International Journal of Hybrid Information Technology
Vol.8, No.7 (2015), pp.85-94
http://dx.doi.org/10.14257/ijhit.2015.8.7.08

Integrate Advantage of Geographic Routing and Reactive Mechanism for Aeronautical Ad Hoc Networks

Xiaoheng Tan, Xiaonan Hu, Pengfei Qu, Zhengnan Zhu and Yan Zhang

College of Communication Engineering, Chongqing University,
Chongqing400030, China
Email: 20121202011t@cqu.edu.cn

Abstract

Large scale range and high dynamic topology are the two major features of Aeronautical Ad Hoc Networks (AANETs), which present severe challenges to provide efficient and reliable data packet delivery in aviation communication networks. Geographic routing has been studied as an attractive option for routing in aeronautical networks due to its simplicity and scalability. However there are still some problems such as low packet delivery ratio and less reliability for long dynamic links. In this paper, we improve the greedy forwarding strategy and start with the idea of integrating reactive routing mechanism with geographic routing protocol, referred to as IRG (Improved Reactive and Geographic) routing protocol. Variety simulations have been performed to evaluate the performance of the proposed routing protocol, and the results show that it can increase the packet delivery ratio efficiently.

Keywords: *AANETs, Geographic protocol, greedy forwarding strategy, reactive mechanism*

1. Introduction

The aeronautical ad hoc network is a new type of decentralized large scale wireless network formed by high-speed aircrafts. AANETs aim to provide direct air-to-air communication between aircrafts by multi-hops, back up and integrate other type of systems. AANETs could substantially reduce the dependence to ground facilities and expensive cost for satellite. Thus, some institutions carry out a series of related projects such as ATENAA (Advanced Technologies for Networking in Avionic Application) [1] and NEWSKY (Networking the Sky for Aeronautical Communication) [2]. Nevertheless, High-speed motion of aircrafts and wide range of network are the main characteristics of AANETs. Therefore high dynamic topology, low node density and connectivity restrictions pose the severe challenges in aeronautical communication networks. In that case, most of the existing classical Mobile Ad Hoc Networks (MANETs) routing algorithms are not ideal for AANETs. These protocols utilized in AANETs lead to a large amount of data packets loss. As a result, AANETs require novel routing protocols to combat these limiting topological characteristics.

The traditional routing algorithms of MANETs can be classified into two basic categories namely topology-based and position-based protocols [3,4]. Topology-based routing algorithms use the information about the links in the network to forward packet. Topology-based protocols can be further divided into proactive, reactive and hybrid ones. In proactive protocols each node maintains a routing table where control packets are broadcast periodically across the whole network. The main drawback of these approaches is consuming bandwidth unnecessarily. Reactive routing protocols only maintain the routes that are currently in use, thereby reducing overhead, but these methods result in large end-to-end delay time. Position-based routing mechanism [5] is seems to be quite suitable for routing in AANETs due to the fact that most modern and

ISSN: 1738-9968 IJHIT

thus aircrafts are already equipped with reliable GPS (Global Positioning System), then aircrafts can acquire their current geographic position information conveniently. In order to deliver packets, other than its own position, each node only need know its one-hop neighbors' position and the destination's position. Besides, it is not necessary to maintain routing tables or set up complete paths before sending a packet. As a result, position-based routing is simple, highly scalable and particularly robust even if the network topology changes frequently.

Among geographic routing protocols, Greedy Perimeter Stateless Routing (GPSR) [6] protocol is one of the most well-known protocols. GPSR mainly works in the greedy mode, forwarding a packet to the neighbor node which has the minimum geographic distance to the destination than itself. When routing voids occur, GPSR switches to the perimeter mode, delivering a packet along the faces of the planar graph according to the right hand rule. However, GPSR utilized in AANETs, the greedy forwarding may cause the problem of local maximum, and perimeter forwarding cannot resolve this issue efficiently. Furthermore, the influence brought by nodes movement is not taken into consideration in GPSR. Researches show that GPSR not only leads to large packet delivery latency, but also results in routing failures and low packet delivery ratio in high dynamic AANETs [7].

In this paper, we focus on geographic routing protocol in aeronautical ad hoc networks. On the basis of GPSR protocol, we improve the greedy forwarding strategy and use reactive mechanism as the alternative scheme to cope with the high dynamic and sparse airborne network. The remainder of this article is structured as follows: Section 2 presents a brief overview of existing AANET routing protocols. Section 3 describes our improved reactive and geographical (IRG) routing protocol for AANETs in detail. Section 4 provides a formal verification of the proposed protocol by NS2 network simulation software, and simulation results are analyzed and compared. Finally, conclusions and an overview of future work are given in section 5.

2. Related Work

Although a great number of routing protocols have been proposed for mobile ad hoc networks [8], few of them has been studied for the specific goal of aeronautical ad hoc network. Until recently some attention has been drawn to the aviation field of multi-hop wireless networks. Sakhaee et al. [9] proposed multipath Doppler routing (MUDOR). The Doppler shift is used to estimate the relative velocity of each node in case the position information is not available and the algorithm selects the path which has the minimum Doppler shift value to construct route. The advantage of this method is the decrease of the Internet traffic load and propagation delay for real-time traffic transmission. ARPAM (Ad-hoc Routing Protocol for Aeronautical Mobile Ad Hoc Networks) [10] is a hybrid protocol based on AODV (Ad hoc On-demand Distance Vector) [11] and TBRPF (Topology Dissemination Based on Reverse-Path Forwarding) [12] applied to commercial aviation networks. It makes use of the position information to discover the shortest and complete end-to-end path based on various criteria like distance between source node and destination node and the number of hops between them. In order to resolve packet loss issues of greedy forwarding at the boundary of voids, a reactive backtracking mechanism is proposed in [13], which reactively detects voids, backtrack packets and propagate information on block sectors. Also this paper proposed an extrapolating algorithm to reduce the latency of void discovery and to limit route stretch. In the NEWSKY project, Medina et al. [14] proposed the GLSR (Geographic Load Sharing Routing) protocol. It uses the advanced velocity, which is the ratio of advance and queue delay, as the metric to avoid link congestion, satisfying the principle that nearest to the destination and join the shortest queue. Hyeon et al. [15] proposed a new geographic routing protocol that can cope with dynamic topology changes adaptively. It makes decisions for the next hop using three-dimensional geographic information and exploits mobility information which is updated frequently by the base station on the ground.

The above proposed routing protocols have their own advantages in AANETs, but they are all lack of satisfactory supports for low node density and fast topology changes, and these researches focus on different aspects of AANETs.

3. The Optimized Protocol Combining Geographic Routing and Reactive Routing

In this paper, we aim at the unique features of AANETs to develop a routing strategy more suitable for the high dynamic and sparse environment. Our work includes improving the greedy geographic forwarding strategy and combining reactive routing mechanism with geographic routing strategy into an efficient and reliable routing protocol.

3.1. Greedy Forwarding Strategy

In GPSR protocol, the greedy geographic forwarding strategy is only based on distance, and data packets are forwarded to the neighbor that is geographically closest to the destination. Since the aircrafts move quite fast in the aeronautical circumstance, there may led to two cases.

Case 1: the selected next hop may move out of the radio range causing routes break. As illustrated in Figure 1, node j is within the transmission range of node i at current time. After Δt, node j moves out of the transmission range of node i, causing packet forwarding failure. So node j is not the stable choice for high dynamic scenario.

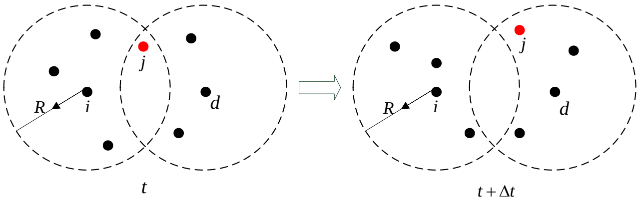

Figure 1. Scenario for Illustrating Neighbor Node Moving Out Of the Radio Range

Case 2: the selected next hop may move away from destination though it is closest to destination at current time. For example, in Figure 2, although node j is closer to the destination d than node k in the present moment, node j will move away from node d in the next time. So node j is not the suitable next hop.

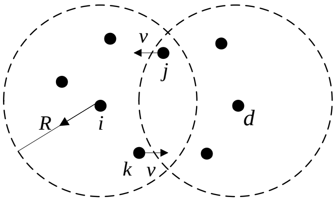

Figure 2. Scenario for Illustrating the Effect of Velocity on the Next-Hop Decision

To deal with aforementioned cases, our optimized greedy forwarding strategy considers the relative velocity for the next hop selection. We first exclude the neighbor nodes which would move exceed the radio range of current node, and then choose the next hop depending on the improved routing metric which takes velocity factor into account. The metric calculate the duration from neighbor node to destination, and choose the next hop which reaches the destination soonest.

The distance $S_{i,j}$ between node i and j at instant t is given by:

$$S_{i,j}(\mathrm{t}) = \sqrt{(x_i(\mathrm{t}) - x_j(\mathrm{t}))^2 + (y_i(\mathrm{t}) - y_j(\mathrm{t}))^2 + (z_i(\mathrm{t}) - z_j(\mathrm{t}))^2} \tag{1}$$

Where $(x_i(\mathrm{t}), x_j(\mathrm{t}))$, $(y_i(\mathrm{t}), y_j(\mathrm{t}))$, and $(z_i(\mathrm{t}), z_j(\mathrm{t}))$ represent the current position coordinates of node i , j at time t respectively. And the relative velocity between node i and j at instant t is defined as:

$$Rv_{i,j}(\mathrm{t}) = \overrightarrow{v_i(\mathrm{t})} - \overrightarrow{v_j(\mathrm{t})} \tag{2}$$

Where $\overrightarrow{v_i(\mathrm{t})}$, $\overrightarrow{v_j(\mathrm{t})}$ denote the velocity of node i , j at instant t .

Suppose the data packet arrives at node i , one of its neighbor nodes is j , and the destination node is d . The radio range of each node is R . Then the distance difference between two nodes to the destination at instant t is defined as:

$$\Delta S_{i,j}(\mathrm{t}) = S_{i,d}(\mathrm{t}) - S_{j,d}(\mathrm{t}) \tag{3}$$

In order to choose the valid next hop, the selection strategy should ensure the neighbor node can be within the radio range over a period of time. Thus the candidate nodes should satisfy the following inequation.

$$R > \Delta S_{i,j}(\mathrm{t}) \cdot Rv_{i,j}(\mathrm{t}) / c + \Delta S_{i,j}(\mathrm{t}) \tag{4}$$

The nodes which do not satisfy the inequation won't be considered as the candidate forwarding node. Also for the sake of better adapting to the high dynamic environment, we define the metric MDT (minimum duration time) as follow:

$$MDT = \min_{k \in N_i}\{MDT_k\} = \min_{k \in N_i}\{\frac{\Delta S_{k,d}(t)}{Rv_{k,d}(t)}\}, MDT_k > 0 \tag{5}$$

Where N_i is a set of neighbors of node i . The metric considers the velocity as well as the geographic distance. The source node calculates the MDT value of all the neighbor nodes and determines which node could reach the destination soonest. The strategy makes nodes choose the more stable and reliable next hop to improve the quality of communication. Consequently the strategy is more suitable for high dynamic aeronautical networks.

3.2. Reactive Mechanism

Although greedy geographic forwarding strategy is efficient and simple, it fails in the presence of routing voids, which is also called dead-ends or local maximum. The scenario is shown in Figure 3. In order to provide a correct routing, a backup mechanism such as perimeter or face routing must be used to circumvent the void area. However, with the perimeter algorithm, a packet often tends to travel on a longer path to the destination node. What's worse, it may get caught in a loop and be dropped finally. This procedure causes a large amount of packets loss due to the large scale range of the network and the relative sparsity of nodes.

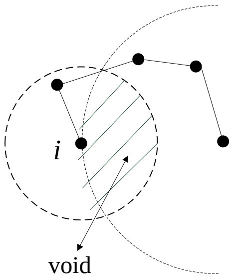

Figure 3. Illustrating For Routing Voids

In our approach, reactive routing mechanism such as AODV can be deployed when greedy forwarding fails caused by routing voids. Instead of taking perimeter algorithm, the intermediate node initiates a route discovery process to find a valid route entry to reach the destination node. Route Request (RREQ) packets are flooded into the network, which is identified by a broadcast ID and the address of the intermediate node failed in greedy mode. Then, when the one-hop neighbor node receives this RREQ, it will check the destination address of RREQ. If the destination address is itself, it will generate and send back Route Reply (RREP) packets. Otherwise, it continues to broadcast this RREQ until the RREQ reaching the destination node. In this way the complicated path is built to solve the voids issues efficiently.

The reactive mechanism can be more reliable and efficient than perimeter forwarding because of its RREQ/RREP mechanism. Though the reactive method has a large overhead cost, we don’t select it as the major approach, just as the candidate choice to salvage packets when greedy forwarding fails.

3.3. Description of IRG Protocol

In our proposed IRG routing protocol, we combine two traditional routing mechanisms to exploit the benefits of different individual schemes. IRG adopts greedy forwarding mechanism as the main routing mechanism, and the reactive part is worked as the alternative method to deal with the routing void issues. The procedure of IRG protocol is described as follows.

Step 1: each node in the network needs to acquire the position information, including the position of itself, the position of its one-hop neighbor and the position of destination. The position information can be obtained respectively by GPS, beacon mechanism and location service such as the Grid Location System (GLS) or Quorum [16].

Step 2: when an aircraft node starts to communicate with others, it first works in the greedy mode. Each node holds a neighbor table periodically updated to keep track of the moving information of its one hop neighbor. It chooses the next hop based on the improved metric MDT, which comprehensively consider the expected geographical distance to the destination and the relative velocity between nodes to select a more stable and reliable next hop.

Step 3: when dead ends occur, it switches to the reactive approach, using the RREQ/RREP mechanism as the alternative approach to find an available route to complete data forwarding.

Step 4: once the node bypasses the void region and a neighbor node has a smaller MDT value than itself, the node switches back to greedy geographic forwarding. The process continues until the data packet arrives at the destination node.

4. Performance Evaluation

In order to assess the performance of the proposed routing strategy in a realistic aeronautical scenario, we have implemented our network model utilize the NS2 [17] software. A series of simulations are performed and the results are averaged and compared with the basic conventional protocols AODV and GPSR.

4.1. Simulation Environment and Settings

In the NS2.35 network simulation platform, we set two groups of simulations and the variable parameters are the velocity of nodes and the number of nodes respectively. To model the realistic aeronautical environment, a two-ray ground model is used as a radio propagation model and the Random Waypoint Model used as the mobility model. The MAC layer exploits the IEEE 802.11 standard. The application layer uses CBR traffic to simulate the aeronautical communication traffic. Traffic is generated as 10 packets per second, and the packet size is set to 512 Kbytes. We performed five simulations for each test and the results are averaged. Each simulation is performed for 1000 seconds. The specific parameters in simulation are given in Table 1.

Table 1. Parameters for Simulation

Parameter	Value
Network size	10 km by10 km
Packet mean size	512 Kbytes
Sending rate	10 packets/s
Mobility model	Random Waypoint Model
Antenna coverage range	1 Km
Transmit RF power	100 W
Simulation time	1000 s

Three metrics are used to measure the performance of the improved protocol and traditional protocol. Including: (1) Packet delivery ratio (PDR): the ratio of the number of packets received by the destination and the number of packet sent by the source at the application layer. This metric is to measure the reliability in a highly dynamic and low node density environment. (2) Average overhead: the excess packets used to forward the packet payload from source node to destination node. This metric reflects the scalability of networks to a certain extent. (3) Average end-to-end delay: the difference in time between transmitting a data packet and receiving the data packet at MAC layer. It includes the latency for route discovery, queuing delay and propagation delay and so on. This metric can evaluate the real-time performance of networks.

4.2. Simulation Results and Analysis

4.2.1. Simulation Results On Different Node Velocity: The velocity of aircraft nodes ranges from 20m/s to 220m/s, with a step of 40m/s.

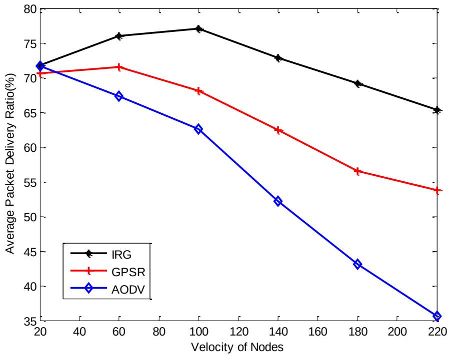

Figure 4. Average PDR with the Velocity of Nodes

Figure 4 shows the average PDR as the speed of nodes increase. Obviously, IRG outperform both GPSR and AODV with the increase of speed, and the performance of our scheme is relative stable. The main reason for this is that we take the relative velocity between nodes into consideration for the next-hop selection, which guarantees that the forwarding nodes are more stable and appropriate. While for GPSR, the metric only considers the geographical distance, lacking support for high speed mobile nodes, hence the PDR immediately degrades as the speed increases. For AODV algorithm, more reactive routes may break in the network as the nodes velocity increases.

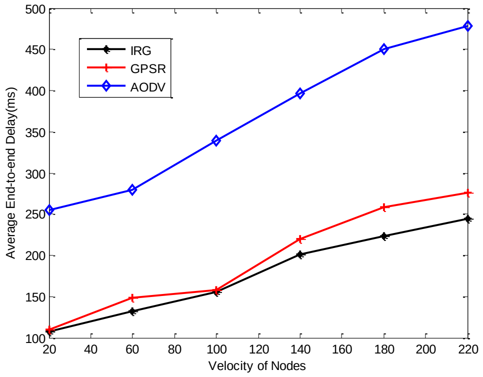

Figure 5. Average End-To-End Delay with the Velocity of Nodes

As shown in Figure 5, the average end-to-end delay of three protocols increases as the speed increases. The delay of AODV continues to increase more dramatically and larger than that of IRG and GPSR as the velocity of nodes increases. Because topology-based on demand protocols such as AODV consume much time to discover and construct routes. While position-based protocols exploit the geographic information to select routes and in consequence reduce the delay time. The delay performance of IRG is slightly better than GPSR. The reason is mostly like that IRG selects more reliable and stable next forwarding node.

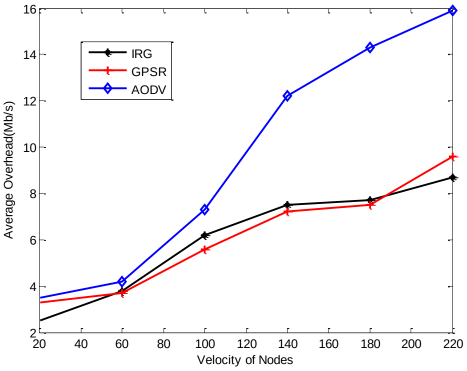

Figure 6. Average Overhead With the Velocity of Nodes

Figure 6 shows routing overhead measured in total number of routing packets with respect to node’s speed. As shown in the figure, the routing overhead of all the protocols increases as the speed increases. The reason is that hello message should be sent more frequently in the beacon mechanism to acquire accurate position information for IRG and GPSR. And for topology-based protocol AODV, with rapid topology change, it requires more control packets to exchange information to update the routing table.

4.2.2. Simulation Results On Different Node Density: We set the number of nodes varies from 10 to 100, increased by 10.

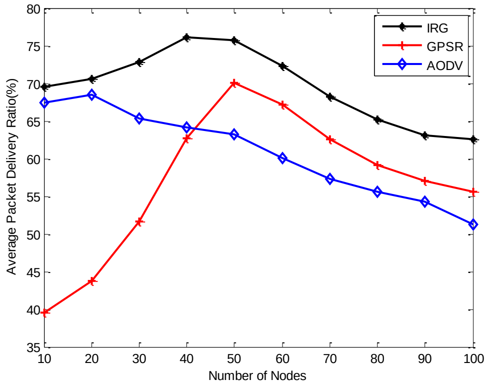

Figure 7. Average PDR with the Number of Nodes

Figure 7 shows the average PDR as the number of nodes increase. As shown in the figure, the PDR for IRG can keep a good performance even in the sparse environment. The improvement of IRG over the GPSR is due to the fact that IRG employs a reactive method alternative. The IRG automatically switches to reactive approach when a path fails. The procedure could salvage some of the data packets that are possibly dropped by the original greedy geographic forwarding when voids occur. The PDR for GPSR increases as the number of nodes increases with the exception of degradation as the number of nodes approaches 50 and higher. The reason is that the perimeter forwarding mode of GPSR is inefficient in sparse environment. The PDR for AODV immediately degrades as the number of nodes increases. This is most likely due to the increase in overhead as the number of nodes increases.

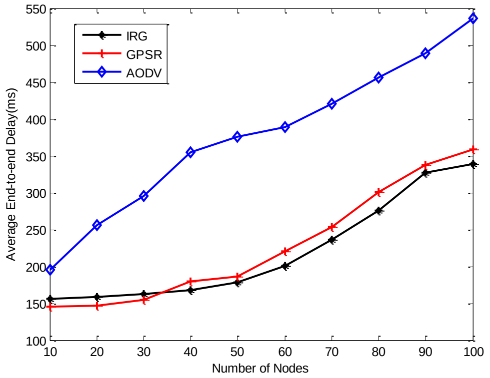

Figure 8. Average End-To-End Delay with the Number of Nodes

The effect that node density has on the average end-to-end delay of data packet transmission is shown in Figure 8. The node density of the network affects the three routing protocols and IRG performs the best, because IRG exploits reactive mechanism as the alternative scheme when suffer from routing voids. While GPSR is applied in low density circumstance, if no neighbor node is closer to the destination, it uses a perimeter forwarding scheme. In this mode, a packet traverses 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.

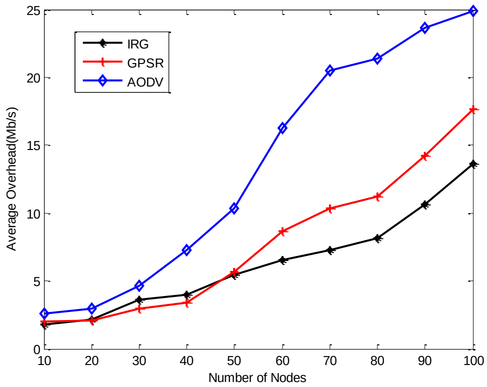

Figure 9. Average Overhead With the Number of Nodes

As illustrated in Figure 9, the average overhead of the network increases with the node density. However, the proactive discovery and maintenance of routes in AODV results in exponentially increasing overhead as the number of nodes increases. Since IRG and GPSR send hello packet frequently to maintain neighbor table, the number of packet also increases as the number of node increases.

5. Conclusions

Aeronautical ad hoc networks can be a good perspective applied in airspace environment. Nevertheless, aeronautical ad hoc networks have many differences from traditional mobile ad hoc network in aspects of node features, communication structure, and wireless medium and so on. It is essential to develop specific routing protocol to cope with the challenges faced in high dynamic environments and meet the communication requirements for AANETs.

In this article, we propose a novel position-based routing protocol, which integrate the advantage of greedy geographic forwarding and reactive mechanism. The proposed IRG protocol is based on two mechanisms for data forwarding and path construction. It could provide better packet delivery ratio while facing frequent topology changes and low node density in AANETs. In the future work, we will focus on optimizing the performance of average end-to-end delay and network overhead in AANETs. Specific measures such as scoped flooding and delay route request can be deployed. More simulations and analysis will be conducted relating to this work.

References

[1] K. Karras, T. Kyritsis, M. Amirfeiz and S. Baiotti, 'Aeronautical Mobile Ad Hoc Networks' in14th European Wireless Conference 2008 Electronics Proceedings, **(2008)**, pp.1-6, Hong Kong, China.

[2] M. Schnell and S. Scalise, 'NEWSKY - A concept for networking the sky for civil aeronautical communications' in DASC 2006: IEEE/AIAA 25th Digital Avionics Systems Conference, **(2006)**, pp.1-6.

[3] E. Alotaibi and B. Mukherjee, 'A survey on routing algorithms for wireless Ad-Hoc and mesh networks', Computer Networks, Vol. 56 No.2, **(2012)**, pp.940-965.

[4] A.Boukerche, B. Turgut, N. Aydin and M. Z. Ahmad, 'Routing protocols in ad hoc networks: A survey', Computer Networks, Vol. 55 No.13, **(2011)**, pp.3032-3080.

[5] Bekmezci, O. K. Sahingoz and S. Temel, 'Flying Ad-Hoc Networks (FANETs): A survey', Ad Hoc Networks, Vol. 11 No. 3, **(2013)**, pp.1254-1270.

[6] A.Karp and H.T. Kung, 'GPSR: greedy perimeter stateless routing for wireless networks' in ACM/IEEE MobiCom 2000: Proceedings of the 6th Annual International Conference on Mobile Computing and Networking, Boston, MA, **(2000)**, pp. 243-254.

[7] R. Shirani, M. St-Hilaire and T. Kunz, 'The performance of greedy geographic forwarding in unmanned aeronautical ad-hoc networks' in CNSR 2011: Ninth Annual Conference on Communication Networks and Services Research, **(2011)**, pp. 161-166.

[8] V. Govindaswamy, W. L. Blackstone and G. Balasekaran, ‘Survey of Recent Position Based Routing Mobile Ad-hoc Network Protocols’ in UKSim 2011:13th International Conference on Modelling and Simulation, **(2011)**, pp. 467-471.
[9] E. Sakhaee, A. Jamalipour and N. Kato, ‘Aeronautical ad hoc networks’ in WCNC 2006: IEEE Wireless Communications and Networking Conference, **(2006)**, pp. 246-251.
[10] M. Iordanakis, D. Yannis, K. Karras, G. Bogdos, G. Dilintas, M. Amirfeiz, G. Colangelo and S. Baiotti, ‘Ad-hoc Routing Protocol for Aeronautical Mobile Ad-Hoc Networks’ in CSNDSP 2006: Proceedings of the Fifth International Symposium on Communication Systems, Networks and Digital Signal Processing, Patras, Greece, **(2006)**, pp. 543-547.
[11] C. Perkins, E. Belding-Royer and S. Das, ‘Ad Hoc on-Demand Distance Vector (AODV) Routing’, RFC 3561 (Experimental), July **(2003)**.
[12] R. Ogier, F. Templin and M. Lewis, ‘Topology Dissemination Based on Reverse-Path Forwarding (TBRPF)’, IETF Network Working Group RFC 3684. February **(2004)**.
[13] F. Theoleyre, E. Schiller and A. Duda, ‘efficient greedy geographical non-planar routing with reactive deflection’, in IEEE ICC 2009: International Conference on Communications, **(2009)**, pp. 1-5.
[14] D. Medina, F. Hoffmann and F. Rossetto, ‘Routing in the airborne internet’ in IEEE ICNS 2010: Integrated Communications Navigation and Surveillance Conference, Cancun, Mexico, **(2010)**, pp. 1-10.
[15] S. Hyeon , K. Kim and S. Yang, ‘A new geographic routing protocol for aircraft ad hoc networks’ in IEEE/AIAA DASC 2010: 29th Digital Avionics Systems Conference, **(2010)**, pp. 2.E.2-1 – 2.E.2-8.
[16] M. Mauve, J. Widmer and H. Hartenstein, ‘A Survey on Position-Based Routing in Mobile Ad Hoc Networks’, IEEE Network, Vol. 15 No. 6, **(2001)**, pp.30-39.
[17] The Vint Project. The UCB/LBNL/VINT Network Simulator - ns (version 2). http://www.isi.edu/nsnam/ns/

Authors

Xiao-heng Tan, he was born in Chongqing City, China, in 1976.He received the B.S. degree in 1998 and Ph. D. degree in 2003, both from the University of Chongqing, Chongqing, and China. He went to the University of Queensland as a visiting scholar during June 2008 to May 2009. He is now a professor and doctoral tutor in the college of communication engineering of Chongqing University, Chongqing, China. His research interests include modern communication technologies and systems (the next generation broad band and wireless mobile communication technology, etc.), communication signal processing.

Xiao-nan Hu, she was born in Chongqing City, China, in 1990.She received the B.S. degree in Communication Engineering from Chongqing University, Chongqing, China, in 2012. She is currently working towards the master degree in communication and information system at Chongqing University, Chongqing, China. Her current interests include wireless communication, aeronautical and mobile ad hoc networks.