Journal of Mobile Multimedia, Vol. 9, No.1&2 (2013) 155-170

A VISUALIZATION SYSTEM FOR MOBILE AD-HOC NETWORKS

AKIO KOYAMA and SHOHEI SATO

Yamagata University, Japan
akoyama@yz.yamagata-u.ac.jp, tan27894@st.yamagata-u.ac.jp

LEONARD BAROLLI

Fukuoka Institute of Technology, Japan
barolli@fit.ac.jp

MAKOTO TAKIZAWA

Hosei University, Japan
makoto.takizawa@computer.org

Mobile ad-hoc networks (MANETs) are autonomous distributed networks, where mobile nodes communicate with each other using wireless links. Since the communication is done by wireless links, it is difficult to grasp the network situation. It becomes even more difficult when the number of nodes is increased. In this paper, we propose a visualization system for MANETs. The system can mainly visualize the network topology, state of nodes, and packet flows in MANETs using mobile PCs and wireless LAN cards. The multi-hop communication function needed for visualization of MANETs was also implemented on the application layer. For visualization of network topology, we implemented three modes: GPS mode, Hop Tree mode and manual mode. Furthermore, in order to show the effectiveness of the system, we implemented DSR protocol and visualized its packet flow. We verified by experiments that the visualization system can promptly represent the network topology, the state of each node, and the packet flow.

Key words: Visualization system, MANET, network topology, packet flow, wireless communication, network management

1 Introduction

Mobile ad-hoc networks (MANETs) are a collection of randomly moving wireless devices within a particular area. Unlike in cellular networks or wireless LAN, there are no fixed base-stations to support routing and mobility management. The wireless devices in MANETs also vary dynamically in their resource-richness. In MANETs, mobile nodes function as hosts and routers. As hosts, they represent source and destination nodes in the network, while as routers, they represent intermediate nodes between a source and destination, providing store-and-forward services to neighbor nodes. Nodes that construct MANETs are free to move randomly and organize themselves in arbitrary fashions. Therefore the wireless network topology that interconnects mobile nodes can change rapidly in unpredictable ways or remain relatively static over long periods of time [1-4].

In MANETs, a route is constructed by a routing protocol and the packets are sent from the source node to the destination node using the constructed route. However, for humans, it is difficult to know which route is used for packet flow. This is because the route is automatically determined by routing protocol and all packets don't flow the same route since the network topology is changed over the time. Therefore, in order to analyse the performance of MANETs, it is very important to grasp the network topology and the packet flow.

Furthermore, MANETs have problems of wireless network link instability and poor efficiency. Since the network is composed of mobile nodes, the battery has a limited functioning time. Moreover, the range of the wireless radio is also limited, thus the network may be disconnected because of unexpected node moving or the radio wave can't reach neighbor nodes.

It should be noted that the topology of MANETs should be adopted based on the density of node allocation. There is a possibility that the density of node distribution is low or high, because at the beginning the nodes are allocated in a random way. For long distance communication is better that node density is high. However, when the network load is high, the ad-hoc node density should be low. For this reasons, in ad-hoc networks, not only routing but also the state and the node density allocation greatly influence the network performance [5].

From these reasons, it is important to grasp the network situation by visualization system. There are some visualization systems for MANETs like Mesh Vista [6], NS-2 [7] and so on. However, they have various limitations and problems.

In this paper, we propose a visualization system for MANETs. The system can mainly visualize the network topology, state of nodes, and packet flows in MANETs by using mobile PCs and wireless LAN cards. A multi-hop communication function and a pseudo protocol needed for visualization of MANETs are also implemented on the application layer. For visualization of network topology, we implemented three modes: GPS mode, Hop Tree mode and manual mode. Furthermore, in order to show the effectiveness of the proposed system, we implemented the Dynamic Source Routing (DSR) protocol and visualized its packet flow by animation. We verified by an experiment that the visualization system can promptly represent the network topology, the state of each node, and the packet flow.

The paper is organized as follows. In Section 2, we discuss related work. In Section 3 and 4, we introduce the proposed system. In Section 5, we show the experimental results. Finally, in Section 6, we present some concluding remarks.

2 Related Work

In this section, we briefly discuss Mesh Vista and Network Animator as related work.

2.1 Mesh Vista

Mesh Vista is a monitoring system for ad-hoc networks developed by the ThinkTube Company [6]. Mesh Vista has a middleware called Mesh Cruzer, which constructs the ad-hoc network and makes its visualization. So, Mesh Vista needs a special node for the Mesh Cruzer. By using Mesh Vista is possible to get the connection status between nodes, MAC address, IP address and the type of communication equipments. However, in Mesh Vista, the node position is not taken into account, only the connection information between nodes is used for visualization. Furthermore, Mesh Vista cannot make the visualization of the packet flow.

2.2 Network Animator

The Network Animator (NAM) [8] is a subsystem of Network Simulator version 2 (NS-2) [7]. NAM can make the visualization by using the output data of NS-2. NAM can also display the packet flow.

Most of the visualization systems developed so far are used for displaying the simulation results [9]. In the best of our knowledge, there are not implemented systems for displaying the situation (network topology, state of nodes, packet flow and so on) of an actual MANETs like our system.

3 Proposed System: Visualization of Network Topology

The MANETs were constructed using mobile PCs and wireless LAN card. We developed the system, which can display in a visible way the topology of MANETs [10]. We implemented the following functions.

- A wide-range multi-hop communication of MANETs for construction of MANETs.
- Communication functions for node information collection.
- Visualization functions for network topology.

3.1 Communication Method

In this system, the communication is done by the flooding. The flooding is a communication technique that transmits the packet in neighbor nodes using broadcasting as shown in figure 1. The received packet is managed by the sequence number in each node. When the same packet is received, the packet loop is prevented by removing second packet. Since for flooding is not needed the routing table, the packet processing is very easy. But, the broadcasting of packets results in the increase of network load. However, in order to make the network visualization we need the information of entire network. This is the reason why we selected the flooding method.

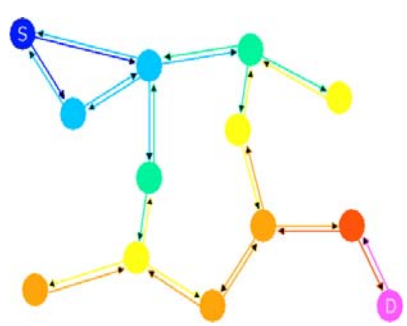


Figure 1 Packet flooding.

3.2 Communication Method for Node Information Collection

The node information collection procedure between neighbor nodes is carried out as follows.

1) Each node transmits a search packet to neighbor nodes.
2) When each node receives a reply packet from the neighbor nodes, each node creates a neighbor node table which includes all neighbor nodes information.

As a result, each node can grasp the information of neighbor nodes.

The communication procedure of a monitoring node for visualization is carried out as follows. The monitoring node is a visualization node of MANETs.

1) The monitoring node transmits the node information request packet to all nodes. The packet is transmitted to entire network using flooding.
2) The node that received the node information request packet returns the reply packet that includes the own node information and the neighbor node table to the monitoring node.

As a result, all nodes information is collected to the monitoring node as shown in figure 2. The monitoring node carries out the visualization by using the network information.

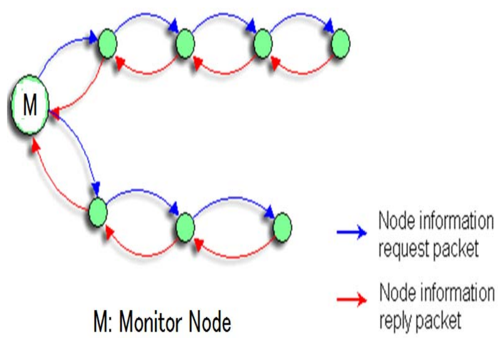


Figure 2 Node information collection.

3.3 Visualization Modes of Network Topology

The visualization by graphics is carried out based on the network information collected by the node information collection communication. We considered three modes for visualization.

GPS Mode: In this mode, real positions of nodes are gotten from GPS devices attached to mobile PCs. It is the same visualization mode as the network diagram. The distance and the azimuth between neighbor nodes are measured by the location information of GPS. This information is used for node placement.

Hop Tree Mode: This is a mode of visualization like the tree diagram. In this mode, the number of shortest hops from the monitoring node are calculated and then based on the number of hops the visualization is realized.

Manual Mode: Basically, this mode is the same as network diagram visualization. This mode can show the connection information of each node, because all nodes in the communication range are connected by lines. In addition, the user can move each node easily to make the display more clear. However, this mode cannot visualize the real position like GPS mode.

3.4 Implementation

A wide-range multi-hop communication cannot be realized only by ad-hoc mode of wireless LAN card installed in mobile PC. For this reason, we implemented a pseudo protocol, which can achieve the multi-hop communication on the system.

3.4.1 Implementation of Pseudo Protocol

The pseudo protocol is implemented and operates on the application layer. A protocol layering model of pseudo protocol is shown in figure 3.

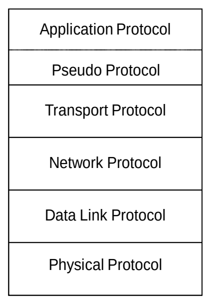


Figure 3 Pseudo protocol in network stack.

In TCP/IP, the data transmission is carried out by TCP and IP protocols considering source and destination. In the system, instead of TCP/IP protocols, we use the pseudo protocol. This has been achieved by using the UDP protocol and the broadcast address.

3.4.2 Operation of Pseudo Protocol

In the pseudo protocol are implemented only some functions necessary for the flooding. For this reason, the routing is not needed. The flow chart of this operation is shown in figure 4.

After a packet is received in a node, the source address and the sequence number are checked. This packet is removed to prevent the packet looping when the sequence number of the packet is the same as the previous received packet. Next, the destination address of the packet is checked. When the destination address does not match its own address, the packet is broadcasted. By this operation, the flooding is carried out. When the destination address of the packet matches its own address, the sequence number is registered. This is because receiving of the duplication packet prevents. Next, the type of packet is examined, and the process of matching each packet is carried out.

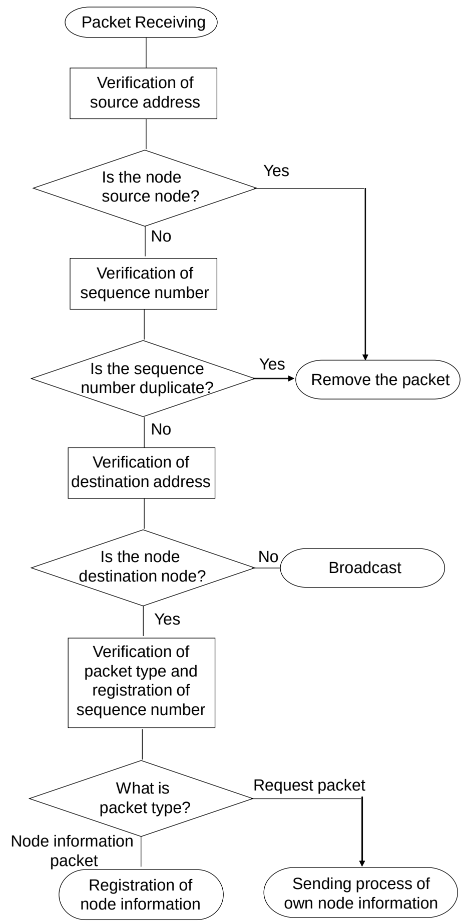


Figure 4 Flowchart of pseudo protocol.

3.4.3 Pseudo Packet

Data is exchanged in the system by the pseudo packet designed for a pseudo protocol. In the header of the pseudo packet are included the following fields: sending node address, source node address, destination node address, sequence number and data type. The pseudo packet format is shown in figure 5. This pseudo packet is capsulized in UDP/IP packet and then transmitted.

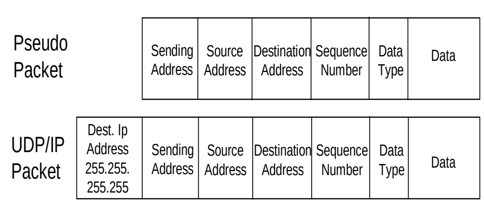


Figure 5. Capsulization of pseudo packet.

3.4.4 Visualization Function

The operation screen of the system is shown in figure 6. This is realized by GUI and provides the drawing region, drawing setting region and the network node table region.

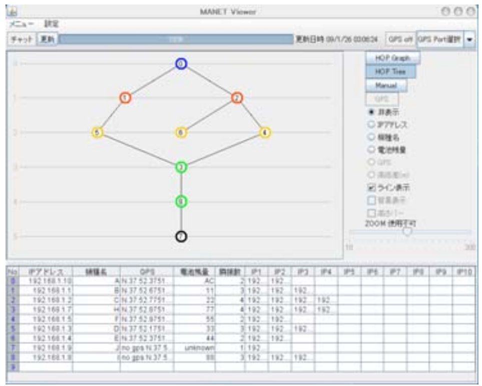


Figure 6 Operation screen.

The system provides three visualization modes as follows.

GPS Mode: GPS Mode is shown in figure 7. The monitoring node is put in the center of the circle and the distance of other nodes from monitoring node are calculated by the GPS and they are displayed. It is also possible to display the distance between monitoring node and other nodes. This mode is equipped with the range expansion and reduction function, so it is possible to be used for networks from several meters to several kilo meters. However, for this visualization mode the GPS device should be provided for all network nodes, so the cost becomes high compared with other visualization modes. Also, it should be noted that the GPS cannot be used in indoor environments.

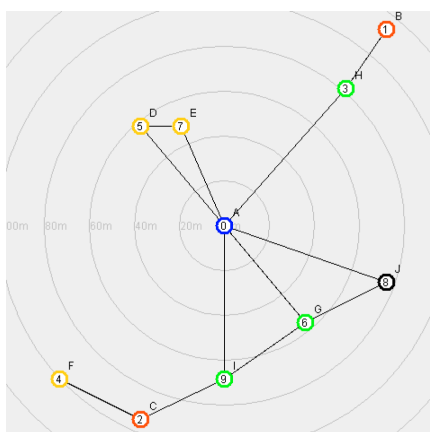


Figure 7. An example of GPS Mode.

We carried out an experiment to show the accuracy of GPS. The distance between two nodes was fixed beforehand and the signal was received 50 times. We calculated the distance between two nodes by the GPS and compared with the real distance. For this experiment, we used the program of Geographical Survey Institute of Japan for the calculation of the real distance [11]. The results are shown in figure 8. We found that the error range between GPS and the real distance is within 1.5 m radius. Since the distance between nodes in MANETs is considered from several meters to several hundred meters, it can be considered a good practicable value.

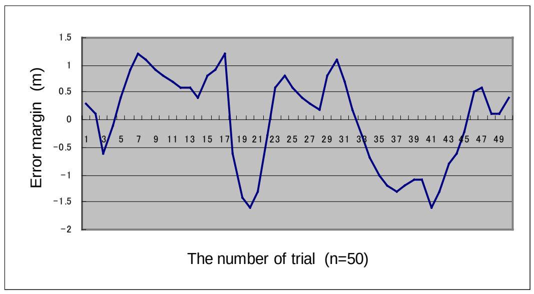


Figure 8 Error between GPS value and real distance.

Hop Tree Mode: The Hop Tree Mode is shown in figure 9. The monitoring node is placed at the top, and other nodes are placed based on the hop distance order. When there are many nodes at the same layer, each node is placed to the same distance. Therefore, the nodes are never overlapped to each other. In addition, since the route between the monitoring node and the target node is the shortest path, the discovery of the shortest route is easy.

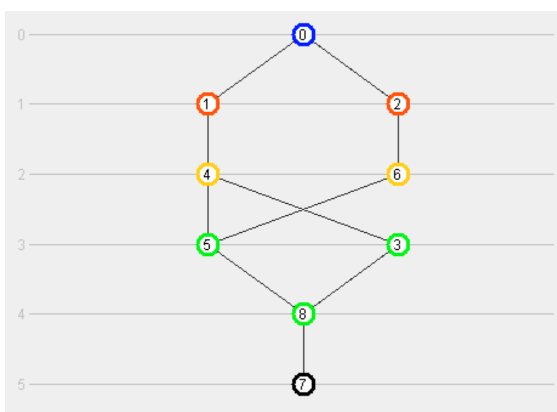


Figure 9 An example of Hop Tree Mode.

Manual Mode: The Manual Mode is shown in figure 10. Since the user can freely change the placement of nodes even after they are allocated by the system, the network structure can be reproduced flexibly and accurately. Moreover, it is possible to put the image into background and to change the placement according to the situation. However, this mode can't be used for networks with mobile nodes because the movement of the node is not supported by this mode. This mode is an effective technique for visualization of a fixed network where the position of the node is known beforehand.

Figure 10 An example of Manual Mode.

The system can display also the node information such as: host name, IP address and so on. This information can be displayed on the upper right side of the node as a common function for all modes of visualization. If user wants to display this information, the user has to set corresponding radio button. In addition, the battery remaining quantity is also shown by different colors for easily viewing as shown in Figure 11.

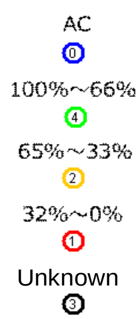


Figure 11 Display of battery remaining quantity.

4 Proposed System: Packet Flow Visualization

In this section, we describe the packet flow visualization by our system. We implemented many functions in order to carry out the visualization of packet flow in MANETs [12].

In our system, we have implemented the following functions:

- Packet Log Acquiring Function,
- Packet Log Collection Function,
- Animation Table Creation Function,
- Animation Displaying Function,
- Viewer Function.

4.1. Packet Log Acquiring Function

Each node records the packet log which is the history of sending and receiving packet for animation displaying during a constant time. The packet log table for displaying animation is shown in figure 12. In this figure, the sequence number is a unique number which is added to a sending packet and is used for distinguishing the packets. The SR field is used to distinguish whether the recorded data are for the sending packet log or receiving packet log. The port, IP1, IP2 and time stamp are changed based on the recorded data type (sending packet log or receiving packet log). The port field shows a source port or a destination port. For instance, in the case of sending packet log, in IP1 field is put the source IP, in IP2 field the destination IP and in time stamp field the sending time. In the case of receiving packet log, in IP1 field is put the destination IP, in IP2 filed the source IP and in time stamp field the receiving time.

Sequence Number	SR	Port	IP1	IP2	Time Stamp
⋮	⋮	⋮	⋮	⋮	⋮

0	S	3100	192.168.100.1	255.255.255.255	12:00:00:000
1	R	3100	192.168.100.1	192.168.100.2	12:00:00:025
⋮	⋮	⋮	⋮	⋮	⋮

Figure 12 Packet log table.

4.2. Packet Log Collection Function

After the packet log acquiring process for animation of the packet flow is carried out, the monitoring node has to do the packet log collection process which collects the packet log of each node.

In order to collect packet logs, the monitoring node sends by flooding a log collection packet to all nodes. The nodes which receive the log collection packet use the packet log acquiring function to collect the log data. That is each node acquires the information of packets which flew during a predetermined time. After the log acquiring function was finished, each node returns a reply packet to the monitoring node. The reply packet format is shown in figure 13. The monitoring node completes the packet log collection by receiving all reply packets.

Furthermore, the collected packet logs have to be integrated to one table since each node has one packet log table. The integrated table is called an integrated packet log table. The format of integrated packet log table is same as packet log table of each node shown in figure 12.

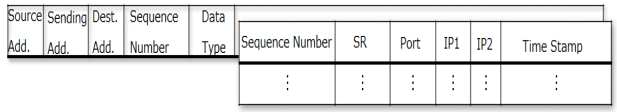


Figure 13 Reply packet format.

4.3. Animation Table Creation Function

The information needed for animation of packet flow is provided by Packet Log Acquiring Function and Packet Log Collection Function. In order to carry out the animation, the arrangement of the information is needed. In MANETs, since broadcast transmission is carried out, many nodes may receive the same packets. For this reason, the number of receiving packet is different from the number of sending packet. Therefore, it is necessary to make an animation table by searching receiving packets which correspond to the sending packet. The content of the animation table is shown in figure 14. The table consists of the source address, destination address, receiving address, sending time, receiving time and port number.

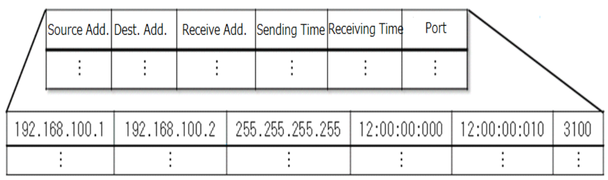


Figure 14 Animation table contents.

The creating procedure of an animation table from the integrated table is as follows. First, a sending packet log is searched. Then, a receiving packet log which corresponds to the sending packet log is searched. After that an animation table is created by integrating sending and receiving packet log information. The conversion example from the integrated packet log table to the animation table is shown in figure 15. Since the flooding process may have many receiving packet logs, it is necessary to refer the all receiving packet logs. When all sending packet logs are processed, the integration of table is finished.

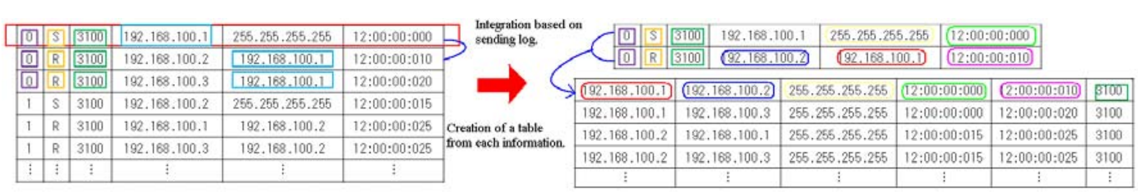


Figure 15 Conversion example from the integrated packet log table to the animation table.

4.4. Animation Displaying Function

After the creation of the animation table is completed, it is possible to display the animation of the packet flow of MANETs.

For animation display, the set up of starting time and finishing time of a packet display is needed. Based on this display time, the record of animation table is searched. The searching records are displayed based on the packet sending time (the packets that are sent first are displayed first). The node display position and packet display position are calculated as follows. The packet display position is derived by Eq. (1) and Eq. (2).

$$PX = SX + (SX - RX) * ((PDT - PST) / (PRT - PST)) \quad (1)$$

where, the PX is the packet axis X, the SX is the sending axis X, the RX is the receiving axis X, the PDT is the packet displaying time, the PST is the packet sending time and the PRT is the packet receiving time.

$$PY = SY + (SY - RY) * ((PDT - PST) / (PRT - PST)) \quad (2)$$

where, the PY is the packet axis Y, the SY is the sending axis Y, the RY is the receiving axis Y, the PDT is the packet displaying time, the PST is the packet sending time and the PRT is the packet receiving time.

The display ways are changed based on the destination address. In figure 16 is shown the display of broadcast (figure 16 (a)) and unicast transmission (figure 16 (b)).

It is needed only few time for creation and searching of animation table. This is very short time. Therefore, the preparing time until the animation displaying is almost the same as packet log collection time.

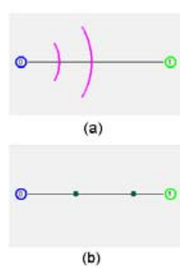


Figure 16 Displaying of (a) broadcast and (b) unicast transmission.

4.5. Viewer Function

1) GUI Interface

The GUI interface used for animation is a new function added to the system for displaying of the network topology. The system operation screen is shown in figure 17. The operation buttons and slide bars of the drawing area are shown in figure 18. The displaying time of animation can be changed by using these components. It is possible to adjust the playing speed and the visualization time freely by operating the speed bar and seek bar. Furthermore, the acquired packet logs can be displayed in real time as shown in figure 19.

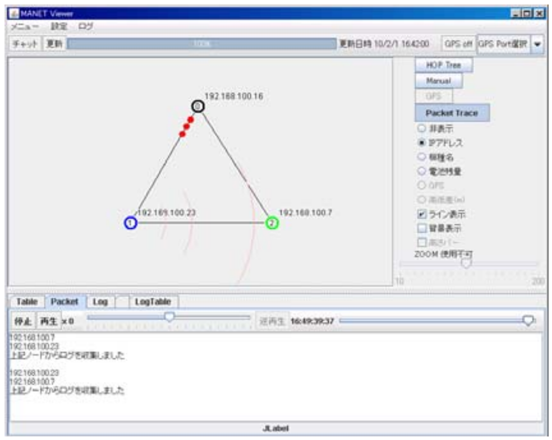


Figure 17 Operation screen.

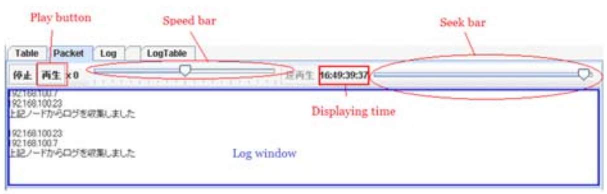
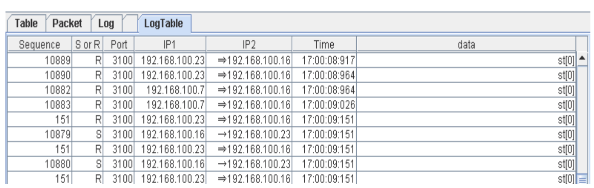


Figure 18 Animation panel.



Sequence	S or R	Port	IP1	IP2	Time	data
10889	R	3100	192.168.100.23	⇒192.168.100.16	17:00:08:917	st[0]
10890	R	3100	192.168.100.23	⇒192.168.100.16	17:00:08:964	st[0]
10882	R	3100	192.168.100.7	⇒192.168.100.16	17:00:08:964	st[0]
10883	R	3100	192.168.100.7	⇒192.168.100.16	17:00:09:026	st[0]
151	R	3100	192.168.100.23	⇒192.168.100.16	17:00:09:151	st[0]
10879	S	3100	192.168.100.16	→192.168.100.23	17:00:09:151	st[0]
151	R	3100	192.168.100.23	⇒192.168.100.16	17:00:09:151	st[0]
10880	S	3100	192.168.100.16	→192.168.100.23	17:00:09:151	st[0]
151	R	3100	192.168.100.23	⇒192.168.100.16	17:00:09:151	st[0]

Figure 19 Displaying of packet logs.

2) Displaying of Animation

The image of the visualization of packets via the system is shown in figure 17.

3) Example of Application

The DSR protocol [13-15] is a routing protocol for MANETs. In the DSR protocol, the collection of routing information is carried out then the nodes communicate using the route. It is possible to verify the situation of route and data transmission by looking at results of the animation displaying (see figure 20).

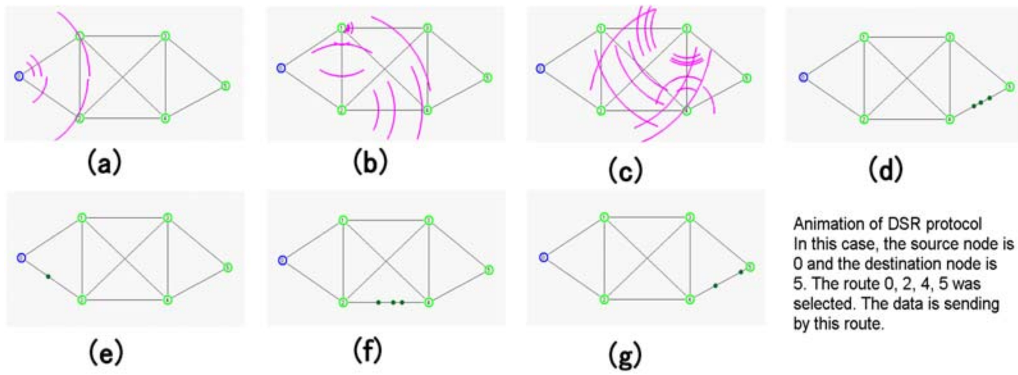


Figure 20 Animation of DSR protocol.

5. Experimental Results

5.1. Completion Time of Animation Preparation

The completion time of animation preparation is summation of the log acquirement time, the packet log collection time and the creation time of animation table. The completion time of animation preparation is influenced by the number of nodes and the hop counts. So, we carried out some experiments for different conditions.

In this experiment, the packet log collection time was measured by changing the number of nodes and hop counts. The visualization time was set to 10 seconds (constant time). Since the time for animation table creation is very small, we omitted from the preparation time. So, the packet log collection time is the same with animation preparing time.

The packet log collection time for one hop is shown in figure 21. We can see that the packet log collection time is increased with the increase of number of nodes. The maximum packet log collection time for 6 nodes was about 3.8 seconds and the average packet log collection time was 3.23 seconds.

The packet log collection time for different hops is shown in figure 22. We can see that packet log collection time is increased with the increase of number of hops.

From two experimental results, we found that the increase of number of neighbor nodes has bigger effect on the packet log collection time compared with the number of hops. To solve this problem, it is necessary to increase the transmission speed between nodes or decrease the amount of information of packet log.

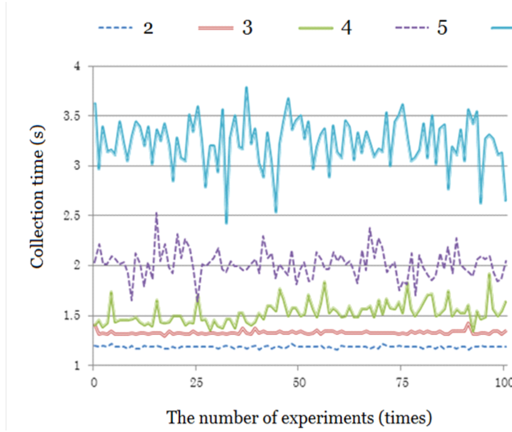


Figure 21 Number of nodes and packet log collection time for 1 hop.

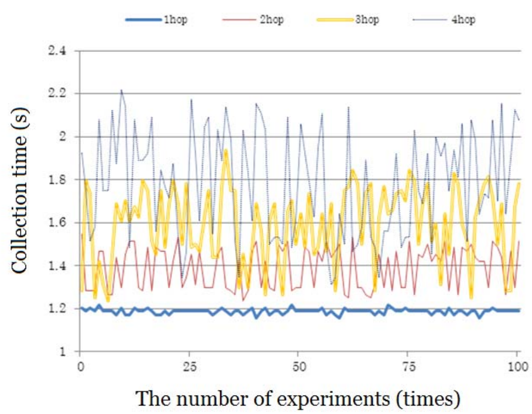


Figure 22 Packet log collection time for different hops.

5.2. Displaying of Animation

The figure 20 shows the result of animation of packet flow for DSR protocol. We could verify the operation of DSR protocol by animation in the system. When we implemented the DSR protocol, there were bugs in the program. But, we could find the bugs by our animation viewer system. Then, the program's bugs could be corrected and we were able to implement the protocol.

6 Conclusions

In this paper, we proposed and implemented a visualization system for MANETs. The implemented system can display not only network topology but also the packet flow.

We evaluated the system by some experimental results. From the evaluation results, we found that the error range between GPS and the real distance is within 1.5 m radius. Since the distance between nodes in MANETs is considered from several meters to several hundred meters, it can be considered a good practicable value.

Furthermore, we found that the packet log collection for packet flow could be completed for about 3.3 seconds when the number of nodes is 6 and for single hop. Moreover, the packet log collection could be completed for about 1.8 seconds when the number of hops was 4. Therefore, we found that by the system is possible to make the visualization in a short time.

Additionally, we implemented the DSR routing protocol in the system and carried out animations. We verified normal operation of protocol from the result.

In the future, we would like to carry out extensive evaluation of the system and use it for the visualization of different MANET routing protocols and applications.

Acknowledgements

The authors would like to thank Japan Society for the Promotion of Science (JSPS) (Project Number: 24500073) for supporting partially this work.

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