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Blended secondary surveillance radar solutions to improve air traffic surveillance

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ABSTRACT

The 1030/1090 MHz frequency band is allocated for air traffic surveillance, including Secondary Surveillance Radar (SSR), Traffic Collision Avoidance System (TCAS), and Automatic Dependent Surveillance-Broadcast (ADS-B) systems. Concerns have been raised that the 1030/1090 MHz frequency band will experience significant congestion to the point of inhibiting ADS-B and TCAS from meeting performance requirement minimums by 2035 in the United States. Even today, intermittent SSR transponder availability has occurred in some high-density air traffic areas. These occurrences will likely escalate as air traffic increases, resulting in the inability of air traffic control to accurately track aircraft. This paper presents three alternative methods of using variable SSR interrogation powers with respect to azimuth sectors and ADS-B aircraft tracking data to mitigate spectrum congestion. Simulation results showed that the presented methods could reduce the spectrum congestion up to 92 percent in terms of an SSR transponder occupancy time. In addition, the proposed methods lessened the required number of Mode-S interrogator identification codes about 50 percent in the simulation environment.

1. Introduction

In the United States, many air traffic surveillance systems commonly use 1030/1090 MHz frequency including Secondary Surveillance Radar (SSR), Traffic Alert and Collision Avoidance Systems (TCAS), Multilateration (MLAT), and Automatic Dependent Surveillance-Broadcast (ADS-B). Except for ADS-B, the interrogator of these systems sends interrogation signals at a frequency of 1030 MHz and a transponder replies back at frequency of 1090 MHz. The reply typically contains the transponder address and altitude messages depending on the type of interrogation format. The slant range between the interrogator and the transponder is determined from the signal roundtrip time. In the ADS-B operation, a transponder periodically broadcasts aircraft tracking data messages without interrogations at 1090 MHz frequency. The motivation of using the same frequencies for multiple surveillance systems was to keep the compatibility with existing transponders installed in aircraft as new surveillance systems were developed. It has been reported that, however, the spectrum congestion at 1030/1090 MHz will be significant enough that the currently existing and planned surveillance systems will not achieve the specified performance level of air traffic surveillance and collision avoidance in National Air Space (NAS) around year 2035 [1,7].

The spectrum congestion results mainly from the excessive interrogation power and the high number of interrogations in the current operation of SSRs in the U.S. The excessive interrogation power is rooted in the fact that an SSR interrogation power needs to be set for the poor receiver sensitivity of antiquated Air Traffic Control Radar Beacon System (ATCRBS) transponders as required in the specifications [2]. The SSR interrogation power set for worst-case transponders effectively provides a much larger coverage to a modern Mode-S transponder having better receiver sensitivity. The larger SSR coverage range with a modern Mode-S transponder could induce extensive RF coverage overlaps with neighboring SSRs. The large overlapping coverage may cause unwanted interrogations and induce False Replies Unsynchronized In Time (FRUIT) that increases the chance of receiving garbled messages or missing desired replies due to unresponsive transponders that are being occupied by processing of other signals.

The overlapping coverage may also induce a conflict of Mode-S Interrogator Identification (II) codes. The II code is encoded in Mode-S interrogation messages such that an airborne transponder is able to tell which interrogator emits the interrogation. How-

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ever, when a transponder is in the overlapped coverage of SSRs using the same II code, the transponder would only respond to the first SSR that establishes contact using the II code (and 'locks' the transponder out from responding to interrogations of other SSRs on the II code). Therefore, the transponder may have delayed, or even no, detection for other SSRs having the same II code. The II conflict is partly due to the fact that the FAA currently uses only 15 distinct II codes. This small number of available II codes is not enough to assign distinct II codes without a conflict given the large number of Mode-S SSR in the U.S. To minimize the II conflict, some Mode-S SSR uses different II codes with respect to azimuth wedges [3]. In the future, the FAA plans to use 63 surveillance identification (SI) codes, which will be sufficient to remove the II conflict problem. However, the use of 63 SI codes will take many years since most Mode-S transponders should be SI-compatible [3].

To reduce spectrum congestion, SSRs outside of the U.S. implement SSR clustering or netting [4]. The SSR netting technique shares the target tracking and interrogation scheduling information in the networked cluster so that multiple SSRs can avoid interrogating the same targets. However, the currently available technologies of variable SSR interrogation power with respect to azimuth sectors and the deployed Automatic Dependent Surveillance-Broadcast (ADS-B) service could be used to provide a more cost effective solution to the problem of SSR spectrum congestion. The 'blended SSR solutions' in this paper refer to the methods of reducing spectrum congestion caused by SSRs from using the combination of variable sectored interrogation power and ADS-B aircraft tracking information. In the blended SSR solutions, although an SSR operates independently from other SSRs, it is expected to provide operational benefits similar to, or better than, SSR clustering. The blended SSR solutions and associated effectiveness are presented in this paper.

2. Blended SSR solutions

This section discusses the use of the sectored interrogation power and ADS-B tracking information in the blended SSR solutions.

2.1. Sectored interrogation power

Using the capability in a modern SSR of varying transmission power by sector, the RF coverage of an SSR is limited by reducing transmission powers in the azimuth sectors where a large RF coverage overlap exists with other SSRs. This would mitigate the unwanted interrogations in a transponder from which an SSR is not interested in eliciting a reply. As an example, Fig. 1 shows 140 terminal and en-route Mode-S SSRs in the eastern U.S. and Canada where a dense population of SSRs exists. Note that the location and operational status of the SSRs shown in Fig. 1 may not be an accurate Mode-S SSR representation.

This paper assumes that all of the populated SSRs could perform the variable sectored power with respect to azimuths through minor hardware/software changes if necessary. Fig. 2 shows the sector-based operational radar coverage on the SSRs. Note that the coverage sectors are determined separately for the groups of the en-route and terminal SSRs because the service airspace of the two groups is different. Thick lines show coverage for en-route SSRs and dotted lines show coverage for terminal SSRs in Fig. 2. This example uses 128 sectors and the sector coverage limit is determined from tracing the equidistant points to the nearest two SSRs. The desired sector coverage, antenna gain, and various losses determine the sector's transmission power. With sectored transmission power, the operational coverage is no longer fixed to the typical range of 60 nm for terminal or 250 nm for en-route but varies with respect to azimuth.

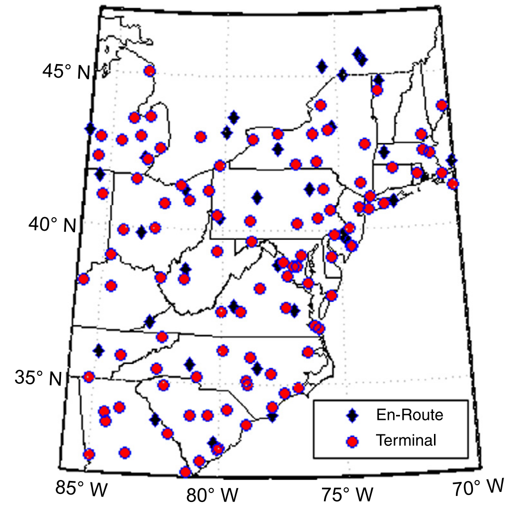

Fig. 1. Mode-S SSRs in Estern U.S. and Canada.

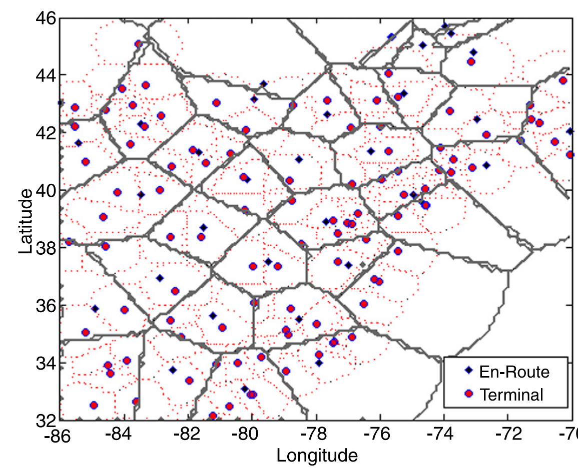

Fig. 2. Sectored RF coverage of en-route and terminal SSRs in eastern U.S. and Canada.

2.2. Optimized SSR interrogation using ADS-B

The ADS-B network has an accurate real-time aircraft tracking information derived from Global Satellite Navigation Systems (GNSS). If the ADS-B aircraft tracking data including position and identification is passed to the SSR, the SSR can use the data to optimize its interrogation schemes. The conceptual operation of the optimized SSR interrogation using ADS-B tracking information is depicted in Fig. 3. In this architecture, the SSR network will ideally share one interrogation code and interrogate a target with Mode A/C and Mode-S roll calls. The Mode-S all-call would be used only when a Modes-S target does not reply to a roll-call, which may happen when the lock-out status of a transponder is expired.

In addition, because the GNSS based aircraft position is highly accurate, the SSR could dynamically adjust interrogation power to the minimum so that the interrogation beam would barely reach the target. Fig. 4 illustrates the strategy of the minimum interrogation power using ADS-B tracking information. The minimum interrogation power for each target would reduce unwanted interrogations as shown in cases (b), (c), and (d) in Fig. 4. Note that the upper limit of the target-based transmission power is either the sector's coverage or the conventional fixed operational coverage. When ADS-B experiences operational disturbances, the SSR would revert to its traditional operation mode.

It should be also pointed out that relying on ADS-B tracking data in the SSR without any sanity checks might cause unnecessary