ETT}_{(i)} + \left(\dfrac{1}{1+\beta}\right) \max\limits_{1\le j\le k} X_j \end{cases} \tag{5}$$

There are two ways to explain how to determine the β parameter. Firstly, we can view it as the affection on the end-to-end throughput between the bottleneck channel and other channels in the route. Secondly, it is a representation of the relationship between the hop, which has the most effect on throughput and the overall route. The average weight can be considered as an attempt to balance these two issues. On the other hand, the total transmission time on the entire *P* route ($\sum_{i=1}^{P} \text{ETT}(i)$) is usually much higher than the transmission time on the channel with a bottleneck connection ($\max\limits_{1\le j\le k} X_j$). Therefore, in order to ensure the balance of influence between these two factors, we determine the binding coefficient β as Eq. (5). The route selection algorithm of IWCETT is summarized as follows:

```
Algorithm 1: IWCETT Route Selection Algorithm
P=routeset(S,D)
Cost=∞, Selectedroute={Ø}
For each p in P
      X[k]={Ø}, Total=0
      For j=1 to sizeof(route[p])
          Total=Total+ETT[j]
          If link[j].chanel=k then X[k]=X[k]+ETT[j]
      Endfor
  β=Total/max(X[k])
    Calculator(A-WCETT[i]) // Equation (5)
  Endfor
  Cost=∞
  For each p in P
  If  Cost< A-WCETT[p] then
      Cost=A-WCETT[p]; Selectedroute=rouset[p]
  Return(Selectedroute, Cost)
```

An example of calculating IWCETT with different β values as in Fig. 3.

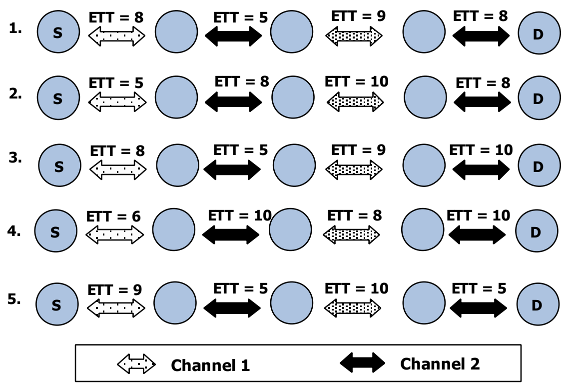

Fig. 3. Illustrate candidate routes after the discovery procedure

Table 1. Effect of β parameter to the cost function

$Route$	$Total$ (ETT)	Max (X_j)	$WCETT$			β $proposed$	$IWCETT$
			$\beta = 0.1$	$\beta = 0.5$	$\beta = 0.9$		
1	30	17	28.7	**23.5**	18.3	1.76	25.30
2	31	16	29.5	**23.5**	**17.5**	1.94	25.89
3	32	17	30.5	24.5	18.5	1.88	26.79
4	34	20	32.6	27	21.4	1.7	28.81
5	29	19	**28**	24	20	1.52	**25.05**

The calculation results in Table 1 show the instability in the route selection decision of WCETT and IWCETT protocols. For different values of β, WCETT selects different routes, specifically as follows:

$\beta=0.1$, route 5 is selected, $WCETT_{min}$=28.

$\beta=0.5$, route 1 or 2 is selected, $WCETT_{min}$=23.5.

$\beta=0.9$, route 2 is selected, $WCETT_{min}$=17.5.

Meanwhile, IWCETT with β parameter determined by the proposed method always selects a suitable and stable route (route 5) with $IWCETT_{min}$=25.05.

5 Experimental Result and Analysis

In this section, we set up a simulation on NS2 software to evaluate the performance of MANETs according to the criteria: average delay, average throughput. The routing protocols are evaluated as AODV, WCETT and IWCETT, respectively. The simulation parameters are summarized in Table 2.

Table 2. Simulation Parameter

Parameter	Value
Simulation Area	1000x1000m
Number Nodes	100
Throughput	11 Mbit/s
Mobile Speed	3m/s
Mobility Model	Random Waypoint
Traffic Type	CBR/UDP
Packet Size	512 Byte
Wireless MAC Interface	802.11
Simulation Time	300s

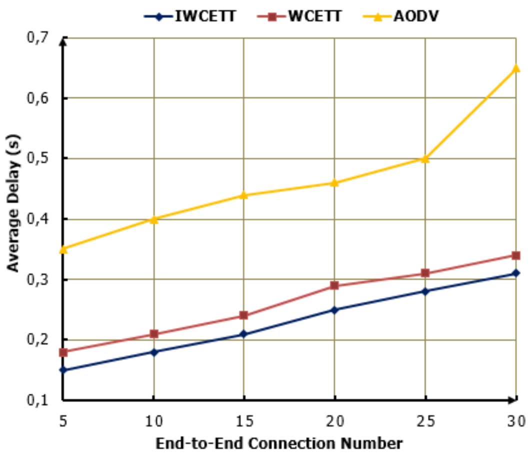

Fig. 4. Performance evaluation based on criteria: End-to-End Delay

In the first simulation, Fig. 4, we evaluated the performance of three protocols based on the criteria of average delay. The results show that the WCETT and IWCETT protocols have lower latency than the AODV protocol. These simulation results are fit with the theoretical calculations. Since WCETT and IWCETT operate multichannel, they have a higher data transfer rate and reduce congestion in the system. However, when the number of end-to-end connections increases to 20, the average delay of all three protocols tends to increase. However, the delay of AODV is still higher than the other two protocols.

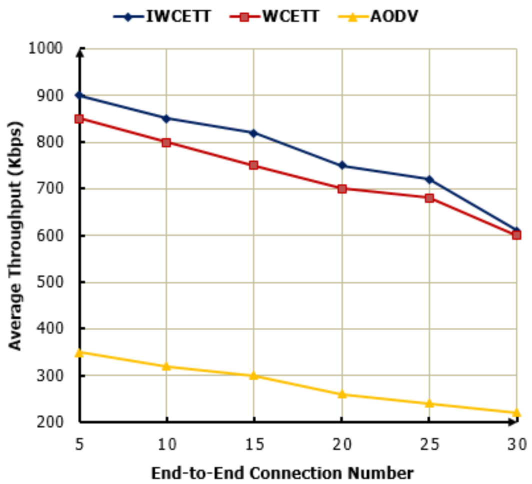

Fig. 5. Performance evaluation based on criteria: Average Throughput

The second simulation, Fig. 5, we evaluate the performance of three protocols based on the criterion of average throughput. The simulation results show that the throughput of IWCETT is always higher than the other two protocols. Specifically, IWCETT and WCETT have the throughput that is nearly three times higher than the AODV protocol. However, as the number of end-to-end connections increases, the system throughput of all three protocols decreases. Notably, when the number of end-to-end connections increases to 25, the throughput is declined suddenly due to the happening environmental conflicts and system collision. In case the number of end-to-end connections is too large, the MANETs have tends to be congested on a large scale, and the performance of IWCETT will not improve over WCETT.

Based on detailed simulation results, it shows that the IWCETT and WCETT protocols operate multiple channels, thus increasing throughput and reducing congestion on the overall system. The proposed protocol improves delay and throughput better than WCETT protocol due to optimized β parameter. Besides, thanks to the use of multichannel technology, two protocols achieved low delay and improved throughput many times more than the AODV protocol. One of the significant concerns for the effectiveness of the IWCETT protocol is the system cost relating to the use of mobile agents. In the next time, we will focus on study this issue.

6 Conclusion

In this work, we proposed an on-demand routing protocol for MANETs, called IWCETT. This protocol is an improvement from AODV, multichannel operation and based on mobile agents. Simulation results show that IWCETT with improvements in β parameters and mobile agent-based routing increased performance better than WCETT protocol. The simulation results also proved that the IWCETT and WCETT protocols have much higher throughput and lower delay than the AODV protocol. However, in this works, authors still not yet consider the issue of information security when using mobile agent solution. In the next researches, we will focus on proposing secure routing solutions in the MANETs.

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