

Alternative Position Navigation & Timing (APNT) Based on Existing DME and UAT Ground Signals

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1. INTRODUCTION

The United States (US) Federal Aviation Administration (FAA) is developing alternative position navigation and timing (APNT) technologies to maintain efficient and safe operations even with a degradation of the Global Positioning System (GPS) and other Global Navigation Satellite Systems (GNSS). Several technologies are being studied and developed including terrestrial passive ranging system, upgraded distance measuring equipment (DME) and multilateration (MLAT) based navigation. Terrestrial ranging systems are attractive as they have little capacity constraints and a simpler architecture than the other alternatives. They can also provide additional capabilities such as signal security and precise time reference. Finally, it may be possible to utilize existing FAA infrastructure and signals thus reducing cost and mitigating spectrum concerns. These last two benefits motivate the study presented in this paper.

This paper examines two of the passive ranging systems being studied for APNT. These are attractive as they leverage existing signals and ground infrastructure. The first design implements a ranging broadcast using existing DME ground transponders without the need for any changes. The second concept is to use the ranging functionality existing within universal access transceiver (UAT) ground broadcast. UAT is a protocol that has been implemented by the FAA to support automatic dependent surveillance – broadcast (ADS-B)

This paper presents the signal and message structure of both systems. It covers their basic concept of operation. Of interest is whether the system has the capability of supporting APNT in the future airspace. To understand this capability the accuracy of both systems are assessed. Additional analysis includes developing the data capacity of the DME based system and examining the current signal in space performance of UAT ranging.

2. BACKGROUND

The Next Generation Air Transportation System (NextGen) is an FAA effort to modernize the national airspace. NextGen relies heavily on GPS to provide

significant operational benefits for aircraft procedures, navigation and traffic management. Indeed, GPS/GNSS is the primary means of navigation and surveillance for NextGen. However, even with the growing use of GPS, the FAA will still maintain additional navigation systems to support safety and robustness of the airspace.

Alternative position navigation and timing plays an important role in the NextGen airspace [1]. While many alternatives to GPS exist in the national airspace, these systems, such as DME and VHF omni directional ranging (VOR), are not capable of supporting the new operations enabled by GPS under NextGen. Without improved capabilities, loss of GPS/GNSS can result in many operational issues, particularly related to the transition to a less capable alternative. Some of these issues are listed below:

- Transitioning from 3-mile to 5-mile separation en route and on arrivals outside of 40 nm
- Shifting some aircraft to radar vectors
- Rerouting aircraft around interference area to reduce demand
- Throttling back demand to compensate for loss of capabilities like parallel runway approaches
- Limiting RNAV/RNP arrivals and departures and reduce options to handling arrivals

Many of these issues can overwhelm the capability of the airspace to adjust in a safe and efficient manner.

The most capable APNT today for aviation is DME. Each DME provides a true range measurement and so two or more DME ranges can provide horizontal positioning and area navigation capability. Scanning DME or DME/DME supports this functionality. Additionally, it is attractive from a stakeholder perspective because it is an operational system and major air carriers already carry DME/DME and DME/DME/Inertial (DDI) avionics. While APNT team is studying whether DME (via scanning DME avionics) can be improved to allow for a safe, graceful transition from and efficient continued operation without GPS, use of DME may be difficult given the performance levels needed for the targeted capabilities.

APNT GOALS & CAPABILITIES

One important APNT target is supporting NextGen operations in the terminal area. In the terminal area, APNT seeks to provide required navigation performance (RNP) 0.3 to support non precision approach and to allow aircraft to get to the final approach fix (FAF) of a precision landing aid such as an instrument landing system (ILS). Another capability that may be needed is to support 3 NM separations by providing 0.1 nautical mile (NM) position accuracy. Previous coverage and performance studies conducted show that current specified accuracy of DME must improve by about a factor of two to support RNP 0.3 in the areas studied [2]. The accuracy has to be even better if separation standards need to be met.

Terminal area, particular in NextGen “Big Airspace”, will have much higher traffic densities than today. These high densities are another important consideration for DME as the system have limited capacity. While DME ground stations are generally able to handle current traffic loads, the NextGen airspace will have twice the number of aircraft operating and higher density airspace which will tax the capacity of DME. The capacity concerns are not completely mitigated even if DME are able to transmit more than current level [3].

Information type	# bits & update rate	capacity & channel
Ground station identification with lat/long/height & time	144 bits every 2 s	72 bps
Authentication to mitigate spoofing	512 bits every 4 s	128 bps
Certificate revocation list	512 bits every 10 s	51.2 bps
Integrity support message (ISM) to support multi-constellation GNSS	256 bits every 10 s	25.6 bps
Assisted GNSS. Includes Doppler shifts for GNSS satellites to strengthen GNSS against RFI	256 bits every 1 s	256 bps
Differential GNSS carrier phase corrections valid for all airports within a terminal area (e.g., San Francisco Bay Area). This supports GNSS use for Category II and III Landing.	512 bits every 2 sec	256 bps
Total data rate (Prior to FEC)		1000 bps

Table 1. Notional list of desirable information for new APNT design.

So the APNT team is studying whether DME can overcome the challenges to supporting terminal airspace. And while DME is an attractive APNT from the stakeholder perspective, it is important to consider more capable but more challenging options, to ensure that there will be an adequate APNT for NextGen. This is one reason why other options such as passive or pseudo

ranging, that may require new equipment are studied. They overcome capacity limits and can be designed to provide higher levels of performance.

For passive ranging, APNT is also interested in providing some data capability. Data support can provide increase security through the use of authentication information. Additionally, data can provide added operational benefits that can be utilized even in nominal GPS conditions. These capabilities may be useful to encourage adoption of new avionics. Roughly 1000 bits per second (bps) is desirable. Table 1 shows a notional list of how the data capacity can be used to support different features.

PASSIVE RANGING ALTERNATIVES FOR APNT

There are many passive ranging systems and signals. However few of these are suitable to aviation and APNT as acceptability to key stakeholders such as aircraft operators and the service provider constrain the choices.

For aircraft operators, incorporating APNT onboard an aircraft should not engender major costs and installation downtime. Aircraft already maintain a host of antennas and avionics. The addition of another set of antennas and avionics may be onerous, especially for an alternative system. Hence if some of the existing equipment, such as an antenna, could be used for APNT, this could help make it more acceptable by reducing costs and installation time. This means that one would prefer a signal in the DME (L band) or VHF band as these radio antennae are carried aboard most aircraft.

For the service provider, use of existing infrastructure is desired as it reduces costs and makes use of the investment and equipment already in place. Additionally, the service provider needs to provide protected spectrum for the APNT signal. This also narrows the solution to the aeronautical radionavigation service (ARNS) portions of the L and VHF bands. Even with the limitation, several potential options are available.

One option is to create a new signal optimized for APNT requirements. A new design could yield significant capabilities providing an incentive to install. While a design can be made to utilize some existing ground assets, modifications will be necessary. However, the more problematic issue is that the target spectrum already contains many transmissions and so a new signal needs to demonstrate that it can operate in this environment. Figure 1 shows the spectrum use on the DME band from 960 to 1215 MHz. The histogram shows the number of DMEs transmitting or receiving on that frequency on the X channel. Additionally, there are the transponder, GPS L5, automatic dependent surveillance broadcast (ADS-B), and Joint Tactical Information Distribution System/Multifunctional Information Distribution System

(JTIDS/MIDS) transmissions. Not shown but also existing are mobile TACANs operating in the national allotment channels is for special uses such as air-to-air and shipboard ranging. A new signal must demonstrate non-interference with and tolerance to interference from existing signal. On top of this technical challenge is an institutional challenge that the new signal must be acceptable to the stakeholders of that spectrum. In the US, that would be the Department of Transportation (DOT) and Defense (DOD).

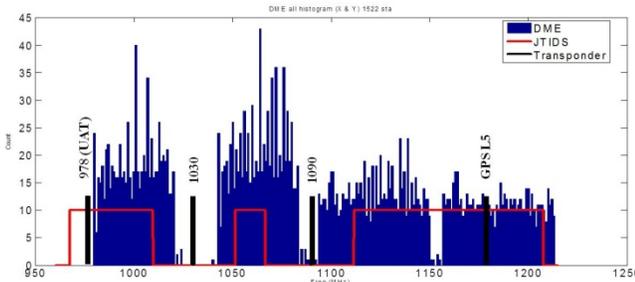


Figure 1. DME spectrum and utilization

Another option is to utilize existing signals. This option is desirable as it avoids the spectrum difficulties with having a new signal. So if there are signals that can meet the desired APNT capabilities, this option is preferred. In examining the FAA signals in the spectrum, two signal options are possible: 1) DME and 2) Universal access transceiver (UAT). Both these signals are well suited to and can provide essential elements (i.e. time of transmission and transmitter location) for passive ranging and navigation. Other potential options are discussed in a later subsection.

DME BASED PASSIVE RANGING

The existing DME pulses pairs, seen in Figure 2, transmitted by a DME ground station as its reply provides a basis for a DME based passive ranging (DMPR). DMPR essentially makes use of an existing part of DME operation - squitter pulse pairs (pp) used to maintain a minimum of transmission level of 800 pulse pairs per second (ppps). DMPR replaces the random in time DME squitter transmissions with a pseudorandom in time sequence of DME transmissions. The DMPR sequence is always on and allows for calculation of time of transmission and transmission of data.

Generation of the DMPR signal is based on existing DME ground station processes. DME works by round trip ranging. An aircraft interrogator sends a DME interrogation to the ground transmitter. Upon reception and acceptance of the interrogation, the ground transmitter broadcasts a reply after a known delay. This reply is broadcast but is only useful to the aircraft sending the interrogation. The process is seen in the left side of

Figure 3. Details on many aspects of DME signals and operations are provided in [4].

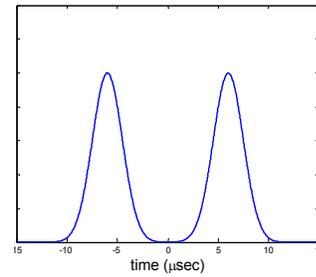


Figure 2. Ideal Gaussian DME Pulse Pair

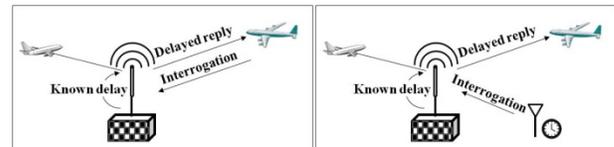


Figure 3. Comparison of nominal DME and DME passive ranging operations

With DMPR, a similar process occurs though the resulting concept of use is different. An interrogator on the ground interrogates the DME at set times creating a pseudorandom sequence of DME signals in time. This is used to broadcast a ranging signal and communicate data and is shown on the right of Figure 3. One difference with nominal DME is that any individual receiving it, not just the interrogator, can use the DMPR signal. Of course, the interrogator will also receive the signal and can use it to provide feedback to aid the accuracy and integrity of the DMPR system. Hence, generating the sequence of the DME replies is accomplished without any changes to existing DME ground station or hardware.

In our initial design, we use 500 reply pulse pairs, with 150 for synchronization and 350 for data, to achieve the desired performance while not having a noticeable impact on DME capacity. This level is less than 20% of the capacity of many fielded DME transmitters which can transmit up to 2700 ppps. It is even lower compared to newer systems are capable of up to 5400 ppps [5]. The structure for the design is shown in Figure 4.

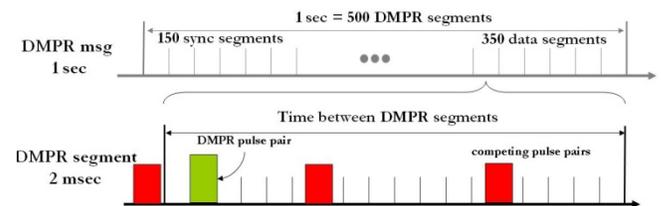


Figure 4. DMPR message & transmission structure

Ranging is supplied via a known synchronization sequence. The synchronization sequence provides alignment and identification of time of transmission (TOT) with a sequence of pulse pairs sent at known times

relative to the reference second. This provides the pseudorange and also sets the time base allowing for data transmission. For the design, data transmission is accomplished by defining 350 two millisecond (ms) frames whose times are set relative the synchronization sequence. Data symbols are provided by sending a reply in one of several acceptable start times within the frame. The number of acceptable start times determines the number of bits in the symbol.

Of course, some replies in the sequence may be interfered with or not sent. For the synchronization bits, reply losses are treated as data drops. For data bits, fountain codes and forward error correction (FEC) are used to mitigate symbol erasures and errors. The data capabilities are discussed more in Section 3.

UAT PASSIVE RANGING

Universal access transceiver (UAT) is one of the two protocol standards implemented to broadcast of aircraft position and traffic reports. Specifically it was designed to support ADS-B as well as traffic information services broadcast (TIS-B) and Flight information services broadcast (FIS-B). UAT is a promising option as its minimum operational performance standards (MOPS) incorporates an option and capability to support pseudorange [6].

The pseudorange signal is transmitted in the ground segment of the UAT basic frame shown in Figure 5. The frame is one second (UTC) with the ground segment residing in the 176 ms after an initial 6 ms buffer. The ground segment is dedicated to transmissions from ground-based transceivers (GBT), the basic ground units supporting ADS-B. This segment is has 32 equally spaced message start opportunities (MSO) that define the slot where a ground transmission can be sent. Knowing which slot the transmission originated tells you the transmission time (pseudorange) and knowing the position of the transmitters allows for position calculation like GPS.

The UAT ground segment transmission is seen Figure 6. The transmission contains a 36 bits synchronization sequence and 4416 raw bits in the payload which yields 3392 bits after forward error correction. The data includes slot number, transmitter location as well as transmitter location and UTC synchronization valid flags. Hence all necessary information is self-contained. UAT is transmitted on 978 MHz and modulated using continuous phase frequency shift keying (CPFSK). An increase of 312.5 kHz (Δf) indicates a “1” bit while the same decrease indicates a “0” bit. Each bit is 0.96 μ sec in length.

The necessary processing to use UAT measurements for ranging depends on the information known *a priori*. Without *a priori* information, the receiver must synchronize on the 36 bit sync and decode the full UAT ground message. Even though the slot and location bits are at the beginning of the message, the full message needs to be decoded as the message uses interleaving and FEC. The receiver may be able to range and position using the 36 bit synchronization sequence if it knows time relative to the UTC second and GBT location. Slot identification only requires a rough knowledge of the time relative to the UTC second (millisecond accuracy) due to the size of the guard band between slots which reduces the likelihood of misidentification even with some user time error. Ranging with only the synchronization sequence may allow increased range as the receiver is no longer limited by data decode range of the UAT signal. However, full decoding may still be needed as it may be necessary to know whether certain flags (such as UTC synchronization flag are set).

$$tx_time = 6 + 5.5 \cdot (slot_num - 1) msec \quad (Eq. 1)$$

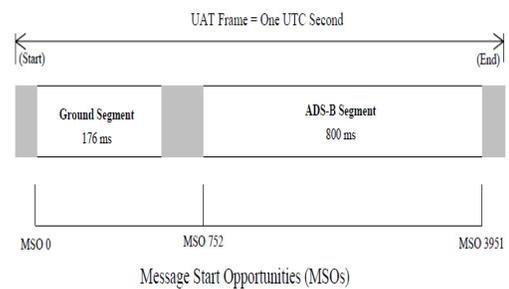


Figure 5. UAT Frame, grey areas are guard band [6]

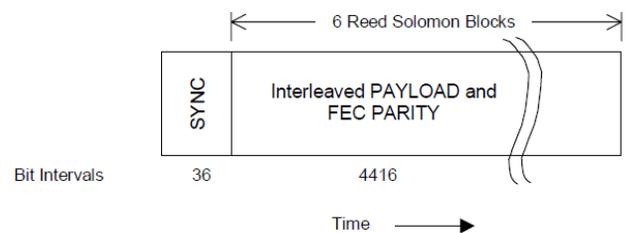


Figure 6. UAT Ground Segment Transmission [6]

OTHER OPTIONS

While the focus of this paper is on using existing signals and systems for APNT, other options for passive ranging are considered. These involve more technical changes or institutional challenges related to spectrum or both.

One possibility is to modify existing or to-be-existing system and their signals. Three such possibilities are: 1) Mode S on 1030/1090 MHz, 2) VHF communications and 3) future communication system (FCS). Mode S extended squitter (Mode S ES) is used for ADS-B and

FIS-B in commercial aircraft and is also transmitted by GBT. Interrogations on 1030 are made by ground equipment such as secondary surveillance radars (SSR). However, these transmissions are random and not synchronized to any time standards. No pseudoranging capability defined in the standards [7]. Hence to use Mode S for ranging, necessary changes include a new message containing GBT location and a means of indicating the TOT relative to a time standard. It may also be possible to use VHF transmission such VHF data link (VDL). Though the frequencies are currently well utilized, some VOR are to be decommissioned making it less congested. Again, new message definitions and time synchronization would be necessary. Similarly FCS may be used. FCS is not yet defined within the US but Europe will decide on one of two (LDACS) for FCS [8]. For example, the possibility of LDACS-1 for navigation is being studied

More challenging alternatives involves new systems and signals. The APNT team has developed a spread spectrum passive ranging signal as an option. Similarly commercial terrestrial pseudoranging technologies may be adapted for aviation. However, such signals require new spectrum and new equipment. Hence their use for APNT is challenging from institutional stakeholder, cost and technical perspective.

3. DME PASSIVE RANGING

Two performance areas of interest for using DME passive ranging are accuracy and data capacity.

ACCURACY MODEL

A basic analysis of accuracy was conducted using on the ideal DME pulse. While it may seem counter-intuitive that DMPR would be more accurate than DME given that the same signal is used, DMPR has some advantages. First, DMPR uses more pulses – an order of magnitude more for ranging (150 pp vs. 15 pp for DME). Second, DMPR uses only DME ground station pulses which are more ideal and tightly controlled than the airborne transmission. Finally, as the DMPR avionics will have to be new, better processing can be employed.

Figure 7 shows the range accuracy of a DME pulse as a function of signal to noise ratio (SNR) in a 1.4 MHz noise equivalent bandwidth (NEBW). The results for two methods of determining time of arrival (TOA) are shown: TOA calculation using the leading edge of the pulse at half peak amplitude point – this is the traditional method – and the peak of the correlation of the DME pulse. The figure also shows that better accuracy can be achieved using the correlation method (comparable to 5-10 dB improvement). Hence one means of improving

performance to utilize more accurate methods for determining TOA.

To get a sense of what the plot means, note that a DME pulse generated by a 100 W transmitter is received with a SNR of approximately 28.4 dB at 200 kilometers (towards the edge of DME coverage). Even though DME replies come in the form of pulse pairs, only the first pulse can be used for ranging as the second is not as well controlled in timing and may suffer significant multipath (due to the first pulse). The result shows that the ideal pulse has a standard deviation of 35 to 70 ns (10 to 20 m), even at the edge of DME coverage. While there are other errors and the pulse is not ideal, DMPR averages over at least 100 pulses and uses the better-controlled ground pulses. The result provides confidence that the signal is adequate to meet the target accuracy.

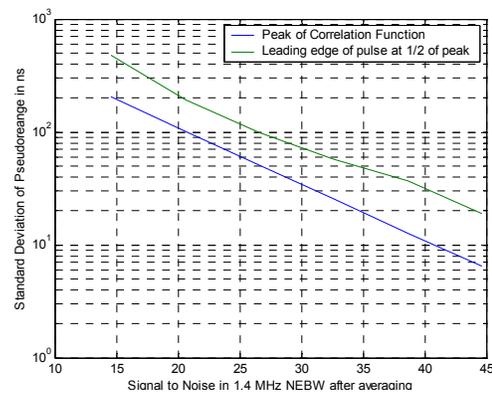


Figure 7. DME Passive Ranging Performance (Analytical Results, 1 Ground Pulse)

DATA CAPACITY

DMPR will utilize some pulse pairs for data broadcast with the current design using 350 pulse pairs each second. This section analyzes the data capacity given the data rate.

For data, each pulse pair, sent every 2 ms on average, represents one symbol. The size of that symbol in bits depends on the number valid transmission times (N_{vt}) exist within the 2 ms segment or frame. For example having four valid transmission times yields four possibilities or 2 bits. More valid transmission times yield higher raw data rates (raw bits per second or rbps) as seen in Equation 2.

$$\text{raw bits per second (rbps)} = 350 \cdot \log_2(N_{vt}) \quad (\text{Eq. 2})$$

However, this comes at the cost of increased interference that can result in data erasures and errors. Both erasure and error depend on acceptable DMPR timing tolerance, number of other DME transmissions and N_{vt} . The tolerance indicates how far from the presumed valid transmission time a pulse pair can be and still be accepted

a DMPR data transmission. Symbol erasures occur when either the DMPR transmission is not sent due to interference or if non-DME reply is transmitted at a valid transmission time (resulting in two or more acceptable DMPR data replies in a frame). Symbol errors generally result when a non-DMPR transmission falls on the start time while the actual DMPR transmission is interfered with and not sent. This is a less likely event than erasure.

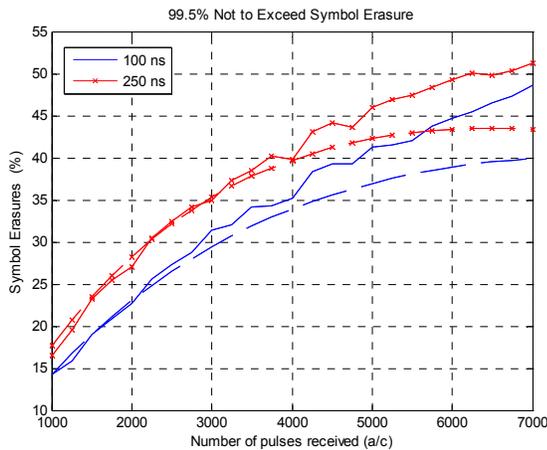


Figure 8. Symbol Erasure Rate at 99.5% Level for ± 100 and ± 250 ns tolerance (7 bits per frame)

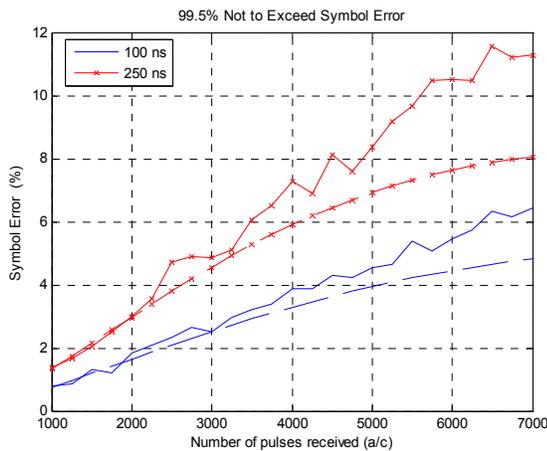


Figure 9. Symbol Error Rate at 99.5% Level for ± 100 and ± 250 ns tolerance (7 bits per frame)

A simulation model was created to determine the erasure and error rates given three factors: 1) number of aircraft DME interrogations 2) bits per frame ($= \log_2(N_{vt})$) and 3) DMPR timing tolerance. Figure 8 and Figure 9 show the symbol erasure and error rate using 7 bits per frame for different levels of DME interrogations at two tolerance levels, respectively. Two curves for each tolerance level are shown: simulation (50 trials, solid line) and analytic results (dashed line). The result determines the amount of erasure and error correction needed to provide proper decode with high availability with the analysis using 99.5% availability. Knowing how many bits or symbols are needed for such corrections then determines of the

actual data rate. At a minimum, correcting a symbol error requires two symbols while addressing a symbol erasure requires one symbol. The resulting rate or bits per second (bps) available for data is given in Equation 3 with a fraction of the rbps used for error and erasure correction.

$$\text{bps} = \text{rbps} \cdot (1 - 2 \cdot \text{percent}_{\text{error}} - \text{percent}_{\text{erasure}}) \quad (\text{Eq. 3})$$

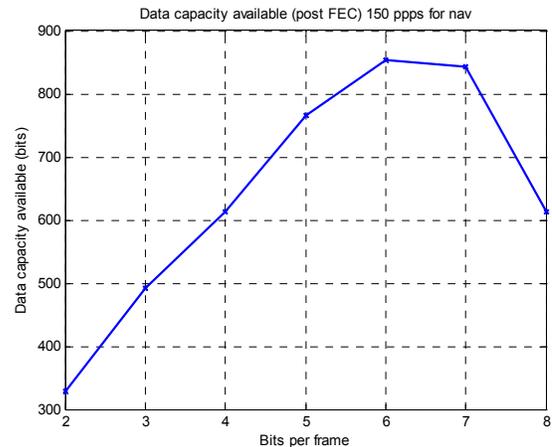


Figure 10. Data capacity post error correction given ± 100 ns timing tolerance based on 7000 aircraft interrogations

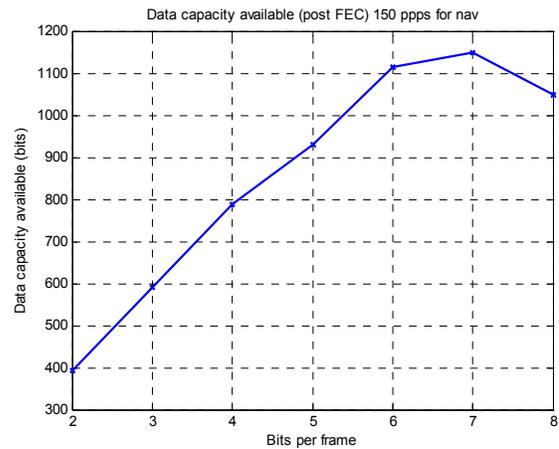


Figure 11. Data capacity post error correction given ± 100 ns timing tolerance based on 5000 aircraft interrogations

For a given tolerance level and number of DME interrogations, the data rate is determined for different levels of bits per frame. For the analysis, some implementation loss is included in the error and erasure correction. Figure 10 shows the result given 7000 interrogations. This is a worst case as 7000 interrogations is a very high level of traffic and would require, if 70% of the interrogations result in replies, current generation DME ground stations to transmit twice their maximum reply rate. In this case, the maximum data capacity is about 850 bits per second. For the slightly lower case of 5000 interrogations seen in Figure 11, the data capacity is

over 1100 bps. Note that the best data rate occurs at different levels of bits per frame (or N_{vf}) for the two cases.

4. UAT PASSIVE RANGING ACCURACY

With UAT, data capability and interference with existing signals are not major concerns at this time. Current measurements show that its full data capacity is not being used as many messages have been decoded with low data content. This may not be true in the future as FIS-B becomes more prevalent. What is important to understand for APNT is ranging accuracy and level of contribution of different error sources.

ACCURACY MODEL

An analysis similar to that done for DME was conducted developed to assess the accuracy performance of the UAT ranging signal. Figure 12 shows the resulting pseudorange error (in nanoseconds) assuming one full UAT message (36 sync and 4416 message payload bits) as a function of the SNR in 1.3 MHz NEBW. Several different processing methods for determining TOA are presented. The maximum difference between the methods is about 3 dB in performance. A UAT message broadcast by a 100 W transmitter is received with a SNR of approximately 28.7 dB at 200 kilometers. Assuming averaging over the 36 bit synchronization sequence instead of the full message, the value drops by 21 dB. Even with this lower value (7.7 dB), the analytical results show that the accuracy can be well below 10 ns (3 m).

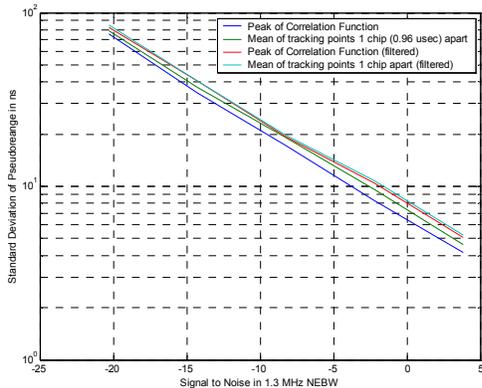


Figure 12. UAT Passive Ranging Performance (Analytical Results, full message)

SIGNAL IN SPACE MEASUREMENTS

The UAT transmission from a GBT is referenced to UTC, making it relatively straightforward to assess range. A data collection system was developed to collect on air UAT transmissions. This system, shown in Figure 13, consists of a DME/transponder antenna connected to a bandpass filter and data tuner/digitizer (VSA). The data

collection is triggered on the UTC second with though GPS derived 1 pulse per second (1 pps) signal. From the roof-top of the Durand Building at Stanford University, two GBTs are visible – one in Woodside and one at San Jose which are roughly 12 and 39 kilometers away, respectively.

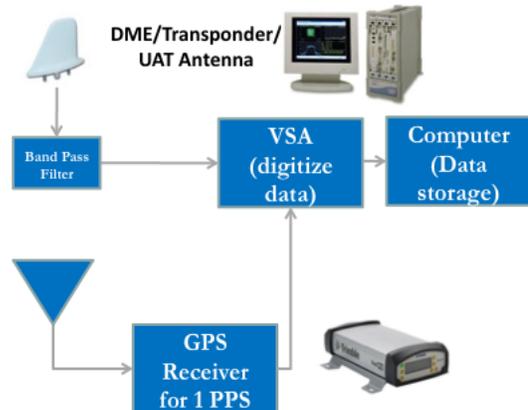


Figure 13. UAT Data Collection Set Up

Data was collected in four second segments over a three month period at intervals of roughly every other day. Figure 14 shows the data across 4 consecutive seconds (top to bottom). As seen in the figure, Woodside (larger signal) transmits twice per second while San Jose transmits three times per second. One interesting observation is that the transmission slots of the station rotates, incrementing by one each second.

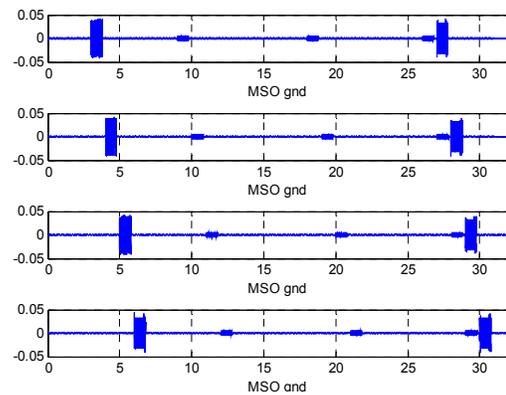


Figure 14. UAT ground segment & messages over 4 consecutive seconds (plotted over 32 opportunities). Larger signal is from Woodside, smaller from San Jose.

The collected data is used to assess various components contributing to overall ranging error. The components of the passive ranging error (PR Error) are shown in Equation 4. These are signal in space (SIS), receiver processing, receiver and transmitter clock errors, and propagation delay error. Examining data across several seconds allows for the estimation of the range accuracy of the signal in space given the processing employed. Over

several seconds, most errors are constant and the only remaining error with significant variation should be SIS and receiver processing.

$$PR \text{ Error} = \text{Signal in space/noise} + \text{Receiver Process} + \text{Receiver Clock Error} + \text{Transmitter Clock Error} + \text{Propagation Delay} \quad (\text{Eq. 4})$$

Figure 15 shows four second UAT data from several days. The variation between days allows for the examination of transmitter clock error that can be seen in the timing variations relative to UTC and between stations. While the SIS and receiver clock error variations still exist, these are known. SIS variation is known from the prior analysis while the GPS receiver timing performance is specified to about 40 ns.

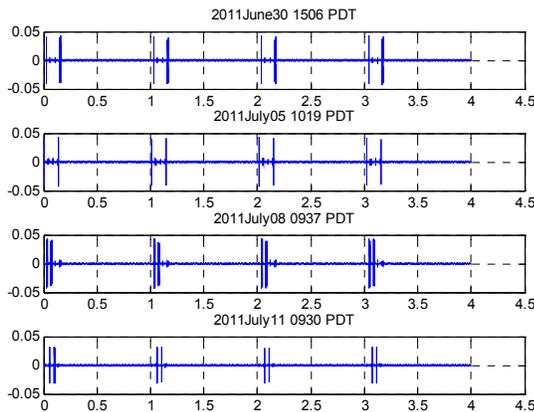


Figure 15. UAT ground segment transmissions (plotted over 4 seconds) on 4 different dates.

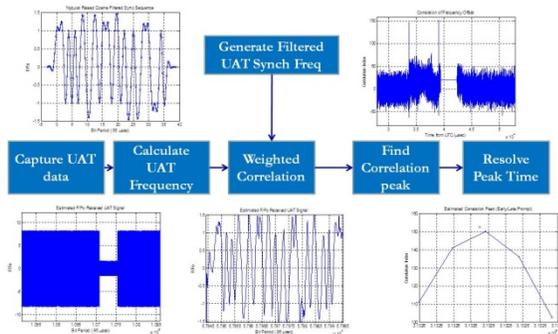


Figure 16. UAT Time of Arrival Processing

Software receivers implementing two different TOA processing methods were developed and employed on the data. The first method correlates in the measured frequency shift with the expected idea frequency shift while the second conducts the process in the time domain. The first processing method is shown in Figure 16. The ideal filtered synchronization data (synchronization sequence passed through a Nyquist filter [6]) is used as a template for correlation. Frequency shift relative to the 312.5 kHz (Δf) is processed from the data and correlated with the template. This provides a coarse correlation peak. The TOA is calculated from interpolating between the two highest points. After determining TOA for each

data (4 seconds), a first order (linear) fit is made to correct for receiver and transmitter clock drift. This correction only changes the results slightly (a few nanoseconds).

The results for the two methods are presented in last two rows of Table 2. The SIS error is seen to be 20-25 ns for both stations. Time variation is the variation of the measurement relative to our UTC. Hence, the variation includes some SIS, receiver processing and clock error. However, these other errors are small compared to the over 100 ns variation seen in the Woodside signal. They are slightly smaller than the variation seen in the San Jose signal. This result is still well within the UAT MOPS requirement of 500 ns. Finally, the variation of difference between station measurements provides an indication of how well the stations are synchronization. This also contains SIS, receiver processing and clock errors but again, these variations are small compared to the variation of the difference. This indicates that the stations are not tightly synchronized. The time variation results show that while good ranging can be achieved with UAT, increased accuracy through timing improvements are possible.

Woodside		San Jose		Difference
SIS (1 σ)	Time variation (1 σ)	SIS (1 σ)	Time variation (1 σ)	Difference btw stations (1 σ)
27.5 ns	120 ns	21.6 ns	54 ns	104 ns
23.1 ns	110 ns	20.0 ns	60 ns	120 ns

Table 2. Components of UAT ranging performance with two TOA processing methods.

Additionally, the signal was also demodulated and decoded. The UTC synchronization indicator was set valid while GBT location while flagged invalid by the message was indeed reasonable. The data occupies the beginning of the transmissions. Many messages were found to contain little data as seen in Figure 17. It shows a segment of about 3000 consecutive “1” bits. This occurs even with FEC and interleaving.

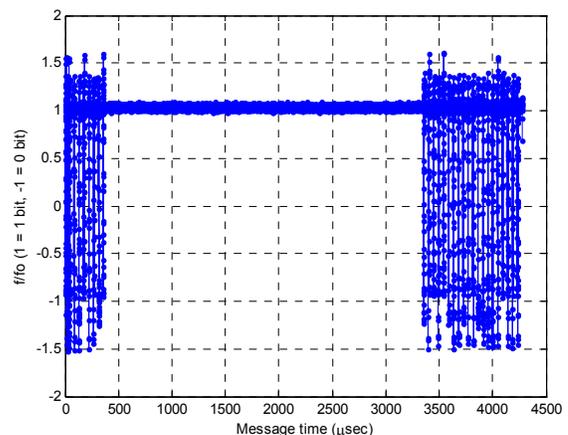


Figure 17. UAT Ground Segment Message Data Bits

5. CONCLUSIONS

APNT will be needed to play an important role in NextGen to maintain for safe and efficient operations even if GNSS becomes unavailable. One option to provide APNT is the passive ranging. Passive ranging is attractive as it has unlimited capacity and relatively simple architecture. It may be achieved using existing signals and systems within the national airspace. An added benefit of a new system is the ability to provide data to support capabilities currently not available today.

Two existing aviation signals, DME and UAT, were examined for their potential for passive ranging. The results indicate that these two are promising options for APNT. The APNT team developed a technique to enable DME squitter to provide a passive ranging function. Reasonable data rates of over 800 bps are achievable with this system. Passive ranging using the UAT ground segment signal is an option provided for by the UAT MOPS.

The key issue examined by this paper is accuracy performance to support the terminal area. Analysis of the accuracy of both signals in space shows that they are acceptable for meeting RNP 0.3 and separation requirements. Measurement of two UAT stations show that the actual signal in space has reasonable accuracy. It also shows that improved time synchronization is possible and would further improve UAT use for passive ranging. Further tests will be conducted on transmitted UAT and DME signals to better understand the various contributors to their ranging errors.

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DISCLAIMER

The views expressed herein are those of the authors and are not to be construed as official or reflecting the views of the Federal Aviation Administration or Department of Transportation.

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