# Mobile Ad-Hoc Network Based Relaying Data System for Oceanic Flight Routes in Aeronautical Communications

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## ABSTRACT

*This paper proposes a reliable system to overcome the weakness of current the HF radio communication system for oceanic aeronautical flight routes. This system uses only one aeronautical VHF channel with air-to-air radio relay system based on local mobile Ad-hoc networks. For access to/from all aircrafts in the system, a TDMA (Time Division Multiple Access) scheme is proposed to be used where each aircraft is assigned one time slot during its presence in the system in order to transmit its own packet by itself or relay them using neighbouring aircrafts. These packets contain aircraft position, ID, relative direction which are used to build a routing table at each aircraft. In addition, several algorithms for relaying packets; schemes to reduce the packet-loss-ratio as well as to reduce the interference caused by surrounding aircrafts have been proposed. The simulations have shown the improvement of such proposals when examining system performance under real air-traffic scenarios. This system strengthens the reliability of oceanic aeronautical communication and increases situational awareness of all oceanic flights as an effective solution to operate more flights on the ocean but in higher safety.*

## KEYWORDS

*Oceanic air traffic control communications, air-to-air communication, air-to-ground, mobile Ad-hoc networks*

## 1. INTRODUCTION

With the development of global world economy, airplanes have become an indispensable transportation means. As a result, the number of international flights has increased considerably. Almost all international flights pass through the major oceans such as the North Pacific Ocean (NOPAC), the North Atlantic Ocean (NAO) etc. The statistical air traffic data in Japan showed that traffic on NOPAC routes in 2000 has increased 1.5 times compared with 1993 [1] and that the 2010 air traffic will have doubled since 2000 [2]. For international flights, takeoff time should be comfortable for travellers in local time which leads to some specific air traffic peak periods. The difference in time zones among those places makes peak periods of outbound flights and inbound flights various and dispersive during the day [see Fig. 6]. At uncomfortable times, aircrafts for goods transportation are preferred to operate. This feature increases the probability to set up a local mobile Ad-hoc network at each aircraft by establishing air-to-air links in its communication range.

To avoid any collision between flights and to use the airspace more efficiently, ATC centres are operated where ATC controllers keep the aircrafts separated from each other and keep providing necessary guidance to the pilots. In continental areas, the VHF system is currently responsible for communication between pilots and the controllers (air-to-ground) within a specific distance of 300 km. In oceanic and polar areas, a long distance communication system in HF band is used instead. To ensure the aircrafts are adequately separated, a minimal interval of 5 Nautical Mile (NM) for continental flights is always required and is managed by several ground based surveillance radars. However, on the oceanic areas that are out of radar's range, the safety interval is required much longer at 50 NM [2]. At present, communication model between pilots and controllers for oceanic flights are operating as described in Fig. 1.

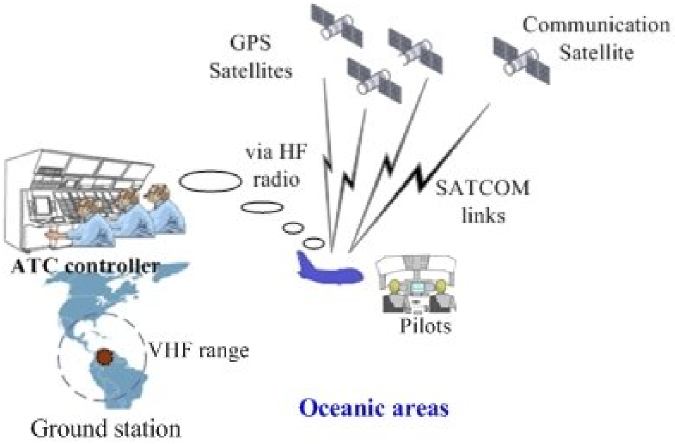

Fig. 1. Current aeronautical communication systems for oceanic flights

The pilots contact ATC controllers mainly use HF radio system (i.e., 2.8-21.99 MHz) to report the aircraft position, aircraft status etc. Theoretically, HF radio waves are reflected on ionosphere tier; therefore, they can provide a multi-hop communication beyond the horizon. However operating frequencies must be adjusted accordingly to different weather condition, time periods and regions. As a result, it normally takes 2 minutes to setup a report with a successful rate around 80% in average [3]. In addition, HF communication is easily affected by interference during the flights and can disturb these communications. To backup the HF system, a controller pilot data link communication (CPDLC) based on satellite communication (SATCOM) has been prepared. However, SATCOM systems are not widely and frequently used because of their high cost. Besides, an HF data link (HFDL) system has also been attempted in Japan but its remained issues have reported in [3] and [4]. Therefore, the HF radio system is still the main method to provide verbal communication between pilots and ATC controllers; meanwhile a SATCOM system is used as a backup for HF system [5]. In this paper, we proposed a highly stable relaying system to relay any aircraft position report to relevant ATC controller with just only one VHF radio channel.

The rest of the paper is organized as follows. Section 2 describes the multiple access scheme used in this system. Section 3 describes the air-to-air propagation model by practical experiment and signal to noise ratio (SNR) adjustment scheme while section 4 explains the operation of the proposed mobile Ad-hoc networks model for relaying data from any aircrafts on the oceanic area to ground station. Simulations in section 5 introduce optimal combination of interval value, SNR adjustment scheme, improved packet-loss-ratio scheme and packet-relaying algorithms by examining the proposed model with real statistical air traffic model on NOPAC routes. Some concluding remarks are presented in the last section 6.

## 2. MULTIPLE ACCESS SCHEME

### 2.1. Description and Structure

At present, the IEEE/802.11 CSMA/CA has been used widely and effectively by using request-to-send (RTS), clear-to-send (CTS) and ACK/NACK packets. This one radio channel model might be inappropriate for such wide area network in aeronautical communications on the oceans; which has a communication radius up to 650 km or more [see Fig. 4]. Actually, in this huge area network, the time to send and receive RTS/CTS and ACK/NACK packets is relatively long and system performance is properly affected. Another factor, there is not much data to be transmitted or relayed in this system but it operate frequently; hence, the strengths of CSMA/CA are not used efficiently. Considering these reasons, we propose a single TDMA channel that accommodates all aircrafts in a certain oceanic area which is commonly world recognized.

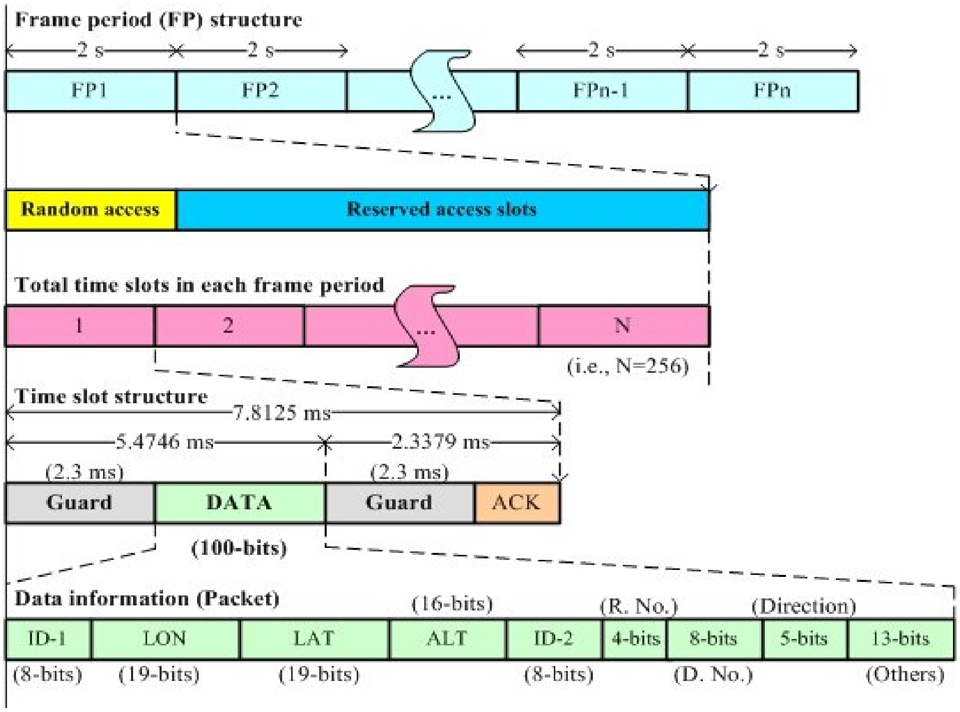

Fig. 2. TDMA frame and time slot structure

Once the aircraft joins the system, it must listen to all neighbour transmissions within a FP and then send a request to the nearest ground station (GS) with a pre-determined time slot by using a time slot in random access part. It is supposed to use slotted-aloha scheme for this random access to the channel. This aircraft needs to wait until being assigned properly with a time slot by ground station. Similarly, when an aircraft leaves the system, it sends a request to GS to release its own time slot. During the flight, its assigned time slot is used and unchanged until completely released.

Each time slot is divided into two parts. One part includes a guard time of 2.5 ms to compensate the free space propagation delay; and a data part of 2.78 ms that can contain aircraft ID, position information (i.e., longitude, latitude and attitude as regulated by International civil aviation organization-ICAO); still some idle space could be used to transmit ground speed, oil status, surrounding weather information to report to ATC centre or broadcast to all other neighbour aircrafts as well. In the other part, a guard time of 2.5 ms and a time to send ACK/NACK plus signal noise ratio to allow transmitter adjust transmitted power to eliminate interference level to others. The relation between time and bit are based on the assumption that a 31.5 kbps VHF transmission system is applied, which is being used widely now in aeronautical communications.

With the above design criterion, at frame period of 2 s, system can provide a maximum of 256 aircrafts [Fig. 2]; which is three times larger than the maximum number of flights on NOPAC routes or two times larger than total flights on NOA routes at any time. Assumes relevant ground stations e.g. GS1, GS2 are synchronized with Global Positioning System, connecting and sharing the channel control information.

Theoretically, guard time length is proportional to communication distance and considered as a dead time period. However, the larger distance the higher the probability of establishing local Ad-hoc networks, which is proportional to relaying performance. Based on theoretical evaluation, a basic communication distance of 678 km is selected for further estimation [see Fig. 4].

## 2.2 Packet Generation and Relaying Mechanism

This part explains how each aircraft generate its own packet or relays a neighbour packet. As described in Fig.2, all aircrafts and ground stations are required to synchronize time slot configuration by using their GPS receiver. Each aircraft is assigned by a unique time slot after the entry to the system. The general way of processing the aircraft packet is in any frame period, at the aircraft time slot, only its own packets are to be processed. This process contains two sub processes. First, it could be done by the aircraft itself when generating a new packet. Second, its packet is processed by another aircraft when its packet is staying at some other aircraft. Whether there is only one sub process or both sub processes are happening at the aircraft time slot depends on how many packets of the aircraft are on the whole system. In addition, to keep the position report updated, after a predefined interval of several frame periods, the aircraft regenerate its position report.

Each position report includes at least the aircraft position, aircraft ID and its relative direction. After receiving, the receiver sends a feedback of ACK or NACK to the sender depends on the correction of the received packet. If the feedback is ACK, the receiver continues to relay the received packet to the next appropriate relay aircraft at the same time slot packet arrived but in the next frame period. In case of NACK, the sender tries to retransmit its own position report after the mentioned interval. This relaying process is continued until the relay aircraft is the relevant ground station.

To describe the interference of neighbour aircrafts transmitting at the same time slot, the neighbours are divided in to two groups: adjacent-relay aircrafts (ARA) where their communication is affected by each other and the opposite group, distant-relay aircrafts (DRA) where they are separated sufficiently and their communication do not make any interference on each other. In time domain, after the interval, the aircraft packets are to be processed by some neighbour aircrafts. Whether these neighbour aircrafts belong to ARA or DRA depends on the value of this interval. The shorter the interval, the more often the aircraft can transmit its position report. However, the shorter interval means that after a shorter time, the aircraft can re-generate its own position report, which may cause unexpected interference to other aircrafts that are relaying the aircraft's packet at the same time slot but just in different frame period. To find the optimal value of this interval, several analysis and simulations have been done and described on the section 5.2.

## 3. AIR-TO-AIR COMMUNICATION

### 3.1. Theoretical Air-to-Air Communication Distance in VHF Band

For oceanic flights, aircraft altitude is fluctuated between 8 and 10 km and propagation among them is line-of-sight in VHF band. Therefore the maximum distance for air-to-air communication, $A_1A_2$, can be calculated [see Fig. 4].

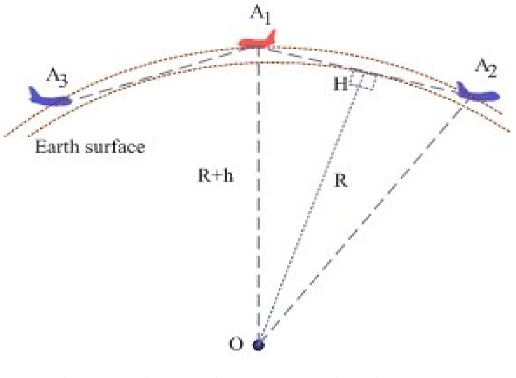

Fig. 4. Air-to-air communication range

The length of $A_1A_2$ could be calculated by following equation:

$$A_1A_2 = 2\sqrt{\left(OA_1^2 - OH^2\right)} = 2\sqrt{\left((R+h)^2 - R^2\right)} \qquad (1)$$

where R is the earth radius (i.e. 6378 km); h is average altitude of the aircraft (i.e. 9 km).

Therefore $A_1A_2$ reaches to a maximum value of 678 km. In reality, this value could be larger when the effect of the Earth curve is accounted.

### 3.2. Receiving Power in Air-to-Air Communication

#### 3.2.1. Experiment Description

The study of air-to-ground propagation channel model was studied deeply in [6]. However, to the best of our knowledge, air-to-air communication between the two aircrafts has not been studied by experiment so far. We have carried out a real experiment to evaluate the relation between bit-error-rate (BER) and receiving power which was presented in [7]. In this paper, the experiment is briefly introduced to show only the relation between receiving power and relative distance between the two aircrafts. Table 1 shows brief configuration of the air-to-air experiment.

Table 1. Air-to-air experiment configuration

| | | |
|---|---|---|
| Frequency | | 123.45 MHz |
| Transmit RF power | | +45 dBm |
| Modulation | | AM |
| Receiver sensitivity (S/N=6dB) | | -98 dBm |
| Transmitter/Receiver antenna | Gain | 0 dBi |
| | Direction | None |
| | Polarization | Vertical |
| Aircraft speed | | 250 m/s |

### 3.2.2. Experiment Data Analysis

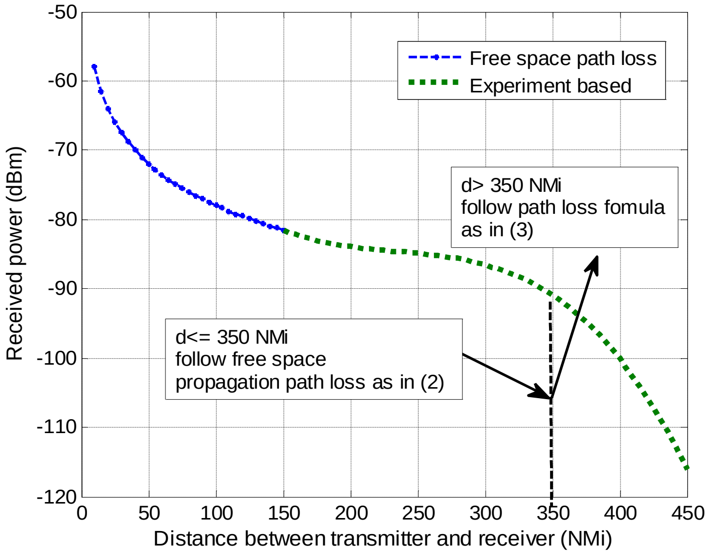

Fig. 5. Relation between receiving power and TX-RX distance

In the experiment, only receiving power at respective distance of larger than 150 NM, was recorded. At distance of lesser than 150 NM, the two aircrafts are always in line of sight communication range of each other; therefore, the propagation path loss definitely follow free space path loss formula. Based on theoretical analysis (for $d<150$ NM) and experimental data analysis (for $d \geq 150$ NM), the relation between receiving power and relative distance is described as in following equations:

$$\begin{cases} P_r(d) = \dfrac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \\ = P_t(dB) + G_t(dB) + G_r(dB) + 20\log_{10}\lambda(m) - 20\log_{10} d(m) - 20\log_{10} 4\pi - 10\log L \quad d \leq 150 \text{ MN} \quad (2) \\ \\ P_r(d) = -45.39 - 0.468d(NMi) + 0.0019d^2(NMi) - 2.752d^3(NMi)10^{-6} \quad d>150 \text{ NM} \quad (3) \end{cases}$$

where $P_t$: transmitted power; $G_t$, $G_r$: antenna gains of transmitter and receiver; $d$: distance between transmitter and receiver; $\lambda$: signal wave length; L: adjustment factor.

Figure 5 shows the description of those equations (2) and (3). From this figure, with $d \leq 350$ NM, receiving power could be estimated by applying free space path loss equation as in (2). At $d>350$ NM, equation (3) could be used to calculate receiving power. Actually, our experimental data analysis results is suitable with theoretical analysis; because at *d*>350 NM (*d*>650 km), almost beyond line of sight range [see Fig. 4], the receiver and transmitter can not see each other; therefore receiving power will be decreased more sharply than that in the area at *d*≤350 NM.

### 3.3. SNR Adjustment Scheme to Increase the Successful Relaying Ratio

In our scheme, the aircraft packet is regenerated frequently after a specific interval. In other way, at the same time slot, one aircraft position reports are generated/ relayed by several other aircrafts that are far from each other in distance or separated by a time interval. This leads to the capability that these aircrafts may cause interference to other aircrafts that are transmitting/relaying packets at the same time slot.

This part introduces a method to keep signal to noise ratio (SNR) higher than the predefined threshold SNR. As explained above, after receiving a packet, the receiver sends a feedback to the transmitter. In case of packet lost due to high interference caused by other neighbour aircrafts, the feedback should contain the measured SNR level and send to the transmitter. In a short time, ground speed of aircrafts are almost unchanged, so the relative distance between the two aircrafts is assumed unchanged (if the same direction) or lesser than before (if opposite direction); therefore to uphold SNR, the simplest way is to adjust transmitting power by following the established formulas in section 3.2. There are two ways to adjust transmitting power. The transmitter can increase transmitting power when retransmitting packet to the receiver. Another way, the transmitter could find a nearer node that ensures that at this receiver, the SNR is higher than the threshold SNR. In the first way, higher transmitting power may cause higher interference to other surrounding aircrafts and may not improve packet loss overall. In the second way, the near node the higher receiving signal power and the transmitter should adjust to a lower power according to a shorter distance which also help to reduce interference to surrounding aircrafts. This method is selected to improve the packet loss due to interferences caused by surrounding transmitters.

## 4. THE PROPOSED MOBILE AD-HOC NETWORK FOR OCEANIC FLIGHT ROUTES

### 4.1. Description of the Mobile Ad-hoc Network Model

At present, aeronautical telecommunication network (ATN) has several shortcomings including the usage of aircrafts only as end nodes; hence, data must be transmitted via ground stations. This leads to one of the bottlenecks for future expansion of aeronautic networks; and the free flight concept in [8] is difficult to obtain. This also makes it impossible for a new concept of networking the sky as in [9]. However, with mobile Ad-hoc networks, both intermediate and end systems can be provided, thus bypassing current ATN limitations. On those considerations, we propose to use local mobile Ad-hoc networks based on air-to-air link once any pair of aircrafts is within their communication distance. These mobile Ad-hoc networks are established locally at each aircraft. They are represented as circles which surround the aircrafts in Fig. 6.

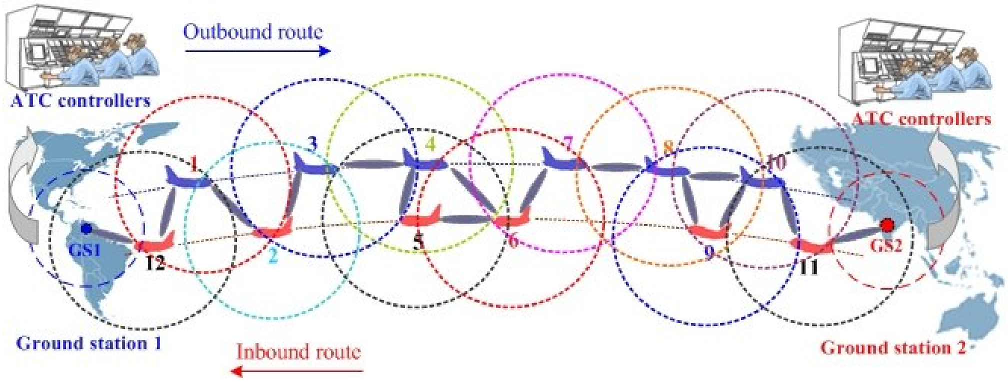

Fig. 6. Model for oceanic flights route employing mobile Ad-hoc network

In this proposal, the system relays position reports of any aircraft to its relevant ground station by relaying via other aircrafts inside the local Ad-hoc network. Each aircraft transmits or relays these packets to the next aircrafts as explained in 2.2. It is necessary to equip the aircraft with one router to route packets to the next destination; and one server to store these packets in a pre-determined delay time if the packets are allowed to stay at each aircraft in case of waiting for link availability. This property is discussed in the section 4.3.

## 4.2. Routing Table and Packet Relaying Algorithms

Based on the model in 4.1., this part describes how the aircraft selects the next aircraft to relay the packet or the relaying algorithms. Recently, mobile Ad-hoc routing protocols for aeronautical communication have been reported in [10] and [11]. However, the protocol in [10] is used with a satellite communication system while some additional internet gateways are essential with model in [11]. Both protocols discuss on internet services for oceanic flight routes which are not for general air traffic control. This paper proposes a communication system to provide position reports of all aircrafts on the oceanic routes for ATC communication without any other infrastructure except existing GPS systems already installed on any aircraft.

To build a routing table, each aircraft first listens to its neighbour aircraft's information through their transmissions within any frame period and then builds a routing table with distance-based and then load-based priority. This is possible because each position report includes aircraft ID, position and its relative direction. The routing table at each aircraft must contain at least aircraft position, relative distance between the aircraft and its neighbour, data load and the relative direction and so on.

In consideration of unequally distributed air traffic at different time showed in several aeronautical reports on typical oceanic routes such as NOA routes in [11][12] and NOPAC routes in [13][14], we propose the following packet relaying algorithms to find out the most effective one:

1) Algorithm 1: each aircraft insists on relaying packets to ahead, furthermost and only the same direction aircrafts.
2) Algorithm 2: each aircraft insists on relaying packets to the ahead and furthermost aircrafts. However, if there is no same direction aircraft, it can select opposite direction aircraft.
3) Algorithm 3: the whole airspace is divided equally into several parts where each part is assigned with one ground station. If an aircraft belongs to some part, its packets will be relayed to the next aircraft in the same part which is closest to ground station of that part. If there is no same direction aircrafts, it selects opposite direction aircrafts.

## 4.3. Improved Packet-Loss-Ratio Scheme

The air traffic in most oceanic routes are not distributed equally during the day; therefore, sometimes there are few aircrafts located inside an aircraft communication distance leading to high packet-loss-ratio due to the low probability of finding an air-to-air link to relay packet to the next. To increase the availability of air-to-air links, we propose a scheme to allow some certain waiting time (wt) at each aircraft in order to keep packets in a longer time before relaying to the next aircraft. For end-to-end system, this proposal does not affect on packet arrival interval. Because the interval of regenerating new packet of the aircraft is fixed and if all packets experience the same delay on each node, the arriving time of these packets is also not changed significantly. Another factor is that the report interval in current oceanic communication is relative large, i.e. 5-10 minutes at horizontal separation is 50 NM. The working process of this scheme is explained as following:

1) Just apply for delaying packet after its arrival at an aircraft.
2) Packets are allowed to wait within the waiting-time (wt) before the aircraft relays to the next aircraft. This waiting time is activated for the first time once this aircraft cannot find the route to relay the packet.
3) The value of waiting time is assumed to be a multiple of frame period since frame period is relative small compared to total delay allowed.

4) As explained above, after an interval, another updated position packet of an aircraft will arrive. If the older packet of this aircraft is still waiting at some aircraft, the newer packet will replace the older one and continue to wait until the allowed wt.
5) During waiting at some aircraft, if this aircraft can find a route to relay the packet, the packet is relayed to the next aircraft immediately and waiting process is reset.
6) If waiting time reaches to wt and this aircraft still can not find any route to relay the packet, this packet is counted as failed and packet-loss counter is incremented ‘1’; waiting process is also reset.

Both relaying-packet algorithms and this scheme are evaluated in the next section.

## 5. SIMULATION AND NUMERICAL RESULT

### 5.1. Input Data and Simulation Conditions

As explained about the air traffic scenario on oceanic routes, it is impractical to assume a fixed air traffic model in the whole day and use that for simulation. In our end-to-end system, the packet-loss-ratio is expected to be lower in higher air traffic routes because of the high availability of aircrafts to relay. In addition, the reports in [8] and [14] express that air traffic density on NOA routes is higher than that in NOPAC routes. Therefore, air traffic model in NOPAC routes are selected for initial input data in our simulation. After analyzing data that are collected on the inbound, outbound of NOPAC routes between Japan and America from March 2000 to February 2001 using Flight Data Processing System described in [14], aircraft arrival and departure distributions in a day on NOPAC routes were obtained in Japan standard time (JST). Based on [2], it is possible to assume that the current number of aircrafts (in 2008) is 1.5 times larger than that in 2000. Therefore, the input data for our simulation is described as in Fig. 6.

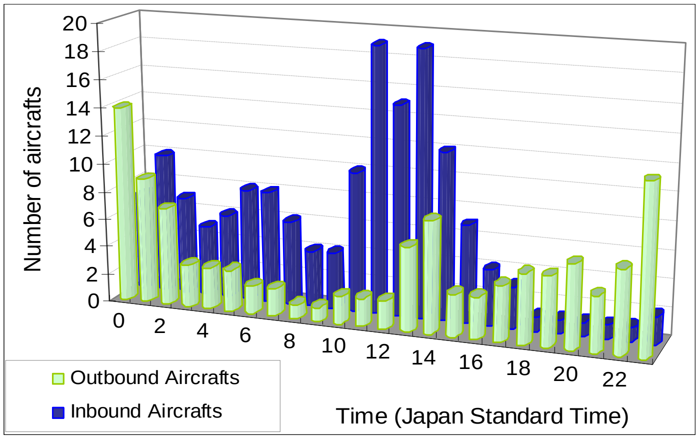

Fig. 7. The number of outbound and inbound aircrafts on NOPAC route

Before the discussion on numerical results, the following conditions are explained in greater detail:

1) The average interval time of arrival/departure aircrafts is calculated based on average hourly-aircraft distribution [see Fig. 6]. Based on the interval time, the aircrafts in each hour are generated randomly but ensured that the minimum time interval between any two aircrafts is always kept at least 3 minutes for both outbound and inbound flights.
2) The maximum radius for air-to-air transmission between aircraft to aircraft is set to 678 km; for the case of air-to-ground between aircraft and ground station, this value is set to 300 km.
3) When a packet arrives at a relay node, based on the routing table at this node, an optimal destination node is decided to relay the packet to. If no node is founded, the number of packet-loss is incremented ‘1’.
4) When a packet arrives at an ATC station successfully, the final destination, the number of successful packets is incremented ‘1’.

5) Three packet-relaying algorithms [see 3.3] were coupled to validate our system proposal. Each case is simulated in 25 days (or 600-hour flying time period) to evaluate the packet-loss-ratio.
6) The distance between ground stations i.e. GS1 and GS2 in our end-to-end system is assumed of 8100 km. The average ground speed of the aircrafts is 900 km/h.

## 5.2. Numerical Results

### 5.2.1. Optimum of time interval and SNR adjustment

Fig. 8 shows the packet-loss-ratio that occurred during relaying packets from all aircrafts in the end-to-end system to their relevant ground stations. This is the ratio between the total number of packets lost and generated packets. The ratio is evaluated for end-to-end system at every hour in the day in JST.

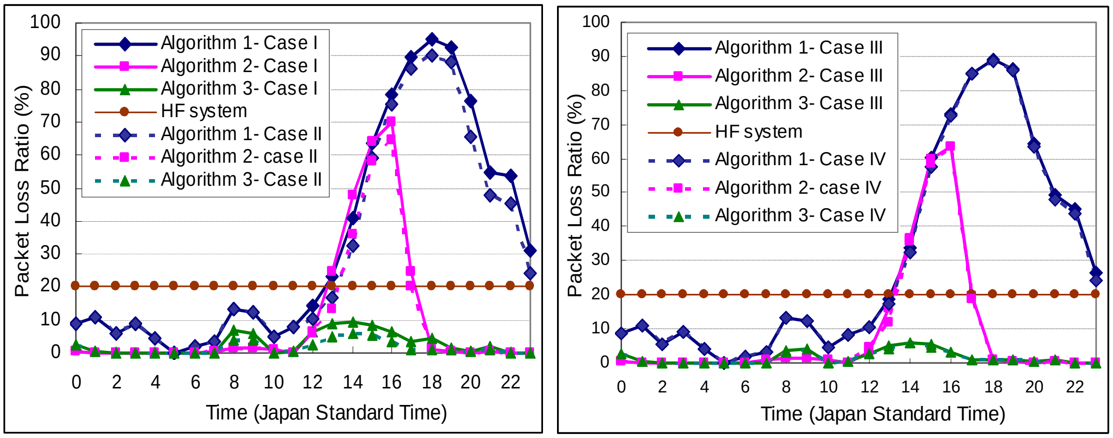

Fig. 8. Packet-loss-ratio of the end-to-end system in the whole day a) without SNR adjustment and b) with SNR adjustment

In Fig. 8a (left side), cases I and II are according to the situations when intervals are 3 and 4 frame periods while the SNR adjustment scheme in 3.3 was not applied. In Fig. 8b (right side), cases III and IV are according to the intervals of 3 and 4 frame periods but were combined with the SNR adjustment scheme. In Fig. 8a, the packet-loss-ratio in cases II is better than that in case I because in case II, the aircrafts transmitting packets at the same time slot are more separated than that in case I, which helps to avoid packet loss due to strong interference caused by the neighbour's transmission. Meanwhile in Fig. 8b, packet-loss-ratio in case III and IV are almost the same and same as case II [Fig. 8.a]. This means that at the interval of 4 frame periods, packet loss due to interference of neighbours was negligible and the power adjustment scheme was not useful. However, at interval of 3 frame periods, the power adjustment scheme was useful and has improved the packet-loss-ratio.

In addition, the packet-loss-ratio of the first two algorithms 1, 2 are relatively high in some periods of time compared to that of algorithm 3. The aircraft distribution is not actually equal in all hours for inbound and outbound flights but the first two algorithms do not allow the flexibility to find the next aircraft. Meanwhile, algorithm 3, the sparseness of inbound flights could be covered by the density of outbound flights or inversely, which could improve the performance in overall.

From these results, the optimal interval values should be 4 frame periods without or 3 frame periods with the SNR adjustment scheme. The latter option with two algorithms 2, 3 will be used to analyze further when coupling with packet-loss improved scheme in the next part.

### 5.2.2. Numerical Results with Packet-Loss Improved Scheme

Even though the packet-loss-ratio in the system coupled with relaying-packet algorithm 3 was the lowest and much lower than that in the HF system. However, to overcome the sparseness of aircrafts in some periods of time or to make this ratio lower is essential in this relaying system. This part describes the results of simulations when applying the two algorithms 2, 3 [see 4.2] with the improved packet-loss scheme [see 4.3] combined with SNR adjustment scheme [see 3.3]. Typical values of waiting time are used in each case, for example:

1) In algorithm 2, waiting time values are selected at: 10, 20, 40, 60, 80 and 100 s [see Fig. 9].
2) In algorithm 3, waiting time values are selected at: 10, 20, 40, 60 and 80 s [see Fig. 10].
3) Each simulation was also done in 25 days (600-hour flying time), the same as in 5.1.
4) Other conditions such as end-to-end system and air traffic scenarios are the same as in 5.1.

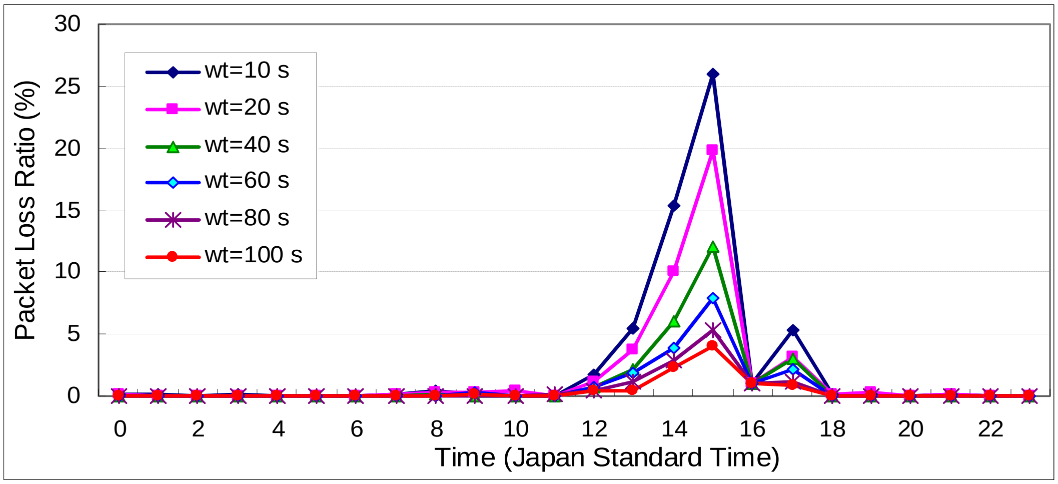

Fig. 9. Packet-loss-ratio of algorithm 2 coupled with a waiting time and SNR adjustment scheme

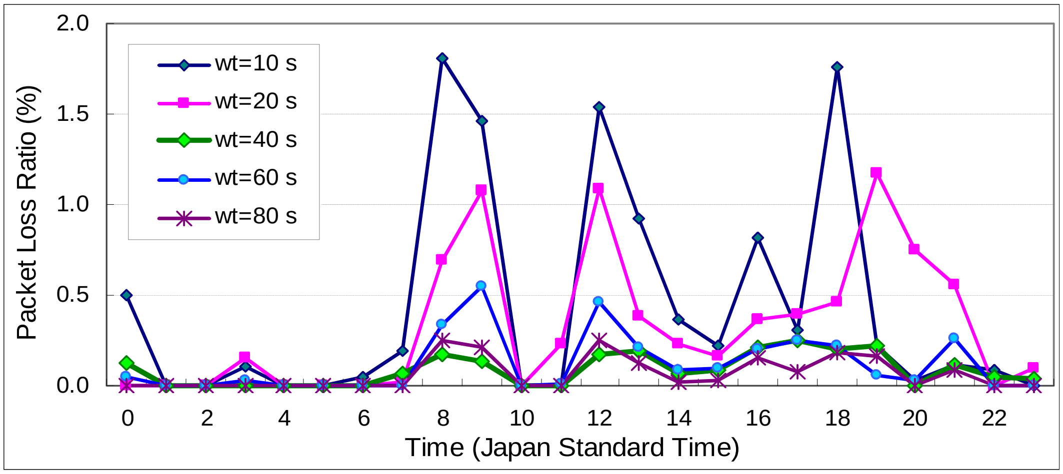

Fig. 10. Packet-loss-ratio of algorithm 3 coupled with a waiting time and SNR adjustment scheme

By using the packet-loss-ratio improved scheme in section 4.3 with a specific allowed maximal waiting time (wt), packet-loss-ratio has been improved significantly, especially at some peaks of packet-loss-ratio in both algorithms 2 and 3 [see Fig. 9-10]. As explained above, even the delay occurred at each aircraft node but for end-to-end systems, the packet arrival interval is still equal to the packet generation interval (this case is 3 frame periods) and does not affect on the position reporting.

In addition, wt will be active and effective only at periods where aircrafts are few and sparse; this means that the packets are additionally delayed only on those periods. On other periods the packets are relayed without any additional delay. For example, at some periods of time such as [7H-9H] and

[13H-17H] in Japan time, the packet-loss-ratio in algorithms 2 and 3 already reached the peak [see Fig. 8] but they became much lower after applying this scheme [see Fig. 9-10].

From Fig. 9 and Fig. 10, the larger value of waiting time the lower obtained packet-loss-ratio in both algorithms 2 and 3. The algorithm 3 always gets a better outcome compared with that in algorithm 2. For instance, with wt of 40 s, the packet-loss-ratio is much improved and reaches below 0.2%.

## 6. CONCLUSIONS

In this paper, a highly reliable communication system, using a single aeronautical VHF channel with air-to-air links based on local mobile Ad-hoc networks, and a TDMA access scheme for aircraft in a wide area has been proposed for oceanic flight routes. The system provides only one channel digital data link connecting aircrafts in a specific oceanic area and relays position reports of any aircraft in system to the relevant ground station (i.e. ATC centre) more frequently and much more reliably than current systems without using any other infrastructure.

The numerical results show that the best system performance is achieved when applying an interval at 3 frame periods combined with SNR adjustment scheme and a packet-relaying algorithm 3. In addition, with an allowed maximal waiting time i.e. wt of 40 s [Fig. 10], the packet-loss-ratio was improved significantly compared with non-waiting case [Fig. 8] and packet-loss-ratio is always below 0.2% in all the cases of air traffic on NOPAC routes [Fig. 10]. Therefore, all flights on the ocean are controlled easily via exact and frequent position reports by relaying from this system.

This feature allows aeronautical authority (ATC centre) to reduce the interval in time or horizontal separation in distance between consecutive flights safely since their situational awareness has been greatly improved. This can increase the number of coexisting aircrafts on the ocean routes and therefore improve airspace use efficiency.

The system can be used independently with current systems to be in charge of reporting all oceanic aircrafts positions to their relevant ATC stations or be used to supplement to current existing HF/SATCOM systems and become a completed system that is essential to any oceanic flights. However, satellite communication is still recommended to use as a backup for this system in case some position reports are not reached to ATC centres in time or for some emergency cases where data and verbal communication with ATC controllers is necessary.

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