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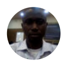

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Surveillance Radar System Limitations and the Advent of the Automatic Dependent Surveillance Broadcast system for Aircraft Monitoring

By

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ABSTRACT
Air Navigation Service Provider (ANSP) direct and control aircraft within its flight information region (FIR) using surveillance systems. To carry out such duty effectively and avoid air traffic collusion, accurate information about each aircraft within the FIR is required from the deployed surveillance systems. Surveillance radar is the conventional surveillance system used by the ANSP but has several operational limitations limiting its ability to support future global traffic demands. The Automatic Dependent Surveillance Broadcast (ADS-B) is considered to be the Next Generation (NextGen) surveillance system introduced by the International Civil Aviation Organisation (ICAO) to address the limitations of the surveillance radar. In this paper, the limitations of the surveillance radar system to support the ANSP in various operational environment is presented and the theoretical justifications for the use of the ADS-B system to overcome the surveillance radar system is provided.

Keywords: Surveillance radar, ADS-B, Air traffic collusion, Limitations

INTRODUCTION

In the olden days, there is no provision for In-flight navigational aids equipment. There was also no governing body within the United States and elsewhere that set and enforce standards giving the impression that developments to navigation would not come easily (Gilbert, 2006). Pilots then relied solely on ground controller flags during the daytime or light at night. These serve as signal instructions during takeoff, landing or making turn. Because there was no capability to communicate information during flight, weather or other pertinent information could not be relayed to the pilot once they takeoff, the ground controller would inform the pilot of weather information on the presence of other aircraft in the same route before take-off (Gilbert, 2006).

Pilots rely on known landmarks like railroad, tracks, cities and/or water towers to know their position and make any appropriate decision. This can be compared to Visual Flight Rules (VFR) used today. VFR are established by the Federal Aviation Administration (FAA) in United State of America and allow a pilot to operate the aircraft in a free-light manner when conditions allow proper operation and control (Magazu III, 2012).

It is the responsibility of the pilot to assume separation from other aircraft. There was then a slight development shortly afterwards. The new improvement then introduced, utilized lighted runways or beacons set apart by a mandated distance (Gilbert, 2006). This improved VFR flying has been in operation, however, as air traffic increased yearly, the need for better instruments become essential especially when navigating through poor conditions (i.e. adverse weather). This result in radar based systems becoming the navigational aid of choice.

RADAR TECHNOLOGY

Radio detection and ranging (Radar) technology has the ability to detect the range and azimuth of an aircraft on the basis of differences in time that exist between transmission of pulses to the aircraft and the receipt of energy from the aircraft. The technology typically utilises associated machinery and a huge rotating antenna (ICAO ASIA, 2007). This technology was designed in secrecy during the World War II but the benefits were revealed to the public soon after the end of the war. Its use then become more expanded and use by both military and for commercial purposes. It works by emitting electromagnetic (radio frequency) waves through a directional or rotating antenna dish. Those radio waves will then reflect off an object and return back to the source, a point where the signal is gathered by a receiver and the target is placed on the plan position indicator (PPI), a display within the ATC tower (Cohen et al,2003).

A radar system typical comprises of secondary surveillance radar (SSR) and primary surveillance radar (PSR). These surveillance technologies are coupled with radio communications to build a complete ATC system. The idea for the use of these systems for ATC purposes started during the 1950's which marked the beginning of radar use (Livack et al, 2000).

PRIMARY SURVEILLANCE RADAR (PSR)

This surveillance technology usually transmits a high signal power usually. Some of these signals are reflected by the aircraft back to the radar. The position of the aircraft in range is determined from time that elapsed between transmission and reception of the reflection (ICAO ASIA, 2007). The orientation of radar antenna determines the bearing of the aircraft in relation to the radar site. The distance is determined by the length of time it takes for the signal to be emitted and for the reflected signal to return to the origin of the transmission (Magazu III, 2012).

PSR is totally passive and does not require the action of any of the object being tracked. The major setback of PSR technology is that, it does not provide the altitude or identity of the aircraft. Another setback is that it can cause issues for ATC when it reflects off birds, atmospheric phenomena as well as ground objects. Due to these disadvantage, PSR has been supported with Air Traffic Control Radar Beacon System (ATCRBS), also known as SSR.

Other weaknesses associated with primary surveillance radar (PSR) that rendered it in-effective include:

i. The Position of the aircraft is determined on the basis on slant range measurement instead of true range (this can present some difficulties in the case of multi-radar tracking systems).
ii. It regularly reports false targets.
iii. It has poor detection performance especially for flight tangential to the radar in the presence of ground and weather clutter.
iv. It is more expensive when compared to SSR technology.

v. The update rate is usually between four to twelve seconds (this is longer than typical Multilateration or ADS-B).
vi. For long range performance, it requires high transmitting power considering interference and environmental effects.
vii. Due to poor azimuth resolution performance, it cannot resolve more than one aircraft at the same location and at the same range (ICAO ASIA, 2007).

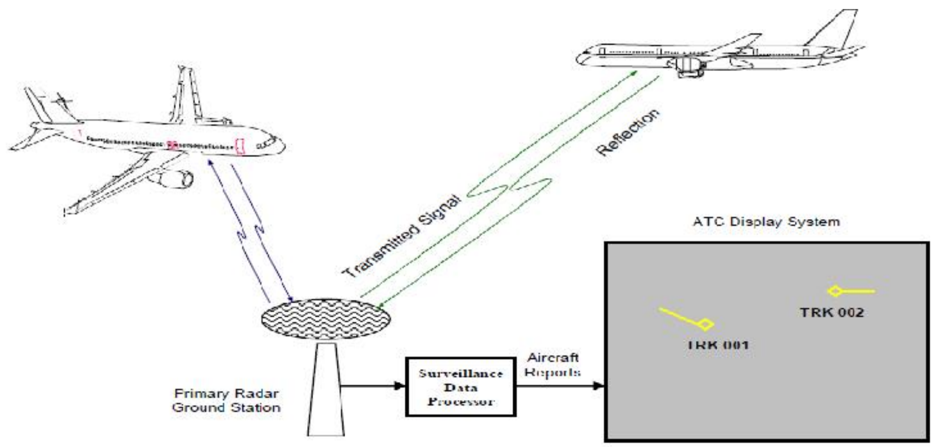

Figure 1: Primary Surveillance Radar (PSR)

SECONDARY SURVEILLANCE RADAR (SSR)

This as an extension over PSR systems and comprises of two main elements, a ground based interrogator/receiver and an aircraft transponder. The aircraft's transponder function is to respond to interrogations from the ground station. This will enable the aircraft's range and bearing to be determined from the ground station.

The idea of developing SSR technology is based on the use of the Mode A/C service for civil aviation. This technology evolved from military Identification Friend or Foe (IFF) systems. Since then, SSR technology has been notably developed to comprise the Mode S (select) service. The SSR frequencies of 1030 and 1090 MHz remain shared with the military. SSRs transmit pulses on 1030 MHz to trigger transponders installed aircraft to respond on 1090 MHz. This data link can theoretically support 4Mbits/s uplink and 1Mbits/s downlink. SSR is Co-located in many cases with a PSR technology. Usually the SSR mounted on the top of the PSR antenna. The ability of SSR to allow communication of altitude and emergency states to ground system is an added advantage over PSR. SSR also provides update rate that is moderately high, this is another advantage over PSR. SSR also provides altitude which allows slant range error to be corrected. However, SSR also has some weaknesses associated with it, hence the call for an improved aircraft surveillance system. Some of these weaknesses includes: SSR can sometimes confuse Mode -C replies as Mode A and vice versa, furthermore, it cannot discriminate two aircraft at the same location, dependent on aircraft avionics and also it is very expensive to install (ICAO ASIA,2007).

SECONDARY SURVEILLANCE RADAR (Mode A/C)

In mode A/C service Transponders usually provide identification usually in (Mode A) service and Mode C (which provide altitude) data with 100-foot resolution information in response to interrogations. As such, the Mode A/C system has the ability to make request to the aircraft to provide its identity as well as its altitude apart from its ability to measure range and bearing of the aircraft (ICAO ASIA, 2007).

Secondary Surveillance Radar (Mode-S Service)

This is an improvement over the just discussed Mode A/C. It possesses all the functions of Mode A/C, and in addition allows unique addressing of targets with the aid of unique 24-bit aircraft addresses. Furthermore, it also makes use of a two-way data link between the ground station and aircraft for information exchange. Additionally, it provides the transponder with ability to make a report of altitude data with 25-foot resolution. The resolution and accuracy will however depend on the altitude sensor systems on board the aircraft.

Mode S radars are less subject to multipath effects and it measure the azimuth position of an aircraft by typically using mono pulse techniques and it has large vertical aperture antennas. Unlike PSR and SSR Mode A/C, Mode S in addition, has the ability to resolve two aircraft when they are at the same geographical position and can also discretely interrogate single aircraft transponders. Mode S radar is designed in such a way that it will be backwards compatible with conventional SSR Mode A/C radar and also the detection and processing of Mode A/C transponder replies is essentially identical (ICAO ASIA, 2007). Aircrafts are required to be equipped with Mode S transponders in order to benefit from Mode S service.

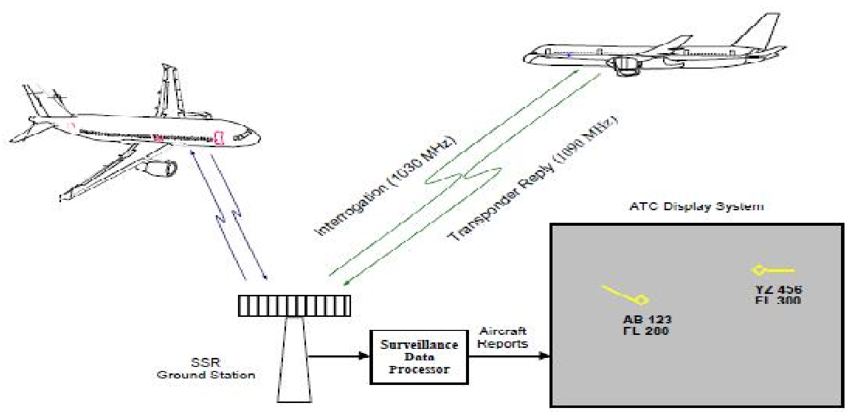

Figure 2: A typical Secondary Surveillance Radar (SSR).

CURRENT ATC LIMITATIONS

Due to certain limitations, current radar systems are quickly reaching their maximum capacity as a result of shortcomings in visibility propagation, limitation of line-of-sight and voice communications and also the lack of digital data links (Purton et al,2010) and (Boci et al, 2009). Additionally, synchronous garbling is another major concern in which the interrogation signal of SSR invokes a response from more than one aircraft, causing the replies sent by both aircraft to overlap at the receiver leading to loss of information at the ground station ATC facility.

ADS-B SURVEILLANCE TECHNOLOGY

Advent of a new aircraft Surveillance technology commonly referred to as Automatic Dependent Surveillance Broadcast (ADS-B) has significantly led to the reduction in the rate at which aircrafts come in contact during flight. This technology typically involves airplanes constantly sending in real time position and flight parameters. The aircrafts use Global Positioning System (GPS) to locate their position information and then broadcast it around so that any ADS-B installed aircraft or receiver at the ground station that are sufficiently close to the aircraft can receive it to prevent collision between the planes (Coote et al, 2012).

ADS-B main purpose is to determine the position of an aircraft and then broadcast same information. The information is broadcasted along with its call sign, heading, altitude and the identity of the aircraft automatically (i.e. Without SSR interrogation signal) to other aircraft and to air traffic control ground facilities. ADS-B is automatic in that it does not require any action or input by the pilot and no interrogation from the ground is required. It is also dependent because it relies on on-board equipment to gather the ADS-B data and broadcast it to other ADS-B users and it is a means of providing surveillance and traffic coordination (ICAO ASIA, 2007).

The Federal Aviation Administration (FAA) has initiated actions to overhaul the traditional radar based surveillance system. This is an effort to save fuel and cost while enhancing aircraft safety with a next generation (NextGen) solution based on ADS-B technology. The ADS-B system is currently only a requirement in Hudson Bay Area, USA, but by year 2020 it will also be a requirement in Europe, Australia and the entire USA (Abdulaziz et al, 2015).

ADS-B surveillance system is backward compatible to the current air craft surveillance transmission mode called Mode S. ADS-B is similar to Mode S for the fact that it uses the same transmission frequency of 1090 Mhz. It differs from mode S in that the message is 112 bits, 120 micro seconds long and are "squitter" messages (Huang et al,2008) and (Valovage et al 2009). A squitter message is simply a message that doesn't require any interrogation while being transmitted.

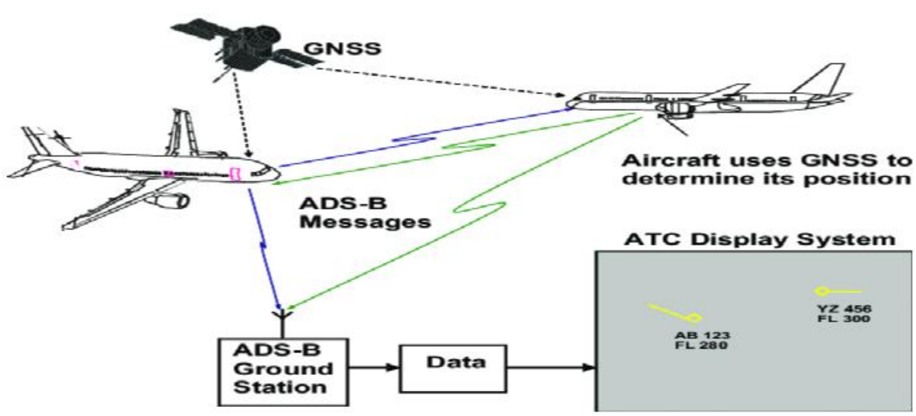

Figure 3: ADS-B System

ADVANTAGES AND POSSIBLE CHALLENGES OF ADS-B SURVEILLANCE TECHNOLOGY

One of the biggest advantages of ADS-B is the ability to provide coverage where radar could not reach before. The primary area in which this is relevant is transoceanic navigation (Barcena-Humanes et al, 2013). Other advantages of ADS-B Surveillance systems include:

i. Increased efficiency
ii. Increased safety

iii. Improved visibility
iv. Reduces the impact on the environment

ADS-B gives ATC a clear picture of the airspace, meaning they can better manage it to allow for a shorter time between take offs and landings, without any sacrifice in safety. This reduces the time that an aircraft needs to spend in the air waiting for landing clearances and in turn decreases the time that ATC needs to spend on controlling each plane. A knock on benefit of the reduced waiting time is the elimination of wasted fuel. This drives down flight costs and reduces the environmental impact. Each aircraft with ADS-B has a complete picture of the airspace surrounding it, something that wasn't possible with traditional radar. The collision prevention systems can use this data and the increased visibility that it provides. Unlike traditional radar, the ADS-B signals do not Deteriorate as the range increases and the plane is either available or out of range. Likewise, they are very rarely affected by poor atmospheric conditions, weather and signal deterioration.

The main disadvantages of ADS-B include the following:

i. Reliance on aircraft transponders. This can cause a major issue to the ATC in some environments.
ii. When satellites are out of service, some outages are expected as a result of poor GPS geometry. However, with the help of Global Navigation Satellite System (GNSS) and internal support, this effect is expected to reduce.
iii. There is stability, integrity and credibility problems associated with ADS-B (Valovage, 2009).

CONCLUSION

In this work, the limitations of radar based surveillance technology for air traffic control and theoretical justification for the use of Automatic Dependent Surveillance Broadcast was analysed. From the analysis, ADS-B Surveillance technologies was found to be instrumental in changing the way aircraft are tracked in the national airspace system (NAS). Instead of relying on costly radar technology, aircraft will broadcast their state vector and other information to ground receivers and other aircraft. ADS-B has the potential to increase capacity, improve efficiency, and reduce costs and safety in the NAS. ADS-B is therefore used to performed applications not possible with today's radar technology. For example, with an ADS-B Cockpit Display of Traffic information (CDTI), pilots are able to "see "other aircraft even in low visibility conditions. Pilots can then maintain separation from these aircraft without instructions from Air Traffic Control (ATC). Hence; due to the relatively low cost of ground receivers, ATC surveillance coverage can be expanded beyond radar coverage areas.

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