A NEW GEOGRAPHIC ROUTING PROTOCOL FOR AIRCRAFT AD HOC NETWORKS

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Abstract

Aircraft ad hoc networks are special network models of mobile ad hoc networks where nodes can move anywhere and at anytime, and can construct networks in a self-organizing way. However, these networks show different features from typical mobile ad hoc networks, which represent the mobility pattern of vehicle or people. Thus, it is required to develop a new routing protocol to support mobility of aircraft in several aspects. In this paper, we propose a new geographic routing protocol that can cope with dynamic topology changes adaptively. The revised protocol makes use of mobility information, which is updated frequently by the base station on the ground. Another contribution is to develop a forwarding mechanism, which makes decisions for the next hop by using three-dimensional geographic information. Finally, simulation model and analysis are provided to validate the high packet delivery ratio with help from the information on infrastructure networks and intelligent forwarding scheme.

1. Introduction

Mobile ad hoc networks [1] can be defined as self-organizing networks in that infrastructure networks are not required to build networks. In addition, these networks have the following properties:

- They can support free movement of the nodes.
- Data transmission is accomplished by way of multi-hop, with the help of each node working as router.

Based on these properties, many applications have a tendency to employ these networks because they need fast network construction without regard to infrastructure. Example includes temporary video conferencing and communications in disaster recovery area.

Due to the different aspects of typical networks, many technologies, including routing protocol, should be developed to cope with dynamic topology changes. In particular, routing protocol takes on a major role in maintaining the path between source and destination without regard to the mobility of the nodes. Many researchers have proposed how to analyze the advantages and disadvantages of each protocol.

In these ad hoc networks, the aircraft is envisioned to participate as a self-aware node and communicates with ground infrastructure and other aircraft. Thus, these networks show different features with typical ad hoc networks; information is delivered and becomes available through in-aircraft, aircraft-to-ground, and aircraft-to-aircraft communications. With the help of these networks, aircraft traffic can be distributed, and reliability and scalability are improved. The need of aircraft ad hoc networks results from the major challenges, due to an unprecedented increase in air traffic, such as airspace congestion, fuel costs, and environmental pollution.

Similar to existing mobile ad hoc networks, aircraft ad hoc networks should solve diverse research challenges to deploy networks. Moreover, they demonstrate outstanding features, due to the properties of the nodes. For example, an aircraft moves faster than vehicles and other transport systems along a predetermined or random path. Furthermore, each aircraft has a longer wireless communication range and locates in sparse areas. It can use geographical information easily, because it employs a Global Positioning System (GPS) for several applications such as navigation. Thus, based on above facts, it is essential to develop communication protocols to reflect several features.

In this paper, we focus on routing protocol in aircraft ad hoc networks. The contribution of new routing protocol includes: 1) modified geographic routing protocol considering the nodes' fast movement and using the information provided through aircraft-to-ground communications; and 2) a

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modified greedy forwarding method, through three-dimensional geographic information and next hop selection based on direction of movement. Additionally, these new functions are employed in the original geographic routing protocol to improve the packet delivery ratio. Since the geographic routing protocol is less sensitive to mobility than other routing protocols, it is chosen as candidate protocol for aircraft ad hoc network in our work.

The remainder of this paper is organized as follows. In Section 2, we review the background of mobile ad hoc networks and research works conducted in this area. A revised geographic routing protocol will be explained in Section 3, followed by simulation and analysis to validate the improved performance in Section 4. Finally, conclusions and further works will be presented.

2. Related Works

In this section, we review mobile ad hoc networks and analyze the existing research, especially routing protocol.

2.1 Mobile Ad Hoc Networks

Mobile ad hoc networks have emerged from the needs of networks, which is different from current mobile networks. Current networks can be described as long deployment time and high deployment cost because they largely depend on infrastructure. However, the mobile ad hoc network can guarantee high performance in the aspects of reliability.

As new network technologies have been introduced, many researchers have paid attention to other applications requiring different features. These include temporary teleconferencing and communications in a disaster area to rescue people. The former does not need infrastructure networks, because it takes a long time to deploy. In addition, since it is formed as temporary networks, deployment cost should be minimized. Therefore, self-organizing networks are strongly recommended for this requirement. In mobile ad hoc networks, each node is independent of others in that each node builds networks in a collaborative way. To construct networks, some nodes within networks take on the role of router, which can forward packet to the destination. An example of mobile ad hoc networks is shown in Figure 1.

Another application for mobile ad hoc networks is use in disaster areas or battlefields where infrastructure networks are not available. In these networks, all nodes should collaborate with others to build networks. Furthermore, all nodes can move for their missions. Thus, mobility support is an essential technology in this application.

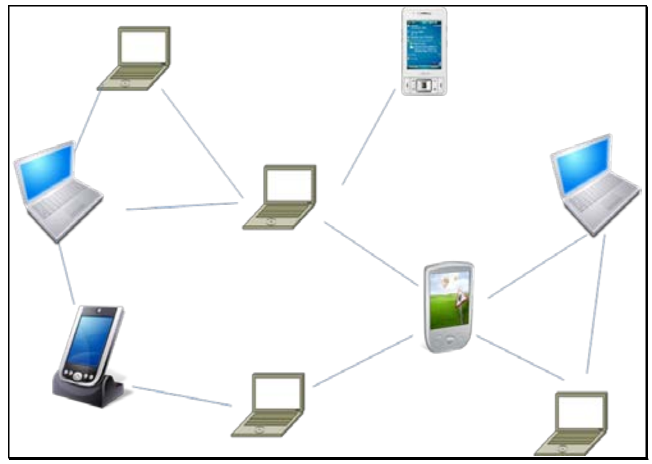

Figure 1. Example of Mobile Ad Hoc Networks

2.2 Routing Protocols in Mobile Ad Hoc Networks [2]

In mobile ad hoc networks, all participating nodes run routing protocol to maintain and establish the connection through an intermediate node. However, mobility and other environments such as low-computing capability and wireless communication medium hinder to adapt current routing protocol in wired networks. To develop routing protocol solutions despite these previous factors, many researchers have developed several routing protocol alternatives. They are divided into two categories, topology-based scheme and geographical-based scheme, according to the information used for the routing process shown in Figure 2. A topology-based scheme exchanges the topology information with the nodes in networks and constructs a routing table by recording next hop node for destination. This basic principle is very similar to one included in routing protocol for wired networks. However, mobility is one of the biggest concerns in routing protocol. Due to dynamic network changes and low computing power, it is necessary to revise and modify current routing protocol in wired networks. Specially, two types of routing protocol have been proposed in a topology-based scheme. One is a proactive scheme; the other is a reactive scheme.

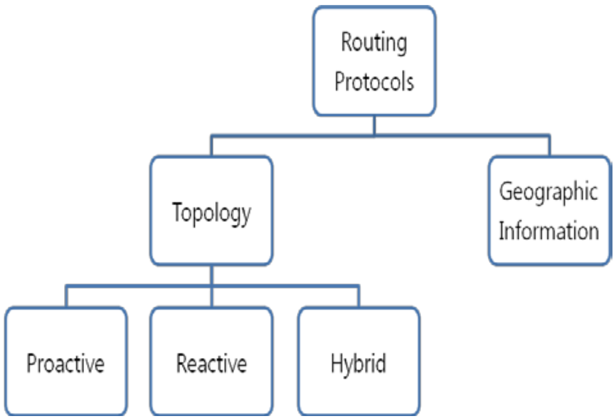

Figure 2. Classification of Routing Protocols in Mobile Ad Hoc Networks

Proactive protocols, also known as table-driven routing protocols, work out routes in the background without regard to traffic demands. Each node uses routing information to store the location information of other nodes in the network; this information is then used to move data among different nodes in the network. This type of protocol is slow to converge and may be prone to routing loops. These protocols keep a constant overview of the network and can be a disadvantage, as they may react to change in the network topology even if traffic is not affected by the topology modification, which could create unnecessary overhead. Even in a network with little data traffic, proactive protocols will use limited resources such as power and link bandwidth; therefore, they might not be considered an effective routing solution for ad hoc networks. Fisheye State Routing [3] is an example of a proactive protocol.

Reactive protocol, also known as on-demand routing protocols, establish routes between nodes only when a source has packets to send. At this time, a source is required to route data packets. There is no updating of every possible route in the network; instead, it focuses on routes that are being used or set up. When a route is required by a source node to go to a destination that does not have route information, it starts a route discovery process, going from one node to the other until it arrives at the destination or a node in-between has a route to the destination. Reactive protocol is generally considered efficient when the route discovery is less frequent than the data transfer, because the network traffic caused by the route discovery step is low compared to the total communication bandwidth. This makes reactive protocols better suited to large networks with light traffic and low mobility. An example of a reactive protocol is Dynamic Source Routing [4].

Hybrid routing protocols combine proactive protocols with reactive protocols. They use distance-vectors for precise metrics to establish the best paths to destination networks and report routing information when there is a change in the topology of the network only. Each node in the network has its own routing zone. The size of this zone is defined by a zone radius, which is defined by a metric such as the number of hops. Each node keeps a record of routing information for its own zone. Zone Routing Protocol (ZRP) [5] is an example of a hybrid routing protocol.

Different from topology based scheme, geographical routing protocol has been proposed to solve scalability, large control overhead, and low packet delivery ratio. The research to develop geographic routing protocol thought that these problems were caused by updating the routing table. To maintain recent information, routing protocol should continue working to exchange information. Rather than topology information, geographic routing protocol tried to solve this problem with an intelligent forwarding scheme through geographic position information. In these protocols, a packet containing geographic position information of the destination will be forwarded by intermediate node, which decides the next hop with some equation based on distance. The process is known as greedy forwarding scheme because they make the best choice with limited information. The example protocols include Greedy Perimeter Stateless Routing (GPSR) [6], Location-Aided Routing (LAR) [7], and so on.

GPSR is one of the most famous geographic routing protocols. Whenever a source node wants to send data, it needs to know the position of the destination in GPSR. The routing decision at each node is based on the destination’s position, which is contained in the packet. Every forward node needs to choose one neighbor from its neighbor table that is closest to the destination to forward the packet. Then the packet will be forwarded directly to the destination.

The most important concept of GPSR is greedy forwarding, which means a node can make a greedy choice for choosing the packets' next hop. To implement this purpose, nodes in the network must maintain their neighbor table, which contains position information of their one-hop neighbors. In GPSR, the neighbor table needs to be updated by a HELLO packet, which will be forwarded within a period. By referring to these tables, every packet will be forwarded until they arrive at the destination. In greedy forwarding procedure, each node should choose one node that is the nearest from its neighbor until the destination node is reached. The nearest one means that the direct distance between the chosen node and the destination has the smallest value. This packet-sending procedure is called greedy forwarding. For example, in Figure 3, the radio range of node A is denoted by the circle around. In addition, the arc with radius equals to the distance between A and D, and is shown as the dashed arc about node D. Node A forwards the packet to B instead of other neighbor nodes, because the distance between B and D is less than the distance between D and other neighbors of A. The greedy forwarding process will repeat until the packet reaches D.

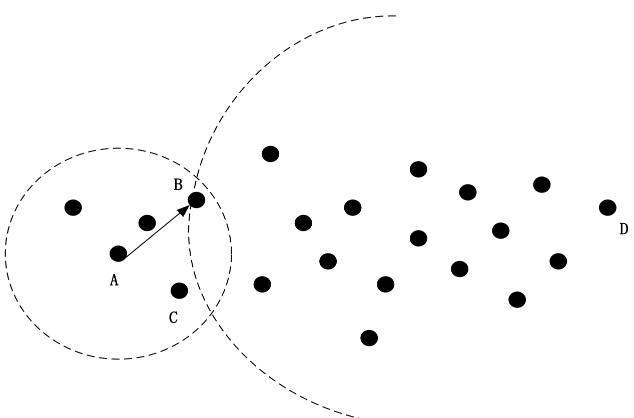

Figure 3. Example of Greedy Forwarding

2.3 Aircraft Ad Hoc Networks [8]

Aircraft ad hoc networks are defined as self-organizing networks where an airplane works as a node. Different from existing mobile ad hoc networks, aircraft ad hoc networks can communicate with ground station. The example of aircraft ad hoc networks is illustrated in Figure 4. In Figure 4, aircraft-to-aircraft communications and aircraft-to-ground communications are illustrated according to participating node in communications.

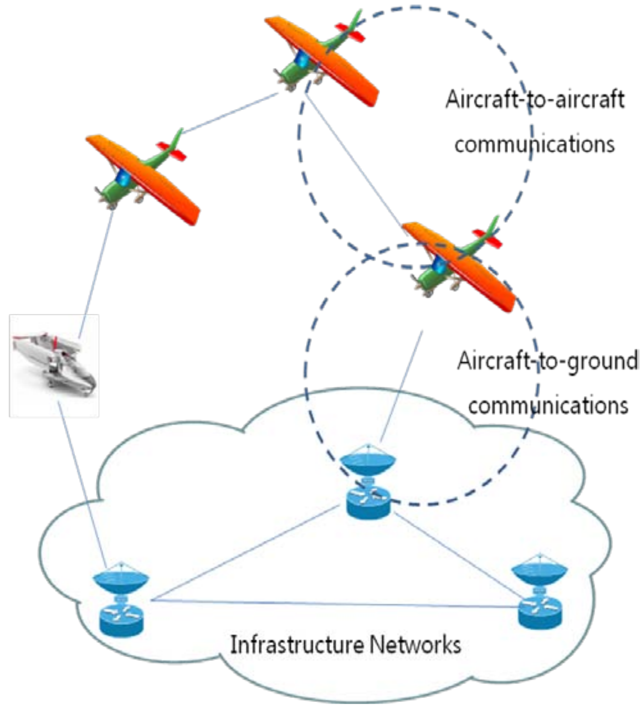

Figure 4. Example of Aircraft Ad Hoc Networks [9]

While aircraft ad hoc networks offer enormous footprint coverage for each node, compared to conventional solutions, this coverage is achieved at the expense of unique problems in antenna placement, transceiver design, protocol design, and integration.

3. Geographic Routing Protocol for Aircraft Ad Hoc Network (GRAA)

3.1 Problem Definition

Previous geographic routing protocol is considered to work in self-organizing networks through information obtained from aircraft-to-aircraft communications. However, aircraft ad hoc networks have different characteristics at this point because it can communicate with base stations on the ground. In addition, the aircraft moves along the predetermined route, according to the schedule. Thus, it is possible to make use of the route information to improve the performance of geographic routing protocol for aircraft ad hoc networks.

Another difference is found in the form of geographical position information. Usually, other mobile ad hoc networks use flat geographic position information represented in a two-dimensional format. However, since an aircraft makes use of three-dimensional information, some revision should be made.

3.2 Movement along the Route

A new GRAA is proposed in this section. GRAA can be considered a hybrid approach in that it combines features of a topology-based scheme with a geographic-based scheme. This means that topology information sent from a base station on the ground and geographic information for destination are used at the same time while deciding next hop.

When a sender has packets to send, the sender creates a packet containing geographic position information of the destination and unique node identification number. When the intermediate node receives the packet, it checks whether the node identification number matches with its own. If a node is the destination, a packet is sent to the application. Otherwise, it tries to forward this packet to one of its neighbors. In this process, the mobility information of the neighboring node can be used. The key point of the proposed scheme is that a node forwards the packet to the next hop, which is expected to move the packet toward its destination. This scheme requires the use of a neighboring table, which records the node ID number and moving direction. Table 1 shows the new terminology used to describe the algorithms

Table 1. Terminology

Terminology	Description
S	Source node
D	Destination node
$P_{i,t}$	node i's geographic position at time t
$Distance_t(i,j)$	Euclidean distance between node i and j at time t
N_i	Set for a node i's neighboring nodes
V_i	A node i's velocity

Five steps are performed for each packet on a node i.

Step 1: Compute the expected geographic position of the destination after time period t.

Step 2: For all neighboring nodes, compute the expected geographic position between the nodes and the destination.

Step 3: Calculate the distance between expected positions.

Step 4: Select the shortest distance in Step 3.

Step 5: The neighboring node that is chosen in Step 4 is decided as next hop.

Algorithm 1: Deciding Next Hop at Node i

1. $P_{D,t1} = P_{D,t} + V_D * (t1 - t)$ where $t1 > t$

2. For all j in N_i

$P_{j,t1} = P_{j,t} + V_D * (t1 - t)$

3. For all j in N_i

$Distance_t(j, D) = EU_t(P_j, P_D)$

4. Select node j that has $Distance_t(j, D)$.

5. Forward packet to the node j.

As explained, GRAA uses three-dimensional geographic information rather than two-dimensional geographical information; therefore, the Euclidean distance can be computed through three-dimensional information.

$$EU_t(P1, P2) = \sqrt{\begin{aligned}&(P_{1,t}.x - P_{2,t}.x)^2 + (P_{1,t}.y - P_{2,t}.y)^2 \\ &+ (P_{1,t}.z - P_{2,t}.z)^2\end{aligned}}$$

Movement along the Random Route

If a node moves randomly, rather than on a predetermined route, GRAA applies a different algorithm to decide the next hop because it is impossible to get the information for mobility. In this case, the neighboring table should record the direction of movement. This information is updated periodically. When an intermediate node receives a packet, it searches the neighboring table with direction of destination. A neighboring node moving toward the destination is decided as next hop. The process continues until a packet is delivered to the destination.

Under random movement, it is impossible to deliver a packet to the destination. In this case, a node moves by carrying the packet until it meets a suitable node, which is expected to move toward the destination. If this node can find a more appropriate node to relay the packet to the destination, it forwards the packet to this node. This scheme can be considered for applying opportunistic networking [10] technology into mobile ad hoc networks. This scheme is better than the geographic routing protocol because the original scheme drops a packet when it cannot find the appropriate neighboring node.

4. Performance Evaluation

We evaluate the performance of a proposed scheme by conducting various simulation studies. The simulation model was built around Qualnet [11]. We performed the simulation to provide quantitative performance analysis with the original scheme and in terms of packet delivery ratio and average end-to-end delay. Each parameter is defined below.

- Packet delivery ratio: The number of received packets among the total sent packets.
- Average end-to-end delay: The elapsed time from the moment when a packet with a unique identifier is received to when a packet with unique identifier is sent. It includes forwarding time and waiting time along the path.

For comparison, GRAA and GPSR were employed. We used IEEE 802.11 DCF as MAC protocol. For each simulation, we provided simulation results over random waypoint model and predetermined route. We chose GPSR for comparison, because it is a well-known protocol and can provide relative simulation results. In addition, we can easily identify the improved performance because only new algorithms are added to original GPSR. Thus, other parts are identical to the original GPSR.

4.1 Simulation Model

Our simulation models a network of 50 mobile hosts placed randomly within a 3000 by 3000 meters square area at the beginning. Each node has a radio transmission range of 200 meters and channel capacity is 2 Mbit/sec. A two-ray ground model is used as a radio propagation model. Traffic is generated as constant bit rate (4 packets/second), and the packet size is set to 512 Kbytes. Without removing other effects by the background traffic, only one connection is assumed.

4.2 Simulation Results

Figure 5 shows the simulation results in the packet delivery ratio along the predetermined route. As the speed of movement on a node increases, the figure shows large difference between two comparative protocols. This is because the original geographic routing protocol contains the expected moving zone when it issues the packet. If the packet is not within the expected zone, it is impossible to deliver this packet to the destination correctly. On the other hand, GRAA uses the updated information from base station on the ground to find the more suitable next hop with up-to-date position information. This implies that hybrid approach between pure ad hoc networks and infrastructure network can take advantage of both networks. To use this approach, another benefit is short end-to-end delay, as seen in Figure 6. This means that the GRAA finds better paths than GPSR. In the GPSR, since decisions are made through current position information, a packet delivered to an unexpected zone, requires one more detour path so it can increase end-to-end delay. The major reason for this simulation result is that GPSR makes decision through current position information. GRAA, on the other hand, makes use of the mobility pattern. Therefore, GRSS should ensure correct delivery.

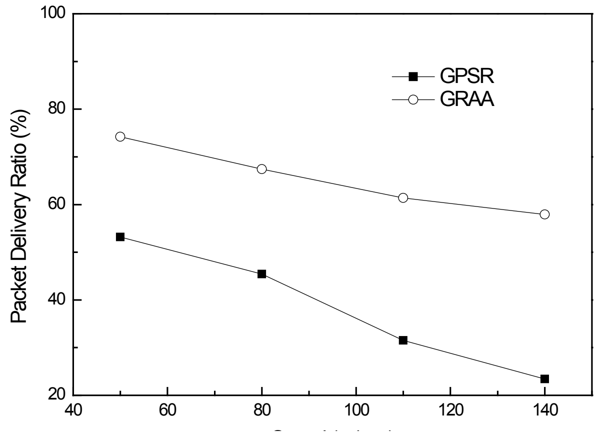

Figure 5. Packet Delivery Ratio along Predetermined Route

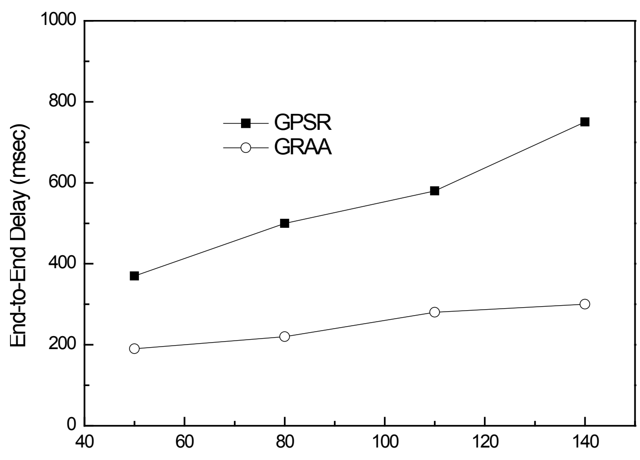

Figure 6. End-to-End Delay along Predetermined Route

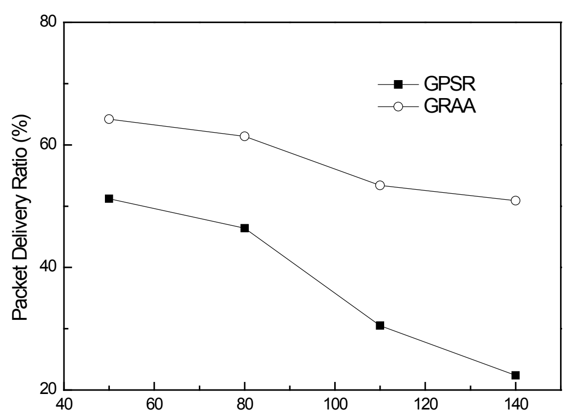

Figure 7. Packet Delivery Ratio along Random Route

Another simulation result was conducted to analyze the performance of GRAA and GPSR with the random mobility model. When this simulation is compared to the ones shown in Figures 5 and 6, we can find the lower packet delivery ratio; we cannot use the mobility pattern in Figure 7. However, GPSR does not show drastic degradation, because it is not dependent on mobility pattern at all.

The performance results differ from the intelligent forwarding scheme. In traditional mobile ad hoc networks, low computing power and energy constraints hinder nodes from keeping large volumes of information and computing complex algorithms. However, aircraft ad hoc networks are very free in these two points; we can keep the mobility direction of the neighbor node and use this information to decide the next hop. This means that aircraft ad hoc networks can contribute to a higher packet delivery ratio. Another feature is combining opportunistic networks technology with GRAA. In GPSR, if no appropriate node among neighboring nodes is available, it uses a perimeter forwarding scheme. In this mode, a packet traverses successively closer faces of a planar sub-graph of the full radio network connectivity graph until reaching a node closer to the destination, where greedy forwarding resumes, and it can increase the end-to-end delay, as shown in Figure 8. However, in GRAA, a node keeps the packet and moves until meeting a more suitable node. In addition, it drops the packet if this step fails. Therefore, end-to-end delay is shortened in GRAA.

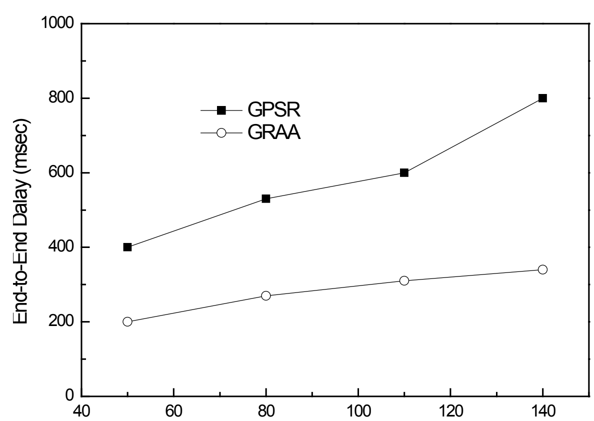

Figure 8. End-to-End Delay along Random Route

5. Conclusions

Aircraft ad hoc networks can be a good perspective and practical model to deploy ad hoc network technology because they can remove many concerns such as low computing power and energy consumption in typical mobile ad hoc networks. Moreover, aircraft ad hoc networks have many differences in aspects of node, communication structure, and wireless medium. It is essential to develop new network technology according to requirements on aircraft ad hoc networks.

In this paper, we propose a new routing protocol called GRAA. This protocol is based on geographic routing protocol because it is good for high dynamic topology change. To accommodate the new properties of aircraft ad hoc networks, we propose a hybrid-forwarding scheme, which makes use of mobility patterns obtained by aircraft-to-ground communication. Moreover, when it is impossible to utilize the mobility pattern, a forwarding scheme based on neighboring table with direction is proposed. This will be combined with opportunistic network technology. Finally, we validate the improvement of performance through simulation and identify the contribution of the proposed scheme.

More simulation works for several network environments will be conducted relating to this work. In addition, other layer protocols for aircraft ad hoc networks will continue under cross-layered concept.

Acknowledgements

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References

[1] IETF Mobile Ad Hoc Working Group Charter, http://www.ietf.org/html.charters/manet-charter.html.

[2] Mehran Abolhasan, Tadeusz Wysocki, and Eryk Dutkiewicz, 2004, “A Review of Routing Protocols for Mobile Ad Hoc Networks,” Ad hoc Networks.

[3] Guangyu Pei, Mario Gerla, and Tsu-Wei Chen, April 2000, “Fisheye State Routing in Mobile Ad Hoc Networks,” in Proc. of IEEE ICDCS Workshop on Wireless Networks and Mobile Computing.

[4] Charles E. Perkins, 2001, *Ad Hoc Networking*, Addison-Wesley, pp. 139-172, Chapter 5.

[5] Zygmunt J. Haas, October 1997, “A New Routing Protocol for the Reconfigurable Wireless Networks,” In Proc. of IEEE ICUPC, pp. 562-566.

[6] Brad N. Karp and H. T. Kung, August 2000, “GPSR: Greedy Perimeter Stateless Routing for Wireless Networks,” In Proc. of ACM MobiCom, pp. 243-254.

[7] Y-.B. Ko and N. H. Vaidya, 1998, “Location-Aided Routing (LAR) in Mobile Ad Hoc Networks,” In Proc. of ACM Mobicom, pp. 66-75.

[8] Airborne Ad Hoc Networks, http://www.csse.monash.edu.au/~carlo/adhoc.html.

[9] Krishna Sampigethaya, Radha Poovendran, and Linda Bushnell, September 2008, “Security of Future eEnabled Aircraft Ad hoc Networks,” In Proc. of AIAA Aviation Technology, Integration, and Operations (AIAA ATIO) Conference.

[10] L. Pelusi, A. Passarella, and M. Conti, November 2006, “Opportunistic Networking: Data Forwarding in Disconnected Mobile Ad Hoc Networks,” IEEE Communications Magazine, pp. 134-141.

[11] Qualnet Simulator, http://www.scalable-networks.com/.