Alternative Positioning, Navigation and Timing (APNT) options for aviation under scrutiny

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Abstract

The advent of Global Navigation Satellite Systems (GNSS) brought an unprecedented advancement in navigation capabilities across all industries. Since the early days of space-based navigation, questions have been asked regarding contingency plans for GNSS outages. The term Alternative Positioning Navigation and Timing (APNT) has thus emerged. There is still an ongoing evaluation of potential APNT candidates in the aviation domain and no specific technology has been elected so far. This paper looks at potential options and creates a qualitative comparison between them. The analysis shows that there is currently no single solution that meets all the requirements. Additionally, it becomes evident that global coordination is required in the APNT field in order to avoid national differences.

Keywords: *APNT, DME, Mode N, LDACS, passive ranging, LOCATA, UHARS*

1. Introduction

APNT systems are primarily needed to compensate outages of GNSS. Nevertheless it would be desirable that they could co-exist with and complement today's navigation infrastructure. There is a general consensus that an APNT system should be terrestrial, i.e. it is not deemed useful to backup one GNSS with another GNSS as they can be affected by common-mode failure conditions such as solar eruptions. Often, the discussion around this topic is limited to the accuracy of systems. It is vital for a complete analysis to include many other aspects such as integrity monitoring and scalability. The following discussion will introduce some of the currently investigated concepts and compare them using a set of common criteria.

2. Options overview

2.1 Mode S passive ranging (Mode N)

The Mode N concept was introduced by the DFS (German Air Navigation Service Provider) in 2012. The basic idea is to create a network of Mode N ground stations (similar to current Mode S ground stations). Based on a common time reference, these ground stations would then transmit navigation data in the L-band. The airborne receiver would use Time-Difference-Of-Arrival (TDOA) measurements to determine its position [1]. While there are three channels immediately available for this system (966, 973, 1154 MHz) [1], the long term goal would be to replace DME/TACAN with mode N ground stations in order to reduce L-band congestion [2]. Mode N could also provide surveillance and communication features [1].

2.2 UAT passive ranging

Universal Access Transceiver (UAT) system is very popular in the US to provide ADS-B functionality. It is mainly used for general aviation. An already existing network of UAT ground stations could be used to enable a passive ranging network [4]. As the system uses Time-Division-Multiple-Access (TDMA) for access control, the basic Minimum Operational Performance Standard (MOPS) already includes provisions for pseudo-ranging using a synchronization with UTC [4]. While being extensively used in the US, the UAT system is not widespread elsewhere and would face significant spectrum usage issues in other parts of the world, as it is operating on 978 MHz. Lo [4] was able to demonstrate the basic suitability for ranging, but also noted that multipath and integrity monitoring are not addressed sufficiently in the current UAT protocol and thus the system would need further refinements in order to become a valuable APNT candidate.

2.3 Conventional DME

Many Air Navigation Service Providers (ANSP) plan to increase the number of DME ground stations and increase their accuracy [5]. It is encouraging to see that most DME ground stations significantly exceed the minimum accuracy requirements currently in place, and thus would allow for more stringent specifications [1][5]. Under the NextGen DME program, the FAA plans to increase the number of DME's in order to remedy coverage issues and eliminate "critical DME's" [5]. This will allow to expand RNAV 1 capability to non-IRU aircraft. This regime cannot provide RNP 0.3 service, as a very fundamental aspect of PBN is missing: System performance is defined in terms of accuracy, integrity, availability, continuity and functionality [6] [7]. Therefore solving the accuracy problem alone using legacy or modified DME equipment does not constitute a very capable solution. Indeed the effort required to add integrity monitoring and spoofing resistance would be quite significant, bearing in mind that the basis of this system is a very primitive pulse-pair propagation time measurement…

2.4 DME passive ranging

An interesting option of passive ranging has been investigated by Lo [4]. If the DME squitter pulses could be organized to be referenced to a common time, it would be possible to create a DME passive ranging network. The idea that was investigated involved a modification of the standard DME squitter's to include a time-of-transmission referenced to UTC [4]. Using less than 20% of pulse capacity, a valuable navigation solution has been demonstrated. Major obstacles for this approach are the missing integrity monitoring and multipath propagation [4].

2.5 LDACS Navigation

Within the scope of SESAR 2020, significant development and testing has evolved around the Future Communication Infrastructure (FCI). While AeroMACS is currently being deployed for ground data link at airports, LDACS will cover the short to medium range air/ground communication [6]. A key aspect of LDACS is the provision of cyber-secure communication and the flexibility of the design towards future demands [9][10]. Industry standards are being developed and expected around 2020, while ICAO SARP's are scheduled for 2026 [9]. Apart from a state-of-the-art communication data link, LDACS has been successfully tested for navigation applications [8]. LDACS could therefore provide a unique opportunity to merge communication and navigation applications in civil aviation [9]. Specific research to merge the two aforementioned applications is taking place in Europe under the "Migration towards Integrated COM/NAV Avionics" (MICONAV) project [10]. It is somewhat surprising, that LDACS does not appear on the FAA Navigation Programs Strategy [5].

2.6 LOCATA UHARS

A ground-based “sibling” of GNSS has emerged in Australia. LOCATA is a constellation that can be deployed anywhere using ground-based pseudolites, so-called “LOCATA-Lites”. It can dramatically improve availability and accuracy in demanding environments or when space-based signals are lost [11]. In the military world, this approach is known under the acronym Ultra High Accuracy Reference System (UHARS) and has been successfully tested in several applications [12]. The system provides sub-meter accuracy using carrier-phase tracking and can also provide Real-Time-Kinematics (RTK) [12].

3. Comparison

This paragraph provides a qualitative comparison of the options discussed above. It does so by merging technical criteria with financial constraints and administrative processes. This enables a holistic judgement of the different options. System/Criteria combinations are judged using a yes/no or low-medium-high rating. Information for Table 1 is taken from the references listed at the end. All classifications are made based on the current state of development.

	Accuracy 2-Sigma 0.3NM or better	Integrity monitoring	Availability (coverage)	Scalability	Retrofit effort on ground	Retrofit effort airborne	Industry standards
Mode N	Yes	Yes	TBD, similar to DME	Yes	High	Medium, replacement of Mode S / DME	TBD, similar as for SSR
UAT passive	TBD	No	Poor (US only)	Med (spectrum)	High (outside US)	High (only US GA is equipped)	Partially (need to address integrity)
Conventional DME	No	No	Good (with IRS)	Yes	Low	Low	Yes
DME passive	potentially	No	Good	Yes	Medium	Medium	No
LDACS	Yes	Yes	TBD, similar to DME	Yes	High Replacement of DME	Medium Replacement of DME	Under development
LOCATA UHARS	Yes	Yes	TBD	Yes	High	Medium	Partially (adapt for aviation)

Table 1: Qualitative comparison of APNT options

4. Discussion

Mode N research has been rather isolated to Germany and DFS. Also, there is currently no mention of it in the ICAO Global Air Navigation Plan (GANP) [6]. The system could add communication and surveillance, but these features are scarcely defined as of today.

UAT provides some interesting capabilities and the standards have been developed with future additional functions in mind. However, there is no global action plan for UAT and the spectrum allocation outside the US might be problematic.

Conventional DME is the de-facto backup RNAV system today, as many large aircraft use DME-DME RNAV systems if GNSS reception is lost. Without on-board inertial aiding, coverage is quite poor [3]. The DME principle is extremely primitive and faces major challenges, such as integrity monitoring and low adaptability for future demands.

DME passive ranging is an interesting concept, very similar to Mode N. It is not surprising that it is subject to the same limitations and constraints. There is no global action plan for DME passive ranging as of today.
In the communication domain, a transition to the FCI is ongoing under ICAO leadership. LDACS will be a significant part of it, for the medium-range communication [6]. Once LDACS is deployed as a communication system, the step towards LDACS navigation would be rather small. It is worth noting that the LDACS frequency band is planned between existing DME frequencies using an “inlay” procedure, so there would likely be no spectrum usage problems. Also, LDACS provides state-of-the-art forward error correction and security features that render the system very capable.
LOCATA UHARS can offer the unique advantage of providing pseudolite-based navigation for receivers that are able to benefit from such an option. As the Dual-Frequency Multi-Constellation (DFMC) SARPS are currently under development, this could be an interesting alternative. The installation effort on ground is probably the most limiting factor for a widespread use of LOCATA UHARS.

5. Conclusion

No APNT candidate meets all the requirements as of today and the analysis has made it clear that the APNT discussion needs global coordination. The system shall have the capability to work in continental areas as well as in remote regions. Further, the APNT solution should provide enough room for development to incorporate future demands using software modifications only without significant ground time for aircraft.

The APNT problem has been growing for decades across multiple industries. Technologies are available today that can solve it and it is vital to promote a unified APNT concept avoiding national differences. From an operator’s perspective but also from a manufacturer point of view, a “global APNT” solution would be desirable. In fact, a collaboration with other entities, such as the International Maritime Organization (IMO) would be beneficial, as the APNT topic is not isolated to aviation.

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