ELEVENTH AIR NAVIGATION CONFERENCE

Montreal, 22 September to 3 October 2003

Agenda Item 2: Safety and security in air traffic management (ATM)

2.5: Safety and security of the ATM infrastructure

6: Aeronautical navigation issues

6.2: Navigation policy issues in the light of present and envisaged GNSS services and architectures, integration and back-up options

AUTONOMOUS BACK-UP SYSTEMS TO GNSS BASED ON LOCAL INFRASTRUCTURE

(Presented by Sweden)

SUMMARY

This paper proposes a cost effective, autonomous back-up system to global navigation satellite system (GNSS) based position determination, using VHF digital link (VDL) Mode 4 without compromising its basic surveillance functionality.

Action by the conference is in paragraph 5.

1. INTRODUCTION

1.1 The ICAO Special Committee on Future Air Navigation Systems (FANS), was set up to enable international civil aviation to overcome the shortcomings of present air traffic management (ATM) systems, and to take advantage of modern technologies to meet aviation's projected growth. Working in two phases (the FANS Committee and the FANS Phase II Committee), a strategy was developed for exploiting modern satellite, communications and other innovative emerging technologies to improve ATM and to bring benefits to aircraft operators around the world. This resulted in the global communications, navigation and surveillance/air traffic management (CNS/ATM) concept.

1.2 One of the key new technologies being fully exploited for CNS is the global navigation satellite systems (GNSS) which will be a fundamental element of CNS/ATM systems of the future. GNSS is expected to play a vital role not only in the navigation aspect but also for surveillance i.e. automatic dependent surveillance (ADS) where the position reporting would be based on GNSS data. VDL Mode 4 was developed as a communication system supporting all three CNS disciplines. It should be noted that VDL Mode 4 supporting ADS is an integral element of surveillance systems being implemented today. The ground infrastructure for VDL Mode 4 consists of ground stations interconnected in a network. Functions in the network ensure constant availability of very accurate time. The ground stations regularly transmit their own position accurately along with accurate time.

1.3 It should be recognised that the current components of GNSS are vulnerable to interference and that the aviation industry as well as other, non-aviation users reliant on GNSS, are proponents of the development of autonomous back-up systems. Various system complements and augmentations have been proposed; this paper outlines an autonomous and cost-effective back-up system and safety net that can be implemented using VDL Mode 4.

1.4 The timing signal provided by the network of VDL Mode 4 ground stations makes available information which can be used by mobile units to calculate their own position, thus providing an autonomous back-up system to navigation systems such as the GNSS. Results from studies show that the accuracy of positions based on information from the ground VDL Mode 4 infrastructure is in the order of 1 NM. Such a system should be very attractive for States that are not in the possession of a GNSS infrastructure or States that have areas where the required GNSS availability cannot be insured.

1.5 The driver for timing accuracy in the VDL Mode 4 system is the ability to independently verify position data in ADS-B messages by ranging based on accurate time measurements.

2. GNSS AUGMENTATION AND SECONDARY NAVIGATION IN VHF DIGITAL LINK (VDL)MODE 4 BASED ON TRIANGULATION

2.1 When using GNSS data for navigation or surveillance, a GNSS augmentation system is required to ensure the quality of the position data. Combined with a GNSS reference receiver for computing differential corrections and integrity data for satellites in view of the ground station, VDL Mode 4 can be used to create a local GNSS augmentation system. Air and ground users can receive GNSS augmentation signals when a VDL Mode 4 ground station is within the line-of-sight.

2.2 Local GNSS augmentation through VDL Mode 4 can be extended to create a regional GNSS network. Such a VDL Mode 4 network is proposed as a complement to the satellite-based augmentation system (SBAS) to provide a GNSS augmentation service over a wide geographical area through a network of ground stations. The network would be used for monitoring of the operation and possibly for exchange of information between individual stations in order to further enhance the integrity of the broadcast augmentation data. Such a VDL Mode 4 network could be expanded indefinitely.

2.3 VDL Mode 4 is capable of providing navigation without GNSS signals as a back-up or fallback function in case of failure in the GNSS receiver or the GNSS signal. The secondary navigation function, which is an optional element within the ICAO provisions for VDL Mode 4, provides for navigation to en-route accuracies (RNP 1) without reliance on GNSS. In remote/oceanic airspace, a user with a failed GNSS receiver can navigate successfully by relying on the Co-ordinated Universal Time (UTC)-synchronised Mode 4 synchronisation bursts of other users in the airspace. In domestic airspace, the secondary navigation function allows a civil aviation authority to use its VDL Mode 4 ground infrastructure as a backup to GNSS. This assumes a stable source of highly accurate time is available to the associated ground-based stations.

2.4 The secondary navigation concept is similar to that of GNSS, illustrated in Figure 1. In GNSS, pseudo-noise (PN) ranging signals transmitted by the GNSS spacecraft are slaved to UTC. These signals emanate from known points in space since the ephemerides of the spacecraft are known. The arrival times of the signals at a GNSS receiver are measured relative to the local clock of the receiver. If the GNSS receiver is synchronised to UTC, the signal travel time (propagation time) divided by the speed of light gives the range to the spacecraft which generated the signal. If the GNSS receiver is ***not*** synchronised to UTC, the apparent propagation time provides a so-called "pseudorange". In the general case the receiver is not synchronised and must solve its (x, y, z) position as well as its clock offset (dt). These four unknowns can be determined if four measurements with good relative geometry are available. If more than four measurements are available, the position can be established with reduced error.

2.5 The key elements of GNSS are:

a) a set of transmitting platforms at known locations which transmit time-synchronised ranging signals, in sufficient numbers to provide a minimum of four ranging signals with good geometry to the user community with high probability; and

b) user equipment able to receive and measure the arrival times of these signals, and to perform the necessary computations to triangulate its own position.

2.6 The fact that the transmitting platforms are moving at orbital speeds is not significant, as long as their paths of motion are known with high accuracy and their locations at any instant can be determined to within a few metres. GNSS performs well because the signals are synchronised with high accuracy; the positions of the transmitting satellites are measured and reported with great accuracy, and the ranging signals have sufficient bandwidth to allow highly accurate measurement of arrival time.

2.7 The key elements of a position determination system are available through VDL Mode 4 as well: (1) numerous transmitting stations report their position with a fair accuracy; and (2) time-synchronised signals are transmitted from the same platforms. In the case of VDL Mode 4, the transmitting stations of interest for navigation are those aircraft or ground stations that report that they are time-synchronised, and whose reported positioning figure of merit is good. Figure 2 illustrates the basic concept, which parallels that of GNSS.

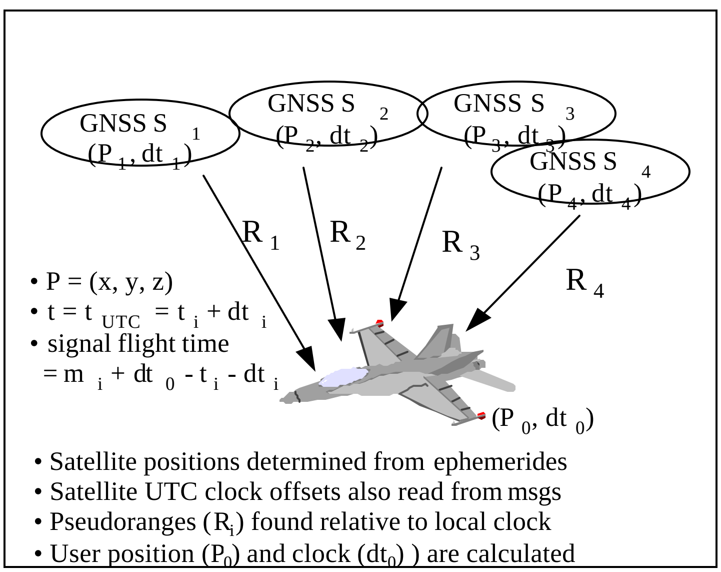

Figure 1. Overview of GNSS navigation concept

2.8 The position solution determined through the use of VDL Mode 4 will be less accurate than that of GNSS for the following reasons:

a) in most cases, the uncertainty in the reported position of a user is larger than the uncertainty in the reported position of a GNSS satellite;

b) the transmissions are emitted with greater time jitter and uncertainty than the transmissions of a GNSS satellite; and

c) the arrival time measurements at a receiving station are not as precise as the arrival time measurements performed in a GNSS receiver.

2.9 Nevertheless, a position solution can be generated. The ICAO provisions for VDL Mode 4 specify a transmit timing jitter £ 1 usec (2s). This corresponds to a range uncertainty of 300 m (~1000 ft). If the signal arrival times can be measured to equivalent accuracies (approximately 1 usec (2s)), ranging errors on each signal would be bounded by 500 m (2s) and users experiencing good geometry would achieve positioning accuracies in the order of 1 km or better. This would be the typical performance for users in active airspace where many suitably-equipped users would be located in all directions around the user, or users in airspaces where the Civil Aviation Authority (CAA) has explicitly designed the ground infrastructure to provide an acceptable geometry (a network of ground stations could be completely independent of GNSS, and could provide enhanced performance[1] due to their highly accurate position reports and possibly their more accurate transmit timing).

- Requires measurement of burst arrival time to a fraction of a symbol
- Achievable with careful design
- User position and time derived from multiple external stations (3 or more) and altimeter
- Expected accuracy approx. 1 –2 km
- System time (without position) derived from autonomous navigation source such as Loran etc.

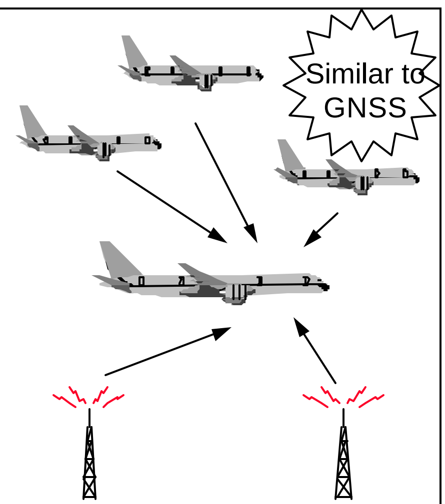

Figure 2. Secondary navigation in VDL Mode 4

[1] Relative to that achieved via ranging from mobile units.

3. OPERATIONAL BENEFITS OF SECONDARY NAVIGATION

3.1 The operational benefits of secondary navigation are:

a) A robust means to maintain efficient communications and resource sharing in the VDL Mode 4 protocol;

b) Ability to generate an independent range estimate to a user (i.e. by estimating the propagation time of the received message) supports enhanced integrity features at the MAC layer and above;

c) In domestic airspace, secondary navigation in combination with a ground network which transmits synchronisation bursts on the global signalling channels (GSC) can provide a full GNSS back-up suitable for en route navigation[2]. This robust, locally controlled back-up may ease the global introduction of GNSS as a primary means of navigation; and

d) Airborne and/or ground stations provide a back-up to isolated users with failed GNSS equipment.

4. SUMMARY

4.1 It can be seen from the above analysis that VDL Mode 4, while providing the ADS-B functionality for surveillance, also can be used for providing a back-up position source to GNSS without compromising its basic surveillance functionality. This autonomous back-up and safety net for GNSS provides a possibility for all States to have a nationally controlled navigation system in the future.

5. ACTION BY THE CONFERENCE

5.1 The conference is invited to:

a) note that inherent functions in the VDL Mode 4 system can be used as an autonomous back-up for GNSS, providing an opportunity for all States to have a nationally controlled navigation system in the future; and

b) recommend that ICAO define requirements and develop appropriate provisions in support of a ground based supplementary safety net to GNSS that is independent to the space elements.

— END —

---

[2] This requires an independent source of accurate time at the ground stations, and sufficient redundancy of ground stations to provide coverage by 3 or more stations, with high probability, to users at or above a designated altitude.