[EN-109]Autonomous Decentralized Coordination Technology for Secondary Surveillance Radar (SSR) Mode S

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Abstract:

Secondary Surveillance Radar (SSR) Mode S is an air traffic control radar system with improved surveillance and datalink capability. As the number of Mode S Ground Station (GS) and aircraft with Downlink Aircraft Parameters (DAPs) and Automatic Dependent Surveillance -Broadcast(ADS-B) capability increases, two new problems for SSR mode S are on the rise. The first is 1090MHz signal environment preservation. The second is interrogator identifier shortage. Networking Mode S GS is the most realistic solution for these problems. However, networking also brings some problems .We need to take these problems into consideration before designing network.

To solve the problems for Mode S using network approach, we propose Autonomous Decentralized Coordination Technology (ADCT) for Mode S. In this paper, we first discuss the problems for Mode S and networking. Then ,we discuss the architecture, coordination procedures and features of the proposed technology and introduce our experimental Mode S network.

Keywords: SSR mode S , II code coordination , DAPs, ADS-B , Autonomous Decentralized Systems

1. INTRODUCTION

Secondary Surveillance Radar (SSR) Mode S is an air traffic control radar system with improved surveillance and datalink capability. As the number of Mode S Ground Station (GS) and aircraft with Downlink Aircraft Parameters (DAPs) and Automatic Dependent Surveillance Broadcast(ADS-B) capability increases, new two problems for SSR Mode S are on the rise. The first is 1090MHz signal environment preservation. The second is Interrogator Identifier (II) shortage. Networking Mode S GS is the most realistic solution for these problems. However, networking also brings some problems .We need to take these problems into consideration before designing network.

To solve the problems for Mode S using network approach, we propose Autonomous Decentralized Coordination Technology (ADCT) for Mode S. In this paper, we first discuss the problems for Mode S and networking. Then ,we discuss the architecture , coordination procedures and features of the proposed technology and introduce our experimental Mode S network.

This paper is structured as follows. In section 2, we discuss the details of problems in SSR mode S. In section 3, we discuss the requirements for Mode S network. In section 4, we explain the details of the proposed technology that is named Autonomous Decentralized Coordination Technology(ADCT). In section 5, we discuss the II code coordination which is apart of ADCT. In section 6, we discuss new features of ADCT. In section 7, we discuss the ADCT experimental network. In section 8, we conclude this paper.

2. PROBLEMS IN SSR MODE S

As the number of Mode S GS and aircraft with DAPs or ADS-B capability increases, two new problems in SSR Mode S are on the rise. The first is 1090MHz signal environment preservation . The second is II code shortage. In this section, we discuss problems in detail.

2.1 1090MHz signal environment preservation

ADS-B is a promising system that will play a major role in air traffic control surveillance systems in the future. In ADS-B, aircraft measures own precise positions by satellite navigation systems such as Global Positioning System (GPS), and

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periodically broadcasts messages . ADS-B uses the same signal and RF band as SSR mode S reply signals. ADS-B uses random access protocol, which does not control message transmission. Therefore, it is susceptible to interference by SSR replies. ADS-B should be operated in radio-signal silent environment.

To obtain an ADS-B friendly environment , not only conventional SSR should be replaced to MS but also SSR Mode S reduces reply signals as much as possible.

As well as attempts to reduce reply signals, there is a growing demand for SSR Mode S datalink. In the 1990s, European states launched a project to use Mode S dataink,-Downlink Aircraft Parameters(DAPs) [1]. DAPs provides air traffic controllers and systems with additional aircraft information such as selected altitude, roll-angle, magnetic heading. These parameters help air traffic controllers accurately image present traffic . In addition, they improve the accuracy of aircraft position prediction in conflict detection algorithms.

The number of replies increases as the number of DAPs aircraft increase. If multiple MS independently downlink the same parameters, excessive replies deteriorate the 1090MHz RF environment.

2.2 II code shortage

In SSR Mode S system, each Mode S GS has II code. The II code is set in interrogation and reply signals. It enables transponders to identify the source site of interrogation and GS to distinguish the destination of reply. The International Civil Aviation Organization (ICAO) standards prepares 4bits of space in interrogation and reply for II code.[2][3] Fifteen II codes are available for GS. An II code should be assigned without conflicts with neighboring GS that have overlapping coverage.

As the number of SSR Mode S GS increases, SSR operators are not able to assign II codes without conflicts with neighboring GS. If the same II code is assigned to a neighboring Mode S GS without any coordination, GS is not able to achieve continuous aircraft surveillance in overlapping area. For example, one GS is not able to acquire inbound aircraft in overlapping area, what is worth that both GS cannot survey aircraft at the boundary of overlapping coverage. To keep continuous surveillance in the coverage , GS are required to coordinate II code.

3. NETWORK PROPERTIES

Networking Mode S GS is the most realistic solution for the problems. However, networking also brings some

problems .We take into consideration the requirements for network before designing network.

3.1 Online test

A network is required to have online test property that allows SSR operator to easily perform tests during operation for the following reasons.

First, the entire SSR Mode S network is not constructed at once but constructed step by step. In Japan , more than 30 SSR have already been deployed. Among them, a few SSR are replaced with SSR Mode S every year. Therefore, it takes several years to replace all SSR with Mode S. When a new GS joins the network, an SSR operator needs to perform sufficient number of tests before operation. It takes many hours for a SSR operator to perform the tests since the systems are composed of wide variety of complex systems and functions. In addition, it is very difficult to have enough test time when systems are in operation.

Second, even after all of the GS are deployed, the network encounters changes. It would be kept to be partially modified, added to, or replaced. After these changes, the SSR operator also needs to perform tests to confirm that the changed sections are working correctly.

3.2 Avoiding the malfunction of the entire network

Aircraft surveillance is critical. The malfunction of the entire network causes a catastrophe. Therefore, it is vital for Mode S network to have a property to avoid entire network malfunction. In such networks, a failure does not affect the entire network. If a failure occurs, the failed section is isolated and blocked from the rest of network . The remaining sections continue to work correctly without interruption. If possible, the remaining sections should backup any deficient activity.

4. AUTONOMOUS DECENTRALIZED COORDINATION TECHNOLOGY

To solve problems while taking into consideration network requirements, we propose Autonomous Decentralized Coordination Technology (ADCT) for Mode S. The architecture of the ADCT network is shown in Figure 1 (i). In this section, we describe the network architecture, messages and subsystems of the network.

4.1 Architecture

The ADCT network is composed of GS ,network control gateways (NCGW) and a network. To compare the structural difference , we show the architecture of the Cluster Coordination(CC) Technology in Figure 1 (ii). CC is a
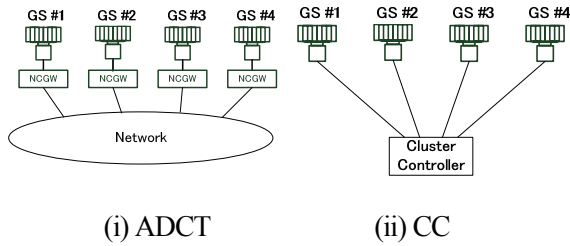
(i) ADCT   (ii) CC

Figure 1.   Architectures of Cluster Control Technology and Autonomous
Decentralized Coordination Technology

network aided coordination technology[4][5],which uses a central processor, so called cluster controller. The cluster controller controls all GS in network. In the ADCT network, there is no central processor but multiple distributed processors so called NCGW. NCGW plays a similar role as cluster controller. This distributed architecture satisfies requirements for network.

4.2 Messages

In ADCT, we can classify messages into two categories, local messages and global messages. Local messages are used for in-site communication between GS and NCGW. Global messages are used for inter-site communication. The messages are designed based on ASTRERIX CAT17, 18, 34 and 48 formats. Most of the items in the messages are common to ASTERIX. Here we define some new items, which are unique to ADCT.

(1) Local messages

Local messages are used for in-site communication between GS and NCGW. There are several types of local message. Here ,we show important parameters of two message(target report and track assist request) in Table1 and 2. GS transmits local target report messages to NCGW. NCGW transmits track assist request messages to GS.

(2)Global messages

Global messages are used for inter-site communication. NCGW transmits only several types of message to network. Here ,we show important parameters of two messages(global target report message)in Table3. NCGW broadcasts them to network.

4.3 Mode S Ground Station (GS)

A GS measures the range and azimuth of aircraft and simultaneously communicate with aircraft to obtain aircraft identification number , altitude and other aircraft statuses.

A GS sends to an NCGW a target report message for each aircraft per scan while it is monitoring aircraft .

A GS receives request messages from an NCGW and change

own operation in accordance with requests from the NCGW.

4. 4 Network Control Gateway(NCGW)

In ADCT, each GS has NCGW. The NCGW only controls the GS that is directly connected to it. A NCGW never controls GS at other sites. NCGW is connected to the GS and   to the network.

The local tracker receives surveillance information of own GS and keep track of aircraft status of own GS . Figure.2 shows the functions in NCGW. The global tracker receives surveillance information of neighboring NCGW(GS) and keep track of aircraft status of neighboring GS Two tracker achieve important roles in NCGW. The target process function produces request message by analyzing target status of two trackers.

4.5 Network

NCGWs exchange global messages through network. The necessary bandwidth for SSR Mode S communication is narrow compared to current data traffic on the Internet . The size of a target report is approximately 50 bytes in ASTERIX

Table 1 Local Target report message parameter

Parameter	Description
Format	Message Format/Content Code
Control	Online/Test Flag
Time	Time of day
Pol. Position	Range, Azimuth, Altitude
Address	Mode S address (Aircraft address)
SN	Serial number

Table 2   Track assist request message parameter

Parameter	Description
Format	Message Format/Content Code
Control	Online/Test Flag
Time	Time of day
Position	Latitude, Longitude, altitude
Address	Mode S address (Aircraft address)
Vector	Ground Speed, Heading
SN	Serial number

Table 3   Global Target report message parameter

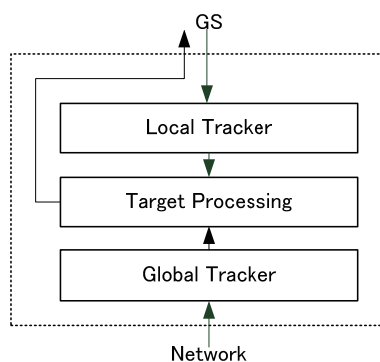| Parameter	Description
Format	Message Format/Content Code
Control	Online/Test Flag
Time	Time of day
Pol. Position	Range, Azimuth
Cal. Position	Latitude, Longitude, altitude
Address	Mode S address (Aircraft address)
Vector	Ground Speed, Heading
SN	Serial number

Figure 2. Functions in NCGW

CAT48 format and the maximum number of targets is 400 aircraft per GS per scan. At its peak, GS for enroute surveillance transmits 50 targets report in 312.5 msec. Therefore, each GS only transmits 16kbps on average and 64kbps at peak times.

5. II CODE COORDINATION IN ADCT

In this section, we explain the II code coordination procedure in the ADCT network.

Two techniques, inbound target acquisition and coast recovery, are required to maintain continuous surveillance in overlapping coverage by assigning the same II code to neighboring GS.

5.1 Inbound target acquisition

We explain inbound target acquisition procedure. As an example, we show a case that aircraft is entering from a single coverage to overlapping coverage in Figure 3. Aircraft is entering at the Point 1 in Figure3. When the same II code is assigned to both GS#1 and GS#2, GS#1 is not able to acquire inbound aircraft in overlapping coverage because GS#2 is locking out targets and targets are not answering all-call interrogations. In an ADCT network, NCGW receives all target messages of the neighboring NCGW. Therefore , the global tracker in NCGW #1 tracks all the targets in GS#2.

1. When aircraft is approaching   the surveillance coverage of GS#1, NCGW #1 detects the approach by referring to the tracked target information in the global tracker .

2. NCGW#1 creates a track assist message by using target information from the global tracker.

3. NCGW #1 sends a track assist message to GS #1.

4. GS#1 generates a new track in the active target list. The active target list keeps the target information which GS#1 send s interrogation at next scan.

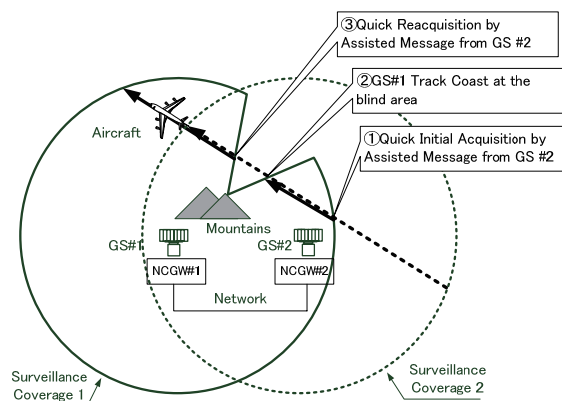5. GS#1 transmits a roll-call interrogation to the target.

Figure 3.   Track assist in the overlapping coverage.

6. If GS#1 receives a reply from the target, GS#1 can obtain the position of   interrogated target.

7. GS#1 creates a local target report message and send it to NCGW#1.

8. NCGW#1 receives the message and know to know the success of the track assist .

9. NCGW#1 stops transmitting track assist messages.

10. If GS#1 fails to receive a reply by roll-call interrogation, GS#1 does not send a target message.

11. NCGW#1 continues to send track assist messages to GS#1.

5.2 Coast Recovery

We explain coast recovery procedure. As an example, we show a case that GS coasts a target at a blind area where   mountains are blocking the radiated signals in Figure 3. GS#1 coasts track at Point 2 in the figure. GS#1 is not able to reacquire the target in overlapping coverage because the GS#2 is locking out its.

1. The local tracker of NCGW#1 detects the target coast from the interruption of the local target reports which are periodically transmitted by GS#1.   .

2. NCGW#1 creates track assist messages by using target information in the global tracker.

3. NCGW #1 sends a track assist message to GS #1.

4. GS#1 updates track in the active target list using track assist message.

5. GS#1 transmits roll-call interrogation to the target.

6. If GS#1 receives a reply from the target, GS#1 can obtain the position of the interrogated target.

7. GS#1 creates a local target report message and send it to NCGW#1.

8. NCGW#1 receives the message and know the success of

the track assist .

9. NCGW#1 stops transmitting track assist message.
10. If GS#1 fails to receive a reply from the target, GS#1 does not send a target message.
11. NCGW#1 continues to send a track assist messages to GS#1.

6.NEW FEATURES OF THE ADCT NETWORK

ADCT has new features s that are difficult to implement in the cluster coordination. We explain a few features in this section.

6.1 One Interrogator Identifier Code

The number of GS or surveillance systems in a cluster coordination network is limited to six in EUROCONTORL standard[5] . On the contrary, the number of GS or surveillance systems in ADCT is unlimited. The practical limit is determined by the site performance such as the NCGW processor performance or ground network bandwidth.

In ADCT, the network only uses one II code in normal network operation. An example is a crowd of Mode S GS in Figure 4, which is in ICAO manual[3]. To operate 15 GS with the cluster , multisite and sectorized operation, four II codes are assigned to a crowd of GS .In ADCT, only one II code is needed to operate 15 GS. network connection is necessary.

6.2 Coordination of downlink

In ADCT, NCGWs are able to coordinate the transmission of downlink request each other. For example, if a NCGW is performing a downlink, a neighboring NCGW suspends requesting downlink. On the other hand, if a NCGW suspends requesting downlink, neighboring NCGW starts a downlink request. This coordination can reduce the number of requests for downlink.
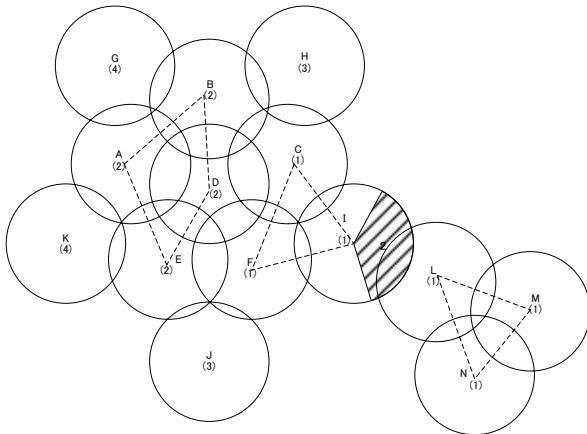

Figure 4.   An example of II code coordination

Figure 5.   A view of IWNANUMA SSR mode S antenna

6.3 Track assistant from new surveillance systems

In ADCT, NCGW can easily increase the number of GS or new surveillance systems since the processing load is not centralized but distributed to multiple NCGW in the network. Cluster coordination has the capability to connect new surveillance systems. However, it needs to pay attention to the processing load of the central processor.

7. ADCT EXPERIMENTAL NETWORK

To validate the ADCT network by monitoring real aircraft in the air, ENRI is developing an ADCT experimental network. Full ADCT network will be completed in the first quarter of 2011. The network is composed of two GS. The feature of two GS are shown in Table 4.

One GS is located in the ENRI headquarter in Chofu, Tokyo. This GS was developed in 2008 and will be upgraded to network coordination functions at the end of 2010.

The other GS is located in the ENRI branch office in Iwanuma, Miyagi prefecture. We completed the development of GS with network coordination function at the beginning of 2010. The full functions necessary for ADCT such as the track assist

Table 4.Features of GS in network

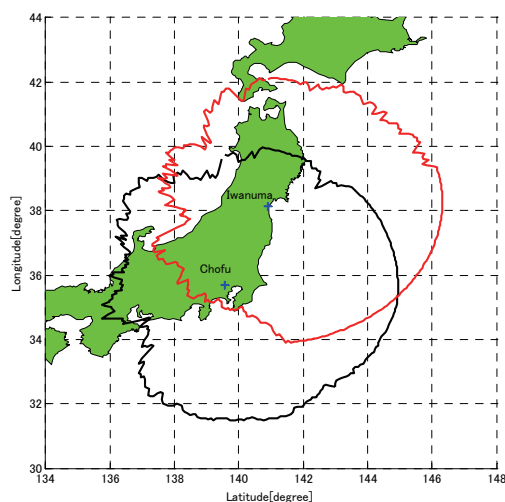|	Chofu GS	Iwanuma GS
Start Operation	April2008	July 2010
Maximum Coverage radius	250NM	200NM
Transmit power	1.5kW	1.5kW
Rotation Period	10seconds	4seconds
Manufacturer	TOSHIBA	NEC

Figure 5.   The coverage of ADCT experimental network

function have been fully implemented .

The NCGW are also under development. Currently several functions such as the track assist message generate function has already been implemented, and unit tests at the IWANUMA GS have started.

The coverage of two GS at 40,000ft is shown in Figure 5 .The Plus signs (+) show the locations of Mode S GS. A black solid line shows the edge of the coverage of the Chofu GS and the red line shows that of the Iwanuma GS. The distance between two GS is approximately 160NM.

8.   CONCLUSIONS

In this paper, in section 2, we discuss the details of problems in SSR mode S. In section 3, we discuss the requirements for Mode S network. In section 4, we explain the details of the proposed technology that is named Autonomous Decentralized Coordination Technology(ADCT). In section 5, we discuss the II code coordination which is a part of ADCT. In section   6, we discuss new features of ADCT. In section 7, we discuss the ADCT experimental network. In section 8, we conclude this paper.

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