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An Improved Agent-Based AODV Routing Protocol for MANET

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Abstract

The mobile ad-hoc network (MANET) is a special mobile network that has self-configuration and self-establish abilities to communicate conveniently. MANET is forming mobile devices such as mobile phones, personal digital assistants (PDAs), laptops, etc. As a result of the rapid, flexibility, and facilitate in communication, nowadays, MANET has revolutionized many real-life applications, ranging from smart agriculture and smart cities to forest fire detection systems, and expected to have vital contributions into the future of the Internet. However, due to the mobile nature of network nodes combined with the network architecture that without relying on central devices pre-installed such as base stations, the high-performance routing problem is one of the most significant challenges in the MANET environment. In this study, we propose a high-performance routing protocol, namely agent-based ad-hoc on-demand distance vector (A-AODV), to select the optimal route with high throughput and low latency. Through the developed routing algorithm, we explain how the suitable route with the lowest cost based on agents. To demonstrate the effectiveness of the proposed protocol, we compared A-AODV's performance with two well-known traditional protocols on NS2. Simulation results show that A-AODV improves superior performance over the traditional protocols.

Keywords: Network protocols, Mobile ad hoc network, MANET, Routing protocol, Mobile agent.

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1. Introduction

In recent years, along with the powerful development of science and information technology, Mobile ad-hoc networks (MANET) have been studied and deployed in a wide range of areas, such as intelligent transport systems, rescue, health care, smart homes, and smart cities [1-2] (**Figure 1**). MANET is expected to be one of the technologies that will meet the connectivity needs of the future Internet thanks to its ability to set up flexible networks and not rely on fixed network infrastructure, low operating costs, fast deployment, and high mobility [2-3].

In a mobile ad-hoc network, the environment has a high dynamic network structure [2]. As a result, system performance is quite low. Some typical protocols introduced for MANET by IETF organizations are Ad-hoc On-demand Distance Vector (AODV) [15] and Dynamic Source Routing (DSR) [16]. For some applications that require high mobility and massive traffic, the responsiveness of on-demand routing protocols such as AODV and DSR has a lot of limits [4]. In order to effectively exploit the system resource, the study of routing protocols is necessary.

Therefore, many studies have been done to improve availability and reliability in MANET [2, 5]. Through the related studies [6-19, 21-25] showed that how to use mobile agent technology with the intention of improving the performance of MANET becomes an increasingly exciting research topic. The specific solution is to integrate mobile agents into the control of routing protocols in MANET to improve the overall performance of the system.

In this study, we propose a routing protocol, namely A-AODV (Agent-based AODV). Inspired by the AODV protocol, our proposed solution is to use mobile agents to

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Figure 1. An illustration of MANET applications in smart cities [29]

collect the information of neighbouring nodes and to select the optimal route. In Section 2, we present some related work. In Section 3, we describe the mobile agent technology in MANET. Our proposed protocol is presented in Section 4. In Section 5, we evaluate the performance and analyze results of the proposed protocol in comparison with two other well-known protocols for MANET; and Section 6 is Conclusion.

2 Related work

Nowadays, mobile agent technology is combined in a range of real applications, such as smart agriculture, intelligent transportation systems, and IoT ecosystems. It promises vital contributions to enhance life quality of humanity. Some typical applications of mobile agent technology are described as follows [22-28].

Aiming to deal with multi objects optimal routing problem for wireless networks, $Chen\ et\ al.$ proposed a routing algorithm that integration between mobile agent and the shortest path algorithm (Dijkstra) [22]. The simulation result demonstrated the proposed method can get an optimal path based on the existing network state.

Beside the increasing travel demand of people, intelligent transportation systems have being breakthrough developments. $T.Semwal\ et\ al.$ introduced an operating model of mobile agents for future vehicle networks [23]. This study indicated the potential application of mobile agents in the exchange of information, signals, and communication between vehicles, roadside units, and traffic infrastructures for Intelligent transportation systems.

In MANET, due to network nodes are heterogeneous on aspects of energy, processing capacity, movement speed, one of the most important problems to enhance performance is load balancing. $Anjum\ et\ al.$ introduced an efficient load balancing schema aim to prolong the network lifetime, enhance throughput and decrease latency based on mobile agents [24]. The results demonstrated the schema enhance robustness reality and against modification attacks mobile agents.

The guarantee of QoS is one of the most important requirements of future routing algorithms [25]. However, the principle of MANET operates without any pre-infrastructure. The lack of central devices such as base stations led to the QoS support of MANET face challenges. *Verma et al.* designed a new routing model based on mobile agents [25]. In this model, mobile agents obtain the vital routing metrics for route quality evaluation. The authors showed that the proposed model enhances the performance and the support for MANET.

An emerging technology trend attracting great interest from both academia and industry is smart agriculture. In this technology, sensor devices operate continuously, day and night in fields and farms to transmit the monitored signal to the processing centre. These devices will consume a huge amount of energy. Therefore, in smart agriculture, the saving energy problem for wireless sensor networks (WSN) is one of the most vital problems. In [26], $B.Liu\ et\ al.$ introduced the integration of mobile agents into WSN, aiming to enhance performance networks and saving energy. The results demonstrated that the solution improves performance in sensors position change scenarios

In the digital society era, the trend of all devices, solutions, and systems being connected through the Internet is inevitable, also known as the Internet of Things (IoT). IoT will connect a huge number of devices, so the device location management problem becomes topical and urgent. In [27], *Mallikarjun et al.* introduced a location management protocol of mobile devices for MANET based on mobile agents. The protocol estimates the location of mobile nodes based on location information and the operating history of the device. The results demonstrated the efficiency of saving energy and determining the device location.

Nowadays, artificial intelligence technology (AI) has been applied in most areas of humanity. Inspired in reality that agents are the main section of AI, $J.Lu\ et\ al.$

introduced an intelligent mobile agent framework [28], namely $iAgent$ integrated between AI and mobile agents. A unique feature of $iAgent$ is the self-learning ability. The experiment results in WSN environments demonstrated $multi - iAgent$ increases the performance, load balancing, and saving energy.

In MANET environment, the purpose of applying mobile agent technology to routing protocols is to collect information about the environment or neighboring nodes, then to select the most suitable route. In the next sections, we will present Mobile agent technology and several solutions for MANET performance.

3 Mobile Agent in MANET

Mobile Agent is a physical or logical entity, capable of autonomous, direct communication with other agents or mobile network nodes to complete the task [2]. In the MANET, agents are tiny packets, which movement between network nodes to collect data from the network environment or network nodes. Mobile Agents can provide information for route selection decisions that directly impact on network load, time delay, throughput and compatibility across heterogeneous environments.

In the MANET environment, the characteristics of the network nodes are mobile, ad hoc, non-priority and peer-to-peer. In some instances, the integration of additional mobile agents into the routing protocol may be the routing protocol optimization.

Some characteristics of mobile agents:

- *Autonomy* is the ability to perform tasks without external control or influence.
- *Mobility* is the ability to transfer between mobile nodes in the network environment.
- *Intelligence* is the ability to learn and gain experiences from the environment.
- *Adaptability* is an ability the agent can execute in different environments.
- *Collaboration* is the ability to contact and coordinate with agents to perform tasks.

With the above characteristics, we realize that the use of mobile agents supporting routing protocols in wireless networks and MANET requires a highly feasible approach. In general, the basic structure of a mobile agent includes four main components: *State*, *Input*, *Output*, *Process*; where *State* means the state of the agent; *Input* and *Output* means a set of input and output data states, respectively; and *Process* means the execution process changing the state of the agent.

Figure 2. The operational model of the agent

With the model (see **Figure 2**), mobile agents operate in a cycle where the vital factor processes the Input and Output information through the processes. The process includes handling mobile agent requests, describing actions, and invoking other mobile agents. This process is done to complete the tasks required and is called the life cycle of the mobile agent.

In this work, we establish two mobile agents to collect routing information from neighbor nodes. The mobile agents' structures are described, such as in **Figure 3** ($A - Request$) and **Figure 4** ($A - Reply$). Note that, the period a probe messages needs to communicate between two neighboring nodes is stored in the Metric field. Some remaining fields are explained similarly in [18].

ID	Src-ID	Dest-ID
16 bits	8 bits	8 bits

Figure 3. The structure of the $A - Request$

ID	Src-ID	Path	Metric
16 bits	8 bits	8 bits	Double

Figure 4. The structure of the $A - Reply$

The proposed agents correspond to two tasks: information request and information response. In our simulations, every 30 (ms), a MANET node sends $A - Request$ probe messages in one hop. When received the $A - Request$ message, the local nodes send back the $A - Reply$ message to provide information for the requesting node. Based on that information, each node will making-decision to find a suitable path.

Where, ID: The identifying number to a route request, Src_ID: Address of the source node, $Dest\_ID$: Address of the destination node, Path: Address of intermediate nodes, $Metric$: Routing Metric.

4 The A-AODV Routing Protocol

Inspired by the know-well AODV protocol, we proposed a protocol to improve the performance compared to the two other know-well models (i.e., AODV and DSR). In this section, we focus on describes the operation principles of the proposed routing protocol, namely Mobi Agent-AODV (aks A-AODV) in three parts: routing metric, route discovery, and routing algorithm. The detailed describes will be presented in the following subsections.

4.1 Routing metric

In typical routing protocols are proposed for MANET, such as AODV or DSR, the cost of a route is determined by the hop numbers that the packet has to travel from the source node to the destination node. This routing method has many limitations [2], [7-14]. For the purpose improve the performance of systems, several studies introduced a new routing metric is ETX (Expected Transmission Count) [18-

21]. The ETX metric is defined as the expected number of transmissions at the data link layer to transmit a successful packet on the link. Aim to determine the ETX value; the MANET nodes send A-Request messages in one hop which is related to the number of messages sent and received. The MANET nodes determine the ETX metric of the connection.

Let d_f denote the probability of sending a successful message, and d_r denote the probability of a received successful message on the link (l). The ETX metric on the connection could be determined such as follows (Eq. 1):

$$ETX_{(l)} = \frac{1}{d_f \times d_r} \quad (1)$$

The ETX metric of a path P is the total of the ETX of links l belonging to P, determined as follows (Eq. 2):

$$ETX_{(p)} = \sum_{l \in p} ETX_{(l)} \quad (2)$$

The experiment results demonstrated that the performance of MANET based on the ETX metric is considerably improved, compared to the hop count metric. Furthermore, the ETX remains limitations such as lacking of taking data rate into account which affects directly the time delay [20].

To address the limitations of ETX, *Draves et al.* proposed ETT parameter (Expected Transmission Time) by integrating the data rate of the link [21]. In particular, ETT is determined by ETX (expected number of transmissions per link) multiplied by the bandwidth of the link. Let S_i denote the size of the message and B denote the bandwidth on link l. The $ETT_{(l)}$ is calculated as follows (Eq. 3):

$$ETT_{(l)} = \frac{S_i}{B} \times ETX_{(l)} \quad (3)$$

By putting into the bandwidth B account to calculate the cost of each link, the ETT parameter is not only abounded from reliability but also the throughput of each link. In this work, we use two agents: *A-Request* and *A-Reply* to determine the ETT value on each link. Based on the cost of ETT, the route with the lowest cost will be selected.

4.2 Route discovery

The route selection process requires knowledge of the ETT of candidate routes between a pair of source-destination nodes. This problem can be solved by the route discovery procedure described below (**Figure 5**).

The operation principle of the A-AODV protocol is developed, relied on the AODV protocol. Particularly, when the source node (denoted S) has data that need transmission to the destination node (denoted D), S invokes the route discovery procedure. First, S broadcasts the RREQ messages with the header changed as follows $\{Model - Flag, ETT, AODV\ RREQ\ Header\}$, then RREQs will be forward on MANET through intermediate nodes to reach D.

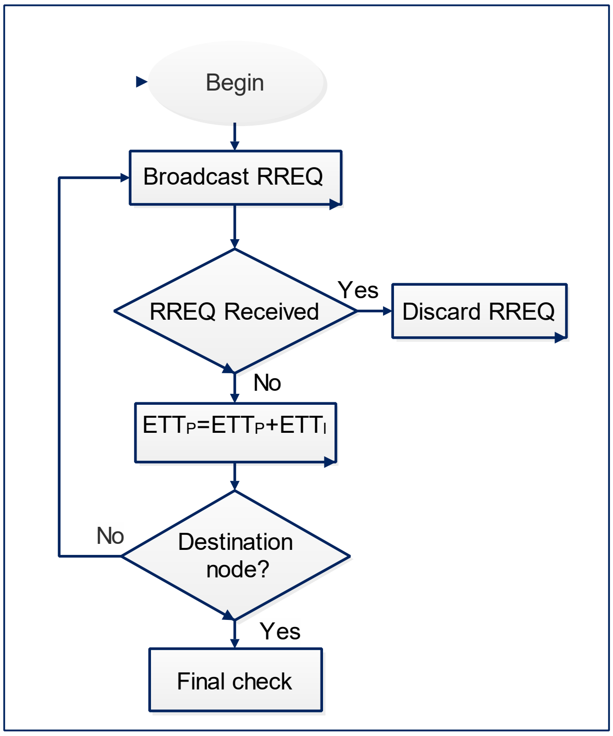

Figure 5. The ETT-Check procedure

A unique characteristic of the RREQ messages forwarding processing is that, at intermediate nodes, then received RREQ message, it invokes the $ETT - Check$ procedure. This procedure is illustrated in **Figure 5**. The $ETT - Check$ procedure has to calculate the ETT of the route. The ETT of each link is determined based on information of the ETT metrics (see Section 4.1 for more details).

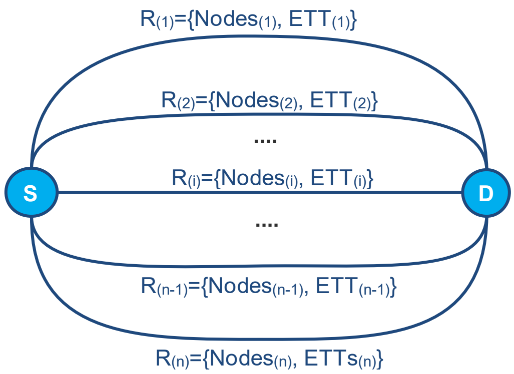

Figure 6. The set of candidate routes

Finally, D sends the unicast RREP (Route Reply) message with the modified header $\{Model - Flag, ETT, AODV\ RREP\ Header\}$ to S. In addition, similarly to AODV, the protocol has route maintenance procedures using RRER (Route Error) messages. S receives possible routes (**Figure 6**) if the process reaches a successful completion.

Algorithm 1: A-AODV Algorithm

//$routeset$: The set of candidate routes received by route discovery procedures
//$minhop$: The hops number of the shortest route in the $routeset$
//$cons\_valid$: The set contains routes that satisfy the condition in Eq. 4
//ETT(i): The function receives the ETT value of route i
//$selectedroute$: Optimal route

$routeset = shortest - route(S, D)$
$minhop = min(shortest - route(S, D))$
$maxhop = minhop + 2$
// $Eq.(1)$
$\boldsymbol{for}\ i = 1\ \boldsymbol{to}\ maxsizeof(routeset)\ \boldsymbol{do}$
    $\boldsymbol{if}\ minhop \leq numhop(routeset(i)) \leq maxhop\ \boldsymbol{then}$
        $cons\_valid \leftarrow route(i)$
    $\boldsymbol{endif}$
$\boldsymbol{end\ for}$
//$Eq.(5 - 6)$
$ETT = \infty$
$\boldsymbol{for}\ i = 1\ \boldsymbol{to}\ sizeof(cons\_valid)\ \boldsymbol{do}$
    $ETT = ETT(cons\_valid(i))$
    $\boldsymbol{if}\ ETT < ETT(cons\_valid(i))\ \boldsymbol{then}$
        $ETT = ETT(cons\_valid(i))$
        $selectedroute = cons\_valid(i)$
    $\boldsymbol{end\ if}$
$\boldsymbol{end\ for}$
$\boldsymbol{return}\ (Selectedroute, ETT)$

4.3 Routing algorithm

At the S node, after it received the possible routes, this protocol defines two constraints as follows:

1) The hop numbers ($Hopcount$) of a candidate route must be within the range [$Hopmin$, $Hopmax$]. The routes with hops not within this range will be discarded (Eq. 4).

$$Hopcount = [Hopmin, Hopmax] \tag{4}$$

Where: $Hopmin$ is the hop numbers of the shortest route and in the candidate routes. Aiming to support QoS and limited end-to-end latency of selected route, this protocol establishes $Hopmax = Hopmin + 2$.

Let N denote the total number of possible routes obtained by Eq. 4, and $ETTSet$ denote the set of ETT metric of the respective routes, then $ETTSet$ can be written as follows:

$$ETTSet = \begin{cases} ETT_1 \\ ETT_2 \\ . \\ . \\ . \\ ETT_{n-1} \\ ETT_n \end{cases} \tag{5}$$

The candidate route with the lowest ETT can be determined as follows (Eq. 6):

$$Optimalroute = \text{Min}\ (ETTSet) \tag{6}$$

Consequently, a suitable route is indicated by Eq. 6. The details of the routing algorithm are described by the Algorithm 1 (A-AODV Algorithm).

5 Results and Analyses

For performance evaluation of A-AODV and comparison with the existing protocols, this work set up a simulation system on NS2. The system has 200 mobile nodes is randomly established in a 1000 × 1000 (m) area. The evaluated protocols are A-AODV, AODV and, DSR on aspects packet delivery ratio, latency, and throughput as described in subsection 5.1. The remaining parameters are described in Table 1.

Table 1. Simulation Parameters

Parameter	Value
Simulation Time	300s
Topology Size	1000m×1000m
Number of Nodes	200
MAC	802.11
Traffic Type	CBR
Bandwidth	11 Mbit/s
Packet Size	1024 byte
Transport Layer	UDP
Mobile Speed	2 m/s
Transmission Range	250 m
Mobility Model	Two-Ray Ground
Protocols	A-AODV, AODV, DSR

5.1 Evaluation criteria

- Packet Delivery Ratio: It is defined as the ratio percentage of the total number of the received packets by the destination node on the total number of packets sent from the source node, denoted PDR. The PDR is determined as follows (Eq. 7):

$$PDR = \frac{P_s}{P_r} \times 100\% \quad (7)$$

- Delay: It is defined as the period to transmit a packet from source node to destination node. In this work, the concept of average end-to-end delay is used. It is the total end-to-end delay of all entire packets during a simulation, denoted $Delay_{avg}$, the unit is second (s). The $Delay_{avg}$ is determined as follows (Eq. 8):

$$Delay_{avg} = \frac{\sum_{i=1}^{n}(t_r - t_s)}{P_r} \quad (8)$$

Throughput: It is calculated by multiply the numbers of the packet travelled and the size of the packet per one unit of time. In this work, the concept of average throughput, denoted $Throughput_{avg}$, and the unit is bit per second (bps), it is determined as follows (Eq. 9):

$$Throughput_{avg} = \frac{P_r \times Size}{T \times Delay_{avg}} \quad (9)$$

where:

- P_r is the total number of received packets by the destination nodes in the simulation process,
- P_s is the total number of sent packets by the source node in the simulation process,
- t_r is the period of the received packet at the destination node,
- t_s is the period of the sent packet at the source node
- T is the period of the simulation process,
- $Size$ is the packet size.

5.2 Simulation and analytical results

In the first experiment, we present the performance of the network in terms of packet delivery ratio (see **Figure 7**). As we can see in **Figure 7,** the three routing protocols have the packet delivery ratio rather high, over 92% when the number of connections in the system is less than 20 pairs. However, as the network traffic increases, the PDR of the A-AODV protocol is better than two other protocols (i.e., AODV and DSR). The A-AODV protocol always presents a higher and more stable PDR compared to the two other protocols. These results is consistent with theoretical calculations. As the in-network traffic is low, congestion will limit occur, routing methods based on hop count are suitable. However, as the in-network traffic increases, routing methods based on hop count only use the route with the smallest hop number. Consequently, it will lead to some overloaded nodes, the congestion and conflict state more and more increase. In that case, the proposed method will be robust effective.

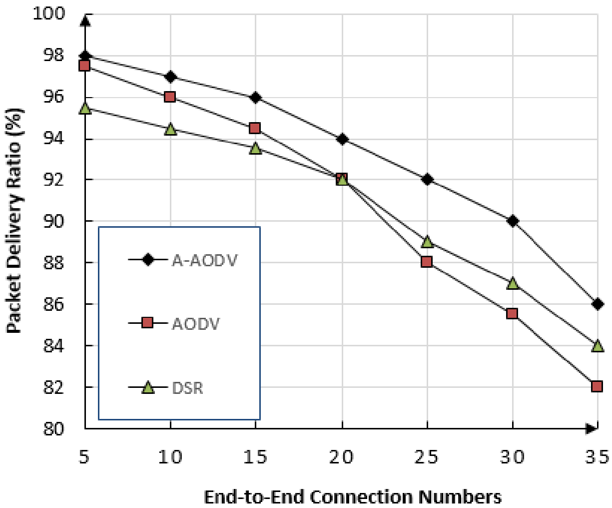

Figure 7. Packet Delivery Ratio

In the second experiment, we present the performance of the network on the aspect of average delay in **Figure 8**. The figures indicate that the delay increases as the number of connection flows increases. As the number of connection flows in-network is less than 10 pairs, the delay of protocols is similarly low, the delay of the AODV routing protocol is the lowest. As the number of connection flows increases to over 15 pairs, the delays of protocols are rapidly increase and rather high. In these cases, the A-AODV routing protocol always obtains the lowest delay.

The simulation results show that with configuration and simulation parameters is established, the A-AODV protocol with routing method based on ETT and hop count parameters always presents best and stable the PDR and delay criterion.

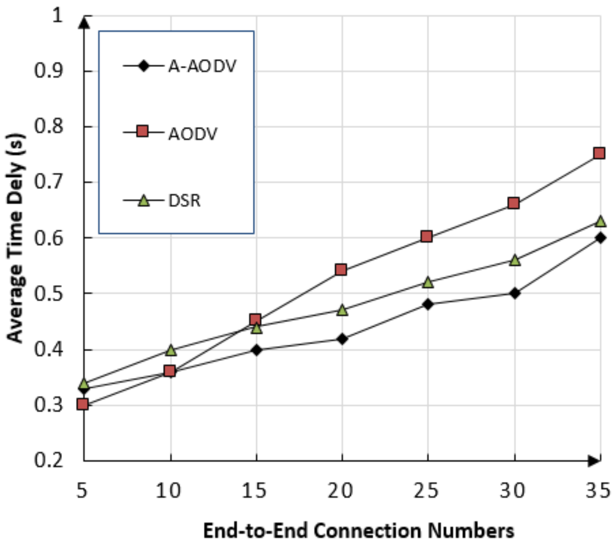

Figure 8. End-to-End Delay

As the number of connection flows in-network is low, the routing method based on hop count is suitable. As the number of the connection flows in-network increases, the protocols such as AODV and DSR reveal many limitations and achieve lower performance than the proposed protocol (i.e., A-AODV).

6 Conclusions

In this research, we introduced a routing protocol for MANET, namely A-AODV which integrates the ETT and hop count parameters to select an optimum route. The simulation results demonstrated that A-AODV obtain a significant performance compared to the two well-known protocols for MANET (i.e., AODV and DSR). Furthermore, we are also aware that the proposed protocol has not been entirely studied for the energy consumption evaluation when mobile agents operate to communicate between neighbouring nodes aiming to get routing information. In our opinion, it is a trade-off solution to obtain high-performance routes. In the future, we are going to deal with these limitations.

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