

Alternative PNT: What comes after DME?

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ABSTRACT AND INTRODUCTION

The development of multi-constellation, multi-frequency GNSS is ongoing, with the aim to enable a robust and reliable navigation and approach service to airspace users. While this will greatly reduce vulnerability to space weather, unintentional interference and constellation weakness, some residual vulnerabilities will remain. In the current, predominantly GPS L1 GNSS environment, aviation has accepted that alternate positioning, navigation and timing capabilities based on terrestrial systems remain necessary. The reversionary navigation capabilities are based primarily on DME/DME, while still providing some residual VOR/DME services. However, DME is being criticized as spectrum inefficient, and aviation-internal and aviation-external pressures to share the DME band with other services are increasing significantly. A key question for the future evolution of Communication, Navigation and Surveillance (CNS) systems is what type of a reversionary capability will be needed in the future (terrestrial or space based), and what performance levels it needs to provide. To answer this question, supported by specific technology options, a project under the SESAR Horizon 2020 Framework (PJ14-03-04) is working on this topic under the title “Long Term A-PNT”.

Long Term A-PNT is a complex, multi-disciplinary topic, with technical and operational aspects going across the CNS domains, and spectrum concerns being an underlying driver. This paper will focus the discussion on aspects related to DME, first by looking at what could be done to improve the current operation of DME, while contrasting it with what could be achieved with completely different alternatives. Possible improvements to current DME include adding more advanced signal processing methods for improved ranging accuracy, reconsidering the introduction of different channel pulse spacings (that have already been standardized), or adding phase modulation to enable data transmission. Alternate options will be subject to demanding criteria, as they will

need to fundamentally increase spectrum efficiency while providing performance advantages over current DME. An overview of current research ideas will be given, with an assessment of their prospects considering technical and programmatic aspects.

DME HISTORY

DME was first standardized in the 1950’s as an addition to the VOR, providing a very intuitive rho-theta navigation capability to support the emerging system of station-referenced airways, as well as a non-precision approach. A major innovation occurred in the 1980’s, when advances in electronic circuitry made it possible to switch from using the second pulse as a timing reference to the first pulse, avoiding second pulse multipath. This happened at about the same time than the introduction of MLS, which added DME/P standards to support approach functions to the existing DME/N standards. The P stands for “precise distance measurement” while the N stands for “narrow spectrum characteristics”. First pulse reference standards are required for newly installed equipment since 1989 and marked with “double-daggers”: ‡ in Annex 10 [11]. Some years ago, the ICAO Navigation Systems Panel considered removing the double daggers to create a single modern standard, but this was abandoned as being of too little benefit.

The 1980’s and early 1990’s can be considered the last major innovation era of core DME technology. However, its exploitation continued to improve in subsequent years, when avionics manufacturers started to build the first area navigation systems using VOR/DME and DME/DME. Moreover, matching the MLS developments with DME/P, DME/N was introduced as a distance to threshold aid with frequency pairing to the ILS, as an operationally attractive and safer replacement of marker beacons. With the introduction of GNSS in early 2000, conventional navigation aids are increasingly taking on a

complementary role in horizontal navigation, where DME/DME (when available) is the most suitable back-up capability to GNSS. Due to improvements in navigation database processes, the formerly infamous “map shift” problems of DME/DME RNAV avionics have decreased significantly. DME therefore retains an important role in both area navigation and approach operations.

Apart from a few notes about Performance Based Navigation (PBN), the current Annex 10 DME standards do not clearly reveal this significant evolution, since a good portion of the standards are not generally used (DME/P, W and Z channels, older non-double-dagger standards). What is remarkable about this 60+ year evolution is that the original pulse pair, using a 3.5µsec half-amplitude pulse width, has remained unchanged. In comparison, SSR has evolved using different pulse spacings and adding additional data first in Mode C and later in Mode S operation. What can also be observed from the multitude of “dormant” DME standards in Annex 10 is that the engineers of the 1980’s must have envisioned a continuing evolution of DME.

SPECTRUM CONTEXT

Few people appreciate today that DME/N was designed to use as little spectrum per channel as possible. In comparison with many other terrestrial systems, DME has very benign frequency assignment planning constraints, which are limited to the co-channel and the first adjacent channel. Many with a communication bandwidth-centric view are outraged that DME uses two times 1 MHz to “only send two pulses” back and forth, neglecting that spectrum constraints are fundamentally different between navigation and communication systems [6]. While similar arguments could be brought against surveillance’s SSR technology, this generally does not happen since the inverse operation permits the use of a single up- and downlink pair.

The criticism of DME spectrum is understandable primarily because the 960 to 1215 MHz frequency L-band is at the so-called “spectrum sweet spot” which achieves an optimal balance between achievable data rates and achievable propagation ranges for many applications. The pulse-based operation of both DME and SSR occupy a significant portion of prime spectrum real estate. It must be remarked however, that this statement seems to become a bit outdated. Just like passenger portable electronic devices were of great concern some years ago since processor clock frequencies were on VHF frequencies, today’s data hunger for mobile applications is driving spectrum demand into the higher Gigahertz ranges. Despite this, hunger for spectrum will continue in all areas of UHF. This includes both internal and external pressures.

Internal pressure stems from the reality that growth in aviation spectrum needs to support ever increasing levels of traffic with more efficient CNS services, while no

more new aviation safety spectrum will be made available. Aviation can consider itself fortunate if the current bands assigned to safety services can be retained. Therefore, the only option to provide new CNS services is to accommodate them in existing spectrum. Due to congestion in the VHF band, it has been envisioned for some time to introduce an aviation datalink in the L-band. This system aptly called L-Band Digital Aeronautical Communication System (LDACS) is currently undergoing standardization by ICAO. LDACS chose to use OFDM (orthogonal frequency division multiplex) modulation, which is considered to be a very spectrum efficient communication system. Unfortunately, no inter-domain discussion took place in the aviation CNS community to see if this was a good choice for co-existence among pulsed systems.

External pressure comes from the continued high demand for spectrum. Non-aviation spectrum seekers generally struggle to understand the constraints of safety spectrum in a certified equipment environment, and the economic realities of achievable innovation cycles linked to a typical aircraft lifetime of 30 years. While aviation may get outrages at such external pressures, rightly citing the huge economical and societal value of aviation, it must be recognized that many of the other applications seeking spectrum also provide such values. This is not always purely driven by industry but often also by the desire of governments to provide benefits to its citizens. Therefore, multiple government objectives can be at odds, fueling the ongoing spectrum use debates.

SHORT TERM A-PNT

In the context of mitigating vulnerabilities of GNSS, the 12th ICAO Air Navigation Conference held in 2012 introduced a task to address the “need for, and feasibility of, an alternate position, navigation and timing (A-PNT) system” [7]. Since that time, it appears to be generally agreed that the answer to the need for an A-PNT system can be affirmed, and that the current A-PNT system is primarily DME. Large scale GNSS outages are possible enough that alternatives need to be available, while they are nonetheless rare enough that it is not expected to retain the same capacity levels as are achievable with the various CNS applications enabled by GNSS. Areas with limited DME infrastructure usually also have lower levels of traffic which can be supported by VOR/DME or even NDB. The same logic can be applied to aircraft, where most air transport category aircraft equipped with DME/DME avionics and Inertial Navigation Systems (INS) will be able to continue operations, while some airspace users may be subject to operational restrictions for a limited time. Both European research and the US FAA have concluded that for the time being, current terrestrial navigation aids are sufficient as an A-PNT system to support navigation applications, while the multi-layer approach in surveillance systems (using a mix of SSR, WAM and ADS-B) can support the other major user of GNSS positioning. Requirements for time and

network time synchronization are also not at the stage where they are so demanding to require another system with an equivalent level of performance to GNSS. Therefore, DME remains an important element of short term A-PNT and warrants further sustainment and minor improvement ([1] and [2]).

LONG TERM A-PNT OPTION SUMMARY

Due to the long equipment update cycles of aviation, it is recognized that current CNS services may need to achieve higher levels of performance, such that the impact of a large-scale outage of GNSS may become more significant. Therefore, the availability of a more performing A-PNT system in the long term remains beneficial. In SESAR I, several technology options have been assessed. Some of those are being studied and developed further in the follow-on project in SESAR H2020 (PJ 14-03-04). A detailed overview of these activities is given in [2]. The following technologies are being evaluated:

- Enhancements to DME
- LDACS-NAV
- eLORAN

Enhancements to DME include updating of current standards to reflect the improvements in ground equipment over the years. For example, current DME transponders do provide an integrity level that has been quantified by manufacturers, without such requirements existing in Annex 10. This, combined with other measures, would simply enhance confidence in DME/DME positioning when supporting the more demanding RNP PBN navigation specifications in a reversionary mode. More significant improvements being looked at by the avionics manufacturer Thales, is to introduce multi-DME ranging which would provide integrity in a similar manner as done in GPS RAIM. On the infrastructure side, new concepts such as passive and hybrid ranging are also being considered. These will be explained in more detail later in this paper.

The idea behind LDACS-NAV is to add a ranging function to LDACS. While this is a highly appealing CNS synergy since it has a path into aircraft avionics due to the needs of COM, the needs of COM will not require the station density needed for supporting navigation. Therefore, current thinking is looking at a hybrid approach using both DME and LDACS ranging where available. This would mix one-way with two-way ranging while the expected higher ranging accuracy of LDACS would improve performance and alleviate DME requirements (less stations).

Technically speaking, eLORAN remains a very attractive option, because it operates at 100 kHz, well outside of the L-band. This greatly facilitates a transition because there will be no spectrum congestion during the period when

both a legacy system and a new system needs to be supported. Various technical improvements could yield further performance gains. However, in Europe it is unlikely for institutional reasons that a continuous coastal coverage including continent gap filling will be achieved anytime soon. If the maritime sector would fully support and require eLORAN as an A-PNT system, then of course aviation would and should reevaluate that view.

Another, German research project is investigating “Mode N” [8]. The idea behind Mode N is to reuse the existing, shorter SSR pulse format to increase ranging performance. It is a one-way ranging system using Time Difference of Arrival (TDOA) measurement from synchronized ground beacons with unique identifiers, similar to the GNSS pseudolite concept. Spectrum efficiency and transition aspects are main topics of consideration of that project.

CHALLENGES AND REORIENTATION

All of the investigated options have their advantages and disadvantages. None of the available options will solve all possible future A-PNT needs. Furthermore, the “benefit space” of A-PNT is really tight. Any significant modification to aircraft avionics will be more costly than doing nothing, while no fundamentally new capability can be offered. Even worse, this new A-PNT would need to be installed on top of another new avionics box, the dual frequency, multi-constellation GNSS receiver, where the A-PNT box is only there in case the GNSS box does not work. Reducing spectrum use in a long term future, while likely needing more spectrum during the transition, is not something that can be easily sold to the aircraft operators as a benefit without a tangible return of investment in a period which is meaningful in the context of competitive business.

The sobering impossibility of A-PNT is met by an equally sobering audacity. If a new A-PNT system would be decided on today, research programs generously funded, and standardization driven forward aggressively, using the logic of current experience would mean that in the very best case, a new A-PNT technology could be available and fielded in avionics by about the year 2050. This means that the DME pulse pair format will have served aviation for 100 years. Those engaged in aviation spectrum defence are finding it increasingly difficult to explain that 100 years should not be more than sufficient to accommodate a transition to a more modern and spectrum efficient technology.

For this reason, the ICAO NSP is in the process of reorienting its work on A-PNT. Traditionally, the A in A-PNT has meant “alternatives to GNSS”. The new activity would study “alternatives to DME” which would have the main objective to be more spectrum efficient while being able to support a feasible transition. The main objective of the new activity would be for ICAO to be able to decide if such a new development and standardization program (to replace DME) should be undertaken. It is of

course possible that ICAO would decide that DME replacement is not possible due to the many challenges involved; but at least more solid arguments would be available as to why it is so difficult. Such solid arguments are expected to be useful for rational spectrum defense.

In the CNS context, one of the main issues that must be settled by such studies is if the L-Band should continue to be the predominant home of pulsed systems. Any evolution to new systems should ensure that spectrum sharing is only between systems which are optimized for such sharing, in order to not end up with the worst possible solution for all involved.

FAA / OHIO UNIVERSITY ROADMAP

The US Federal Aviation Administration (FAA) has studied the topic of A-PNT intensively during the years 2010 to 2016. Similar to SESAR, several options, primarily geared at providing improved performance compared to current DME, were investigated. While the studies never made it to the point of committing to a development program, the most favored option appeared to be improvements to current DME. Just as in SESAR, no assessment was done so far on the impact of each option on the L-Band spectrum and overall CNS landscape.

Ohio University has proposed an incremental development roadmap for DME [3]. Each step requires an increasing level of effort. The first step is also to tighten current standards in line with currently achievable performance. The second step would introduce a pseudorandom pulse sequence to enable hybrid ranging and a number of signal processing enhancements. The third step would require ground transponder synchronization to enable full passive ranging. The fourth and last step would be to add an alternate modulation, which starts to resemble the other A-PNT options a lot more than DME evolution.

What can be concluded from both the US and European programs on A-PNT is that the number and type of options arrived at is very similar while it remains very difficult to identify a clear favorite due to missing decision logic and supporting metrics. Clearly, minor evolutionary enhancements of DME would be the simplest option for navigation. But it is quite possible that such a choice would continue to exacerbate compatibility challenges in the L-Band, therefore leading to a dead-end street when taking into account the overall CNS context. The ICAO Spectrum handbook [9] already discusses the idea of freeing up a contiguous sub-band to accommodate LDACS in a pulse-free environment, while recognizing that this will be very difficult.

This paper proposes that all long term A-PNT options should be evaluated in terms of their spectrum efficiency gain during and after accommodating a transition. The fundamental question to be addressed is if it is in the best

interest of aviation to continue improving DME or its successor as a pulsed technology, or if at least parts of the band should change to other forms of modulation to ensure that compatibility challenges can be reduced. A related question is what could be done with any freed-up spectrum. No effort to reduce aviation spectrum use should be undertaken without being able to answer that question due to the risks of losing such spectrum to users which are not subject to the same safety requirements and regulatory constraints. Not much work has been done on these topics so far. This paper makes a first step by further detailing the hybrid and passive ranging options and subsequently discussing the impact on spectrum evolution.

PASSIVE AND HYBRID DME RANGING

One of the most common proposed DME evolutions is the concept of DME passive ranging. A solution can be based on the native capability of a ground transponder to broadcast unsolicited pulse pairs in the same form as replies: squitters, identification code and, for TACAN, azimuth bursts. Passive ranging can be implemented using periodic broadcast of a pre-defined and known a priori pseudorandom pulse pair sequence. The sequence can be received and decoded on-board by any user connected to the DME channel and a range can be derived as an alternative to conventional two-way ranging. The solution is attractive for several reasons:

- A single ground transponder can serve an unlimited number of aircraft becoming independent to traffic load concerns.
- The solution is deployable as an additional service over the current DME capabilities and it is therefore interoperable with conventional DME service.
- Being a one-way unidirectional transmission system it eliminates some sources of conventional range errors: transponder application of reply-delay, received multipath and received low signal to noise ratios.
- Current DME ground transponders in operation can be “upgraded” for the provision of this new service by adding an external ground interrogator to elicit the desired pseudo-random reply sequence.
- The pseudorandom sequence can be modulated for also broadcasting a data channel in addition to the synchronization pattern used for ranging.

DME passive ranging and data broadcast based on conventional Pulse Pair Position Modulation (PPPM) has been translated into a design and proven, at prototype level, by several real time measurements on ground [4] and through flight tests [5] with very good positioning accuracies.

However, a purely passive ranging system also has important drawbacks:

- It requires all ground stations to be accurately and mutually synchronized. This generates an impact on ground equipment at a single site for accurate local clock synchronization and at the network level for synchronization distribution.
- On board position derivation requires the availability of at least three ground stations with suitable siting geometry. This generates an impact for the on board processing equipment (as currently and in the short/mid-term foreseen evolutions as well), because a position, including integrity assessment, is typically obtained by evaluating range pairs of DME ground transponders. In addition to the avionics impact, passing from two to three needed stations, increases the ground infrastructure availability requirements.
- Data channel addition, even if feasible and attractive, would be difficult to achieve using the current multi DME scanning avionics, which is based on receiving a single channel at a time. Passing to multi-receive channel receivers would imply a complete on-board interrogator replacement. A data channel, depending on the type of transmitted data, also implies new interfaces between interrogators and other systems, likely including flight management systems.

An intermediate solution is called hybrid ranging. It is less revolutionary and identified in [3] as part of the DME-Next architecture. This includes a passive-ranging DME system where a conventional ground transponder transmits an un-synchronized pseudorandom PPPM sequence as described above. However, on board range determination is performed by a DME interrogator by merging both low rate two-way conventional ranging and PPPM sequence reception. In such a system, conventional two-way ranges are used for periodic absolute range determination and transponder synchronization, while the PPPM sequence is used for propagating the solution using relative range variation measurements.

The concept can be shortly described as follows: let t and T be the flows of times as given by a local and free running clock on ground and on board, respectively.

The relationship between the two times can be represented by $T = t + \delta(t)$ where $\delta(t)$ is a function of time representing the bias between the two clocks. A common model of such a function could be a linear relationship

$$\delta(t) = \delta_0 + \Delta \times t \quad (1)$$

Let $t_0, t_1, t_2, \dots, t_n$ be a known and predefined sequence of instant times representing the starting times of pulse pair emissions by a ground transponder according to its local clock and let be $T_0, T_1, T_2, \dots, T_n$ the measured Time of Arrival (TOA) of the on board interrogator pulse pair reception of the same sequence according to its local clock.

In an ideal case where no other delays are introduced by processing, cables and atmosphere, the relationship between t_n and T_n can be represented as follows:

$$T_n = t_n + \delta(t_n) + D_n/c \quad (2)$$

Where D_n is the slant range distance between the aircraft interrogator and the ground transponder and c the propagation velocity of the transmitted signal.

Any difference Δt between two transmitted elements of the sequence would generate, in absence of TOA measuring errors, a difference ΔT in the respective on board reception which can be expressed as follows:

$$\Delta T = \Delta t + \Delta \times \Delta t + \Delta D/c \quad (3)$$

Where ΔD is the slant range variation between the aircraft and the ground transponder in the Δt time interval. ΔD can also be expressed in terms of aircraft relative slant range variation v as follows:

$$\Delta D = v \times \Delta t \quad (4)$$

From (3) and (4), any variation $\Delta T - \Delta t$, at reception side, of the received sequence elements from its nominal known values Δt , has the following relationship:

$$\Delta T - \Delta t = \Delta t \times (\Delta + v/c) \quad (5)$$

Relationship (5) allows determining range variations by reception of a known emitted sequence once the clock offset Δ is resolved. This is possible using periodic two-way ranging measurements.

In real application, both the pseudorandom sequence reception and conventional two-ways ranging are subject to measurements errors linked to propagation and multipath. We think that it is worthwhile to quantify this through further study, including implementation and measurements, of an algorithm based on such hybrid one-way/two-ways ranging and to establish which kind of ranging and positioning performances are obtainable.

The algorithm design should consider the following inputs:

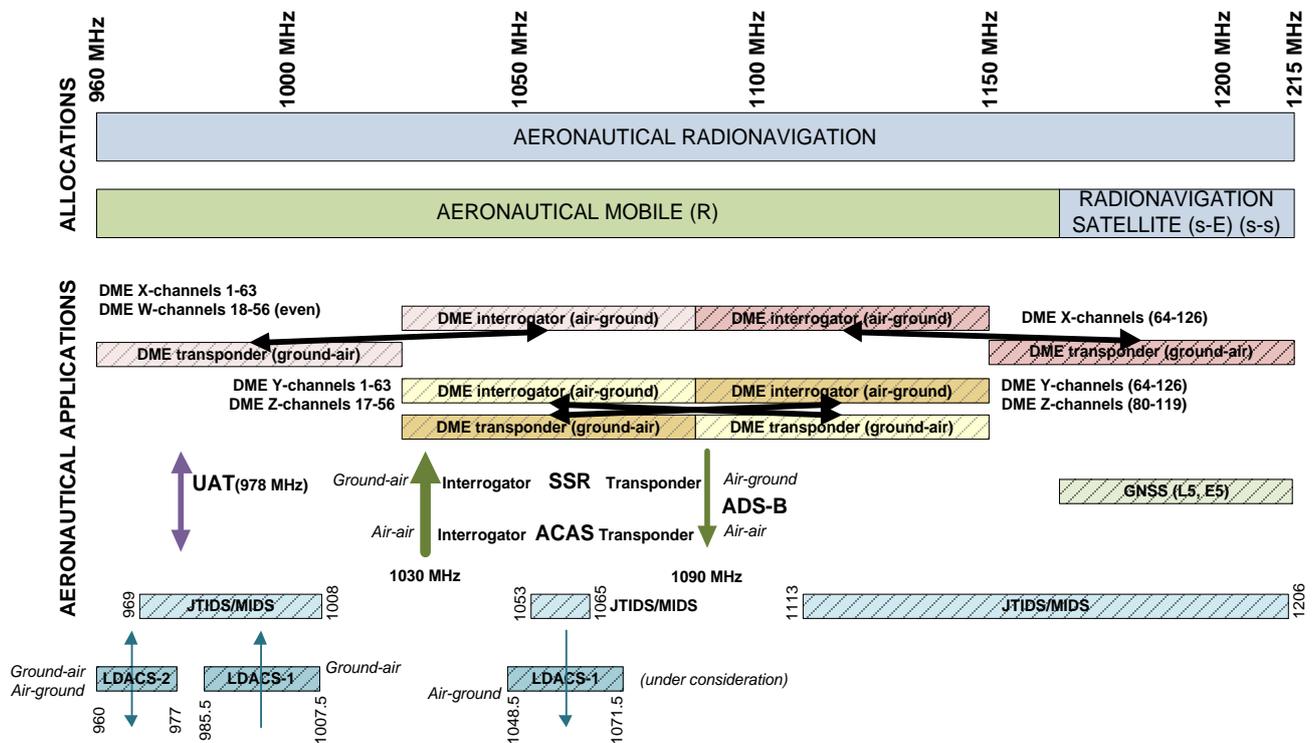
- Assume currently existing deployed clock oscillators both on ground and on aircraft side.
- Define a robust pseudorandom sequence in terms of number of pulse pairs, time distribution and periodic transmission considering that most currently operating on board interrogators are

equipped with receivers that scan one single channel at a time

- For a ground transponder, the pseudorandom sequence transmission shall be shared with conventional operation: identification code and azimuth bursts (for TACAN) transmissions and in presence of traffic dependent elevated interrogation loads as experienced by legacy transponders
- Minimizations of on board interrogation rates
- Evaluation of impact due to the presence of propagation and multipath errors
- Consideration of the impact due to different aircraft dynamic conditions
- Assume that no interface changes between the on board interrogators and flight management system or other systems are required

In addition to the algorithm assessment as formulated above, the study plans to address the following DME system aspects:

- Possibility to define sets of pseudorandom sequences that can include stations identification transmission such that the same sequence can be used for passive ranging and for identification decoding as alternative to the current interruptive conventional Morse code transmission and decoding
- Development of system integrity monitoring, including of the transmitted pseudorandom sequence (auto- and cross-correlation properties)
- Due to the potential transponder interrogation load decrease, study scenario implementation paths which have the goal to free part of the actual DME band utilization



Note: Services in upper case are primary services

Figure: Current Spectrum Allocations and Applications in the 960 to 1215 MHz Frequency Band

L-BAND EVOLUTION EXAMPLE

Given the spectrum challenges identified in the earlier chapters of this paper, this last bullet of the previous paragraph is the most relevant point of this discussion. The introduction of a pseudorandom pulse sequence allows aircraft to uniquely identify transponders. Current avionics typically discard DME channels when two co-

channel transponders are in radio range. However, this should no longer be necessary, and enable the operation of more facilities on co-channels. Studies conducted so far on any type of A-PNT system proposal have not evaluated the impact on L-band spectrum utilization (including eLORAN, because transition aspects in the L-band remain even if compatibility is trivial).

The impact on L-band utilization and especially the feasibility of managing a transition are the main factors to facilitate a selection of an A-PNT system to lead to a successor of current DME. What becomes immediately obvious when considering changes to DME channeling, such as by significantly reducing co-channel distances, is that this will be severely limited by the currently hardwired interrogation and reply channel frequency scheme. Even when maintaining the integral 63MHz offset between interrogation and reply channels, the problem with hybrid ranging is that the conventional two-way ranging still needs to be possible. This moderates the previously listed, compelling “minimum change” arguments for hybrid ranging. Current DME positioning already needs to eliminate one ambiguity (normally done by the FMS), and forcing more ambiguity options by increased co-channel use will quickly turn into an integrity problem, complicating the interaction between FMS and DME interrogator.

The addition of pseudo-random pulse sequences to conventional DME would therefore likely require that the possible set of such sequences and their association to the normal station IDENT is known. Optimal search strategies would need to be determined, but likely involve the following steps, not necessarily in that order:

- The conventional interrogation of a desired transponder would elicit multiple replies, from all co-channel stations in radio line of sight
- All the known PPPM sequences would need to be evaluated. This could lead to the receiver needing to track, for example, three two-way range gates and three pseudorandom PPPM sequences
- Since the modernized, hybrid ranging avionics would know which conventional IDENT corresponds to which pseudo-random PPPM sequence, they could be associated. Verifying that both range types yield the same range rate would add some integrity as long as sufficient geometric diversity exists

While the above description reasons that combining more channels on a single frequency pair could be quite feasible for hybrid ranging, it would completely overwhelm conventional two-way ranging. Therefore, as long as legacy interrogators need to be accommodated, no spectrum gain could be achieved.

The figure above shows current and envisaged L-Band allocation and occupation, illustrating the amount of sharing already implemented. When trying to identify spectrum which could be freed up, the upper and lower transponder-only parts of DME appear to be a little simpler (960 to 1020 and 1150 to 1215 MHz). It would seem advisable to not touch the region that is interspersed with SSR operation on 1030 and 1090 MHz. Unfortunately, DME X-channel use is significantly more popular today than Y-channels – it should not be assumed

that a significant increase in Y-channels could be accommodated to offload conventional X-channel DME users. Furthermore, the bottom X-channel also contains the ILS-paired DME. Even if the X-channel transponder bands could be freed up, it would leave systems behind which have been specifically designed to get along with pulsed modulations. While the military JTIDS-MIDS operates on a non-interference basis, this basis has been well established over many years with a lot of fielded equipment building on a constant sharing partner with a similar operational and regulatory environment. GNSS L5/E5 operations, where currently, satellites with such capabilities are still in the process of being launched, foresee the implementation of a pulse blanker. Of course it could be good news to both those systems if DME usage of the band would reduce or even disappear; in the case of GNSS L5/E5 it would represent an immediate gain of 8dB in interference robustness which stems from not having to exercise the pulse blanking margin. However, it would be foolish to assume that once DME vacates those parts of the spectrum, nothing else comes in. After all, the objective of spectrum re-planning would be to accommodate system growth. This means that any new sharing partner would inherit the constraints that have been set up by DME.

Returning to the previous discussion on DME spectrum optimization enabled by hybrid ranging, another option could be to use dedicated channels for passive ranging, while maintaining separate channels for relative ranging using the pseudo-random PPPM sequence. This again quickly turns into a headache at all system levels: the interrogator, the transponder, and the objective of gaining in spectrum efficiency.

The Mode N system proposal is more appealing in this respect. It envisions to first deploy using a few little used L-band channels (966, 973 and 1154 MHz). Once a transition is achieved, the system could move to other frequency ranges to further accommodate system optimization. The approach used by LDACS on the other hand is to fit in-between current DME channels with a 500 Mhz offset. This puts the majority of the signal into “white space” between DME channels but also fully overlaps at the LDACS edges. For both LDACS and Mode N, only limited results are available on the resulting frequency assignment planning constraints. Corresponding discussions are underway between the ICAO communications panel and NSP on LDACS. Mode N on the other hand will have to mitigate the frequency-domain effect of the significantly tighter pulse rise time compared to DME/N (some ideas are under investigation).

CONCLUSIONS

About the only thing that can be concluded from this paper other than hopefully a new appreciation for the incredible complexity of the subject is that frequency agility is an important basis for any type of significant

evolution in every part of the 960 to 1215 MHz band. While this is foreseen for new system proposals such as LDACS and Mode N, it is subject to its own set of constraints beyond simple tuning mechanisms in terms of antenna and RF front end design. The risk is that any additionally imposed requirements on frequency tuning agility that may or may not be used in a far future would reduce spectrum efficiency in terms of achievable frequency selectivity. If a flexible channel assignment approach would be imposed on a forward fit basis on DME (respecting the 63MHz offset, but lifting VHF channel pairing and maybe changing the sign of the 63MHz offset), the achievable planning flexibility would be quite limited while having to wait a good 30 years until such benefits could be exploited.

Evolution of spectrum use from one user to another has always been a complex process, even in the non-aeronautical world. Clearly, the simplest and most achievable form of evolution is when the new service uses a new part of the spectrum, as was done in the example of MLS. The approach chosen for GBAS shares the VHF Data Broadcast (VDB) with ILS localizer and VOR. This has turned out to be a challenging issue for GBAS especially given that the target service areas overlap in many cases (the VOR Minimum Operational Network approach foresees to give priority to retention of VOR systems located at airports [10]). It is manageable because some reduction in VOR is actually occurring in some States and fielding of new GBAS stations is slow.

The system evolution used by SSR could serve as an inspiration for DME: simply adding new features to reduce interrogation load, optimize ranging performance (pulse shape optimization, passive ranging, carrier phase tracking, etc) and adding a data channel could yield considerable benefits. However, this would further cement pulse-type modulation as the underlying logic for a much larger part of the L-band compared to SSR. Therefore, this could only be done with a convincing justification that it is the most spectrum efficient approach that can be realized when comparing it with other options.

Any transition to a fundamentally new form of modulation will require new, additional spectrum to make a transition feasible. Compared to just using current channel allocations more efficiently, this option is significantly more complex. Mode N will need to demonstrate that the so far not so desired channels envisaged are usable without introducing unacceptable adjacent channel constraints. While LDACS will also need to determine its frequency assignment planning impact, the in-lay approach is a sort of hybrid between optimizing current channel use and using different spectrum. If LDACS-NAV can be realized, it would need to be analyzed further how the reduction in DME channels could be exploited. This could both be helpful to in-channel DME system evolution and detrimental to future L-band spectrum use optimization.

Beyond raising appreciation for and sensitivity to these issues, the aim of this paper is primarily to underline the mutual dependence of CNS systems in the aeronautical L-band. What a future LDACS or Mode N may do will impact DME, as well as JTIDS/MIDS and GNSS, and vice versa. Therefore, integrated spectrum thinking across the CNS domains will be necessary – domains which are, due to the conscious separation through the CNS safety triangle, not used to working together. DME as the current A-PNT choice for navigation seems to be the systems which stands in the middle of the crossroad of such cooperation.

DISCLAIMER

This paper contains no official EUROCONTROL or SESAR position, and does not represent an endorsement of any company, a particular A-PNT system proposal, or previous studies.

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