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航空機追跡システムの一案
－ MH370 の悲劇を二度と繰り返さないために－

市吉　修

二十一世紀を楽しく生きよう会

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あらまし

マレーシア航空 MH370 便は今年 3 月 8 日未明に南シナ海南方にて消息を断ち、その行方は杳として知れない。乗客乗務員 239 名の運命は全く不明である。この事故の不運は飛行機の位置が地上側に全く未知であった事及び通信の途絶であった。この事故によって現在の洋上飛行航空機の追跡および通信システムに重大な欠陥がある事が明白になった。本論文は今回の悲惨な事故を二度と繰り返さないために(1) 洋上飛行中の旅客機に音声通信も可能な航空追跡通信測位システムを提供する。(2) そのために利用可能な全ての通信衛星システムを活用する。(3) 既存の衛星通信に与える特性劣化を最小化する(1.0dB 以下)通信測位システムを提案するものである。

キーワード MH370, ATC, Satellite Communication, Mobile SATCOM,　Spectrum Spreading,　Process Gain, Location, Black Box

A Proposal for Aircraft Tracking Satellite System
~ Never to repeat the disaster of MH370 ~

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Abstract

Malaysian Airways Flight370 (MH370) lost contact with the air traffic controllers on 8, March, 2014 and was never discovered since. The fate of the flight MH370 with 239 people onboard is totally unknown. The failure of the rescue operation is due to the lack of knowledge about the location of the aircraft after its last contact with the air traffic controllers. It is clear the existing aircraft tracking systems have serious defects. The GPS provides exact positioning tool for the mobile users but it was useless in this case because the communication links between the aircraft and ground controllers were lost.

The requirements for the desirable aircraft tracking system shall be (1) frequent exchanges of flight data , at least once every second, (2) Exact location determination with triangulation through more than 3 satellites or GPS,　(3) Non-ceasing contacts during flights.

In reality we have many communication satellites in operation. Theoretically there are sufficient numbers of satellites for triangulation functions in many parts of the world. In order to use them for the aircraft tracking system, we need to add more requirements; (4) the newly added aircraft tracking system shall not inflict any serious degradation for the existing services.

This paper makes a proposal of a system that meets the above requirements and can also provide continuous communication links between aircrafts and air traffic controllers, which are broad enough to allow voices or even some video communications.

Keywords　MH370, Aircraft Tracking Satellite System, GPS, Triangulation through 3 satellites, CDMA, Spectrum Spreading, High Process Gain, TDMA, Existing SATCOM systems, Degradation, Interferences

1, Disaster of MH370

Malaysian Airways Flight MH370 headed for Beijing, China from Kuala Lumpur, Malaysia lost contact with the air traffic controllers on 8, March, 2014 and was never discovered since. The failure of the rescue operation is due to the lack of knowledge about the location of the aircraft after its last contact with the air traffic controllers at 1:19. The lack of the knowledge about the location of the aircraft caused waste of the precious initial time for the rescue operations. Search operations were continued by cooperation of many countries in the Thailand Bay, South Indian Ocean and other areas for months but none of the aircraft remains were found.

2. Critical Communication Links for Aircraft Tracking

The MH370 disaster revealed the essential defects of the current aircraft tracking system. The positioning systems today are based on GPS for its accuracy and low operation cost. The MH370 event has revealed the essential defect of the current aircraft tracking system is loss of communication. Therefore the new aircraft tracking systems must provide communication links that can never be lost during flights of the aircrafts.

3. Availability of Multiple Satellites for Positioning Functions

The positioning systems can be classified into 3 categories; passive, active and hybrid [1]. The passive positioning systems including GPS require a simultaneous view of 4 satellites to determine the three spaces and one time coordinates. The positioning function is conducted by the mobile terminals. No two-way communication between the systems and mobile terminals are required. On the other hand, the active positioning methods require two way communications between the system and mobile terminals. It is the system side that conducts the positioning functions for the mobile stations. The feature of the active positioning method is that the required number of the satellite links is 3, one less than the passive positioning systems. The hybrid positioning system is the combination of the two methods.

The aircraft tracking system we want to develop here can provide voice-class communication links that can also be used for active or hybrid positioning functions.

The integrated communication / positioning service is classified as Radio Determination Satellite Service (RDSS). One such system titled as GEOSTAR was once planned and partially constructed [2] but abolished by satellite failures and other reasons. Another RDSS services in operation is OmniTracs [3]. The non-geostationary mobile satellite communication systems with CDMA schemes such as Globalstar [4], New-ICO [5] (in paper) could have provided excellent RDSS services for the aircrafts. Other mobile satellite communication systems such as Inmarsat, Thuraya, Aces, Iridium etc., are quite suitable to realize a prompt improvement of the aircraft tracking system; providing the communication links that can transfer flight data including location of the aircrafts. However, the communication channels capacities of the mobile satellite communication systems are very limited. In this paper the author proposes a universal satellite communication system that can provide continuous communication links broadband enough to carry not only flight data but also voice conversation to a large number of aircrafts flying over the oceans all over the world. .

4. The Proposed Aircraft Tracking System

4.1 System Architecture

The proposed system architecture is depicted in Figure 1.

The operational principle of the proposed aircraft tracking system (ATS) is described as follows.

[1] The aircraft is equipped with a communication system that can transmit and receive signals through multiple satellites in its view.

[2] The “Gateway Stations” are equipped with the Aircraft Tracking System (ATS) that can provide communication links with the aircraft stations and can simultaneously measure the round trip satellite links delays through their satellites.

[3] The gateway stations are linked with “ATS center” through the terrestrial data networks, which is typically the Internet.

[4] The ATS center requests the gateways to measure the satellites links delays to the target aircrafts.

[5]The ATS center collects round trip propagation delays data from multiple Gateway stations.

[6] The ATS center calculates the positions of the aircrafts.

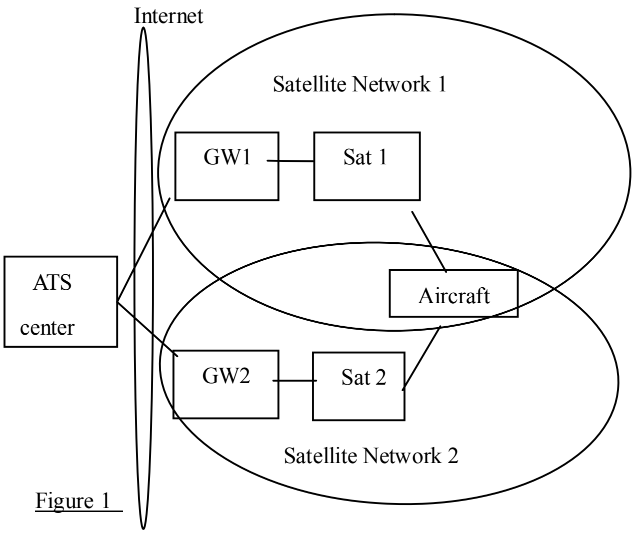

Figure 1

System Architecture of the proposed aircraft tracking system

4.2. Performance Requirements

The following requirements for the proposed aircraft tracking system (ATS) are listed based on the lessons from MH370 disaster and the reuses architecture of the existing satellites systems.

(1) Frequent exchange of flight data ; at least once every second,

(2) Exact positioning with triangulation through 3 satellites,

(3) Non-interrupted contacts during flights

(4) The added ATS shall not inflict any serious degradation on the existing services.

4.3. System Design

4.3.1. Adding ATS to existing satellite communication systems

At the gateway stations the ATS subsystems will be added to the existing systems at IF; commonly at 70, 140MHz or at L bands. The ATS signals need to be of sufficiently low level to avoid giving interferences to the existing services. The ATS signals also need to be of wide bands in order to achieve timing precision. Those requirements can be met by spectrum spreading technology.

4.3.2. Operation of the Proposed ATS system

[1] System Time Base

The ATS center and ATS subsystems at the Gateways are mutually synchronized to form System Time Base. GPS will be used to synchronize the System Time Base.

[2] Forward ATS Control Signal

The Forward ATS Control Signal is generated based on the System Time Base. The information contained in the TX ATS Control signal includes Time Stamp, GW ID and Location Data, Satellite ID and Location Data, and Acquisition Control Signals for the Aircraft ATS terminals. The frame timing (frame period is 1 sec) is given by the Time Base. The TX signal is modulated (typically QPSK) at a common IF frequency (i.e. 70MHz). The TX Control signal is then spectrum-spread by TX PN Generator which generates a Pseudo-Noise (PN) signal with the code designated by the ATS gateway controller and at the timing given by the Time Base. The ATS GW Controller controls the operation of the ATS system through the satellite links communicating with aircraft stations and exchanging data with the ATS Center. The spectrum-spread TX ATS Control signal is sent to the existing Gateway system for transmission over the forward satellite link.

[3] Aircraft Station

The Aircraft station receives the forward satellite link signals which are superposition of the ATS Forward Signals and the existing communication signals. The power density level of the ATS signal is even lower than the thermal noise in order to avoid bringing performance degradation to the existing services. The receive signal is put into PN Code correlation circuit which establishes the PN Code timing, de-spreads the wanted signal and re-spreads all the other signals by correlation processing. The de-spreading improves the S/N ratio of the wanted signal as much as the spreading ratio. The PN code for the ATS Control signal is a priori known by the aircrafts. The PN Code Correlation circuit establishes the system timing for the aircraft terminal. If the aircraft terminal receives forward ATS signals through 4 satellites, it can conduct its positioning by the same principle as GPS (passive positioning).

For communication and active positioning, the aircraft generates a Channel Request signal including its ID, modulates and spectrum spread by the ALOHA PN signal. The PN code of the ALOHA signal is designated by the system through the ATS Control signal.

The Gateway ATS receives and regenerates the ALOHA request signal by correlation processing with the ALOHA PN code and then by demodulation. Then the GW ATS controller allocates ATS Channels composed of PN Codes, frequencies and the Time Slots on both forward and return ATS channels for the aircraft station.

The aircraft station receives the forward ATS Control signal to obtain the allocated ATS channel parameters. The aircraft station then starts communication with the gateway station through the designated return and forward ATS channels.

[4] Communication and Positioning by ATS signals

The gateway and aircraft stations communicate through the allocated ATS channels. For simple positioning the GPS measured data can be included in the return ATS channel.

The proposed system can also conduct active positioning independent of GPS in the following manner. The ATS controller allocates the ATS channels for three different satellites. The ATS channels are transmitted via three different satellites in TDMA (Time Division Multiplex Access) mode. The aircraft station receives the forward signals from satellite 1, 2, 3 in that order every second. Then the aircraft station transmits return signals through satellites 1.2.3 every second. Thus communications links through three different satellites can be established quite naturally.

The Gateway ATS receives the Return signals, establishes the receive signal timing by PN code correlation. The detected receive signal timing is compared with the timing for the forward signal to measure the round trip satellite links delays. The measured delay data are sent to the ATS Center. The ATS center receives the delays data from three gateways to calculate the location of the aircraft.

As the above positioning is conducted within every one second, the precision of the location measurement for the aircraft flying at the speed of the sound is about 340m.

[5] ATS Center

The ATS center exchanges data with many Gateways for the Aircraft Tracking System operations.

<1> ATS Center holds the list of aircrafts in its User File.

<2> The aircraft, after taking off, achieves synchronization with the forward ATS Control signal.

<3> The aircraft station requests the gateway station for allocation of the ATS Channels for communication and/or positioning through ALOHA channel sent at a random timing on the TDMA frame.

<4> Upon detection of the ALOHA signal, the Gateway notifies the ATS Center of the aircraft requesting for the service.

<5> Based on requests by the ATS center, the Gateway stations allocate the ATS Channels for the satellite links and notifies the aircraft station through ATS Control channel.

<6> The aircraft and gateway stations communicate through the satellite(s) by the allocated ATS channels.

<7> The Gateway conducts the satellite link delay measurements for the aircraft and delivers the data to ATS Center.

<8> The ATS Center conducts the above operations with multiple satellite systems to calculate the locations of the aircrafts.

<10> The ATS center maintains communication & tracking for the aircrafts all the way of their flights over the oceans.

4.3.3 Major system parameters

[1] Symbol rates of ATS signals	20kbaud
[2] Chip rate for spectrum spreading	20 (Mchip/s)
[3] Process gain;	30 (dB)
[4] Operating conditions of existing systems;	
(1) Operation C/N	10 (dB)
(2) Degradation caused by added ATS	< 1.0 (dB)
[5] Positioning Errors (km)	< 1.0

4.3.4 Performances

The frequency spectrum analysis is depicted in Figure 2.

[1] Existing communication channel

The parameters for the existing communication channels ;

- Carrier signal power (W) ; Cc
- Frequency Bandwidth (Hz); Bc
- Noise power density ; No (W/Hz)
- C/N ratio without positioning signal;

$$(C/N)co = Cc / (No \cdot Bc)$$

[2] Added ATS signal

- Carrier signal power (W) ; Cp (W)
- Frequency Bandwidth before spreading ;Bp (Hz)
- Frequency Bandwidth after spreading ; Bc (Hz)
- Spread Ratio or Process Gain ; Gp (Bc / Bp)

[3] Degradation of existing services by added ATS signals

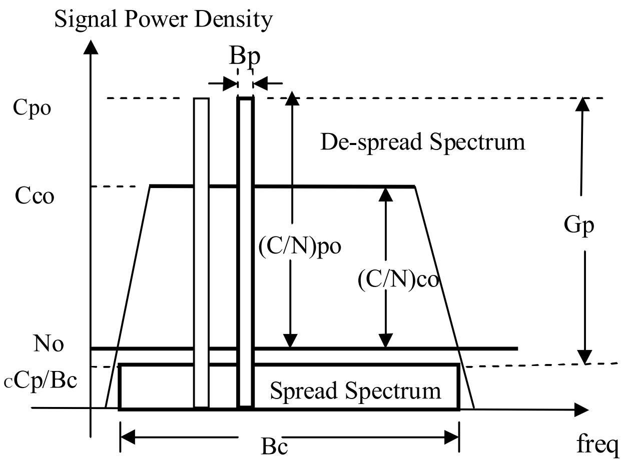

Fig 2 Spectrum Analysis of the System Operations

The added positioning signal is spectrum spread to Bc. The ATS signal power density is Cp/Bc (W/Hz). If we add n ATS channels, the equivalent noise power density is $No + n \cdot Cp/Bc$.

The resultant C/N for the existing communication channel with n positioning channels is;

$$(C/N)c = Cc / \{Bc \cdot (No + n \cdot Cp / Bc)\}$$

$$= (C/N)co / \{ 1+ n / Gp \cdot (C/N)po\}$$

Where

$$(C/N)po = Cp / (No \cdot Bp)$$

The degradation of the communication channel is;

$$[C/N]co – [C/N]c = 10 \cdot \log(1+ n / Gp \cdot (C/N)po)$$

$$(=)\ 4.3 \cdot n / Gp \cdot (C/N)po \qquad (dB)$$

$$(as \quad n / Gp \cdot (C/N)po << 1)$$

Where (=) means nearly equal.

[3] C/N of ATS signal after spectrum de-spreading

At the receiver, the signal power density of the ATS signal after de-spreading is Cp/Bp. Other signals including thermal noise are re- spread over bandwidth Bc. Thus the resultant (C/N)p is;

$$(C/N)p = Cp / \{Bp \cdot (No + (n-1) \cdot Cp / Bc + Cc / Bc) \}$$

$$= (C/N)po / (1+ (n-1) / Gp \cdot (C/N)po + (C/N)co)$$

$$(=)\ (C/N)po / (C/N)co$$

$$(as \quad (C/N)co >> 1 >> (n-1) / Gp \cdot (C/N)po)$$

[4] Noise performances of communication and ATS signals

An example system design that uses a 27MHz transponder is given as follows.

Existing channel; [C/N]co = 10 (dB)

Spectrum spread ratio; Gp = 1000, or

Process gain [Gp] = 30 (dB)

Let C/N degradation of existing communication channel due to a single positioning channel less than 0.1(dB).

$$4.3 / Gp \cdot (C/N)po < 0.1, \qquad or$$

$$(C/N)po < 0.1Gp / 4.3 = 23.2 , \qquad or$$

$$[C/N]po = 10og((CN)po) = 13.7 (dB)$$

The actual C/N ratio of the positioning signal is

$$[C/N]p = [C/N]po – [C/N]co = 13.7 -13.0 = 3.7 (dB)$$

Note the noise in this case is actually the interference signals from the existing channels with a limited amplitude distribution; the BER performance is better than the case of a purely white noise.

[5] Effects of multiple ATS signals

The existing channel degradation is;

$$[C/N]co – [C/N]c = 10 \cdot \log(1+ n / Gp \cdot (C/N)po)$$

$$= 10 \cdot \log(1 + 0.023n) \qquad (dB)$$

For n= 10, $[C/N]co – [C/N]c = 0.9 (dB)$

The mutual interferences between the ATS signals are negligible as they are of FDMA (Frequency Division Multiple Access) mode as depicted in Figure 2. As the number of ATS signals increases, the C/N remains almost the same as the dominant interferences come from the existing systems.

[6] Communication capacity

Let us assume we use 20MHz of a 27MHz transponder. Then the above analysis tells that we will have a 20kHz ATS channel with 0.1dB C/N degradation to the existing channels. The number of ATS channels can be increased to 10, with the degradation 0.9dB. Since a satellite has usually more than 30 transponders, we can expect 300 channels of 20kHz per satellite. With QPSK, a 20kHz channel can carry about 40kbps, which can support 3 communication links that can carry voice and data. Thus a satellite will be possible to support 900 aircraft stations.

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4.4 Detection of ALOHA channel

The ALOHA PN code is common in the ATS network. All aircrafts use the same PN code for channel request functions. Hence, the ALOHA PN correlation circuit must be of a transversal filter type. The receive signal is put into a delay line with taps each of which is multiplied by each of the ALOHA PN code C(0), C(1), ,,C(L-1) (take values +1, or -1) followed by an adder. The output of the adder gives the correlation output of the ALOHA detector.

The frequency errors cause degradation of the correlation detection. Let fe be the signal frequency error at the input of the ALOHA signal correlation circuit. Then the output of the correlation output is;

$$1 + e^{j(\Delta\theta)} + e^{j(2\Delta\theta)} +,,,+ e^{j((L-1)\Delta\theta)}$$

$$= e^{j((L-1)\Delta\theta/2)} \cdot \sin(L\Delta\theta/2) / \sin(\Delta\theta/2)$$

Where

$$\Delta\theta = 2\pi \cdot fe \cdot Tc$$

Tc is the chip symbol length which is 50ns for 20Mchips/sec.

$$L\Delta\theta/2 = \pi \cdot fe \cdot (Tc \cdot L) = \pi \cdot fe \cdot Td$$

Where $Td = Tc \cdot L$ is data symbol length which is 50μs for 20kbaud symbol rate. Note $\sin(\pi feTc)$ (=) $\pi .fe.Td / L$ (<< 1)

Then the correlation output value is

$$V[Corr] \text{ (=) } e^{j(\pi feTd)} \cdot L \cdot \sin(\pi .fe.Td) / (\pi .fe.Td)$$

Note it equals L for fe = 0.

The amount of degradation for fe.Td =1/2, i.e., fe = 10kHz ; the correlation output reduces by $2/\pi$, or 4dB degradation.

As the aircraft terminals regenerate the Forward Frame signal, the forward link frequency errors are compensated. The return links frequency errors can not be compensated by the aircrafts. In a Ka band the above fe = 10(kHz) is achieved if the frequency stability of the return links are better than $10k/20G = 5 \times 10^{-7}$.

5. Conclusion

By reuse of existing satellites, it is shown that a large number of aircrafts can be provided with communication links broadband enough to carry flight data and voice conversations. The communication links can be also used for positioning of the aircrafts by triangulation through 3 satellites with accuracy much better than 1 km. The spectrum spreading technology can achieve the exact positioning and at the same time reduce the interferences on the existing services to a permissible level. It is expected the proposed method will realize a much safer flights over oceans all over the world.

References

[1] Olof Lundberg, "Cutting the cord, introducing mobile satellite communications" Never Beyond Reach , Inmarsat, 1989

[2] Martin A. Rothblatt, "Radiodetermination Satellite Service"
2213-7/850000-029 $1.00 1985 IEEE

[3] Omnitracs ; http://www.omnitracs.com/

[4] Globalstar ; http://www.globalstar.com/

[5] Osamu Ichiyoshi, "New ICO, A Proposal for a CDMA Mobile Satellite System" IEICE Technical Report, SAT2007-42(2007-11)

[6] V.K.Vhargava, D.Haccoun, R.Matyyas and P.P.Nuspl,
Digital Communications by Satellites,
John Wiley and Sons, Inc, 1981

[7] J.J. Spilker, Digital Communications by Satellites,
Prentice Hall Inc. New Jersey, 1977