UAT-WP-12-10

8 April 2002

RTCA Special Committee 186, Working Group 5

ADS-B UAT MOPS

Meeting #12

Draft #2 of Proposed Appendix D:
UAT GROUND INFRASTRUCTURE

SUMMARY
This is a working draft for Appendix D of the UAT MOPS. This version still has some placeholders, so is not ready for final reading or review. Please read it if you can to comment on content, level of detail, and any other relevant points.

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D UAT Ground Infrastructure

As part of the Minimum Operational Performance Standard for the UAT, this informative appendix describes the working concept for a UAT ground infrastructure. This infrastructure supports the ground-air segment of the overall UAT network. This is not intended to be a specification or set of requirements for such a ground infrastructure, but rather a context in which to understand the intentions of the UAT data link.

D.1 General Description

The role of the ground infrastructure is twofold:

a. To receive ADS-B broadcasts and generate a summary of the air traffic in a given area, possibly fusing it with other surveillance data (e.g. radar or multilateration systems).

b. To transmit this traffic data along with other flight service information (weather, NOTAMS, differential GPS corrections) to the airborne traffic for use in the cockpit.

There is considerable flexibility within the UAT MOPS for the deployment and functionality of the ground infrastructure. The receive and transmit functions may be physically separate and even have different providers, or they could be a single ground network of transceivers feeding an integrated system providing all the above functions. This will probably be decided more by economics than by engineering design. It will certainly not be decided by the time this document is published. Fortunately, this Appendix need only describe enough of the system to allow understanding of the UAT data link and be reasonably sure that it will provide the necessary functionality.

D.1.1 Uplink: Broadcast

D.1.1.1 Geometric Coverage

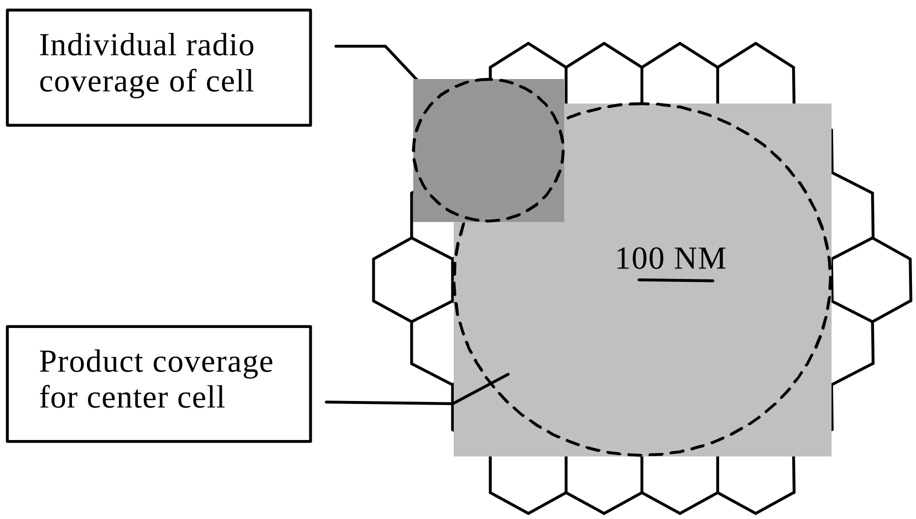
Due to the limited range and geometry of a single ground station, a network of ground broadcast transmitting stations will be required. Each station will have associated with it two types of coverage. One is the *radio coverage* of the transmitted signal. This is the airspace that can be usefully reached by signal from the ground station. The other type of coverage is the *product coverage*. This is the geographic scope of responsibility the ground station assumes for each product (such as a weather map) broadcast.

D.1.1.1.1 Radio Coverage:

In designing the radio coverage, there are two concerns. One is the coverage being *relied upon*. This is the minimum required coverage. The other is the maximum coverage under the "best" conditions. This can cause one station to interfere with another distant station. We design minimum radio coverage to assure a data link under worst cases cable loss, receiver sensitivity, unfavorable antenna attitude (a banking aircraft), etc. When experiencing conditions better than worst case, the coverage can be considerably greater.

The UAT system uses time division multiplexing to allow multiple stations to operate on the same frequency. At the designer's disposal are the 32 ground broadcast time slots. Since time slots must be re-used geographically, there is a potential for self-interference where radio coverage is greater than the designed minimum. The allocation of one or more time slots to a given ground station based on some re-use pattern will mitigate this self-interference.

As a sample coverage scheme, a hexagonal “cellular” pattern of ground stations with a nominal intersite spacing of 100 NM would assure coverage everywhere down to about 3000 feet above ground level (AGL). (This is based on a 4/3 earth refraction model a nominal antenna height, and ignores terrain effects.) This intersite spacing would require a minimum broadcasting range of about 70 NM. A nominal coverage cell layout is shown in Figure D-1. In this example case, the radio coverage covers about half way into the adjacent cell, giving at least dual coverage to every point. Such a system is tolerant of single station failures if the product coverage is sufficient, as discussed below.



<u>Figure D-1:</u> Example Coverage Cell Layout

D.1.1.1.2 Product Coverage:

The product coverage and update rate can be tailored to suit the characteristics of individual products. For example, products that are relatively small in terms of total data volume and that are updated infrequently such as Automated Terminal Information Service (ATIS) messages could have a relatively large product coverage such as 500 or 1000 NM radius of the ground site with a relatively low update rate. A product such as traffic data may call for a relatively high update rate and a smaller coverage area – say within a 200 NM radius of ground site – to keep data link bandwidth requirements at a reasonable level.

The product coverage should exceed the radio coverage to assure overlap between ground station boundaries. This will allow site transitions to appear seamless to the user. In addition, some data products require a context larger than one radio coverage cell to be meaningful (such as weather data).

When an aircraft receives uplinks from multiple ground stations, it has the task of fusing these data. This task can be minimized by having the ground infrastructure assure that redundant information from different ground stations is identical. For example, adjacent uplink stations reporting precipitation strength for a given point or grid element should report exactly the same data. Then the application in the aircraft need only associate the reports and choose either for displaying or processing (rather than averaging, interpolating, or inferring data integrity). Note that with autonomous, isolated ground stations this is not an issue.

Looking back at Figure D-1, a sample product coverage is shown along with radio coverage for a single cell. For this coverage, there is ample overlap for at least dual coverage of any point and a seamless, consistent picture of the product as the aircraft flies through, even with failure of a single ground station.

D.1.1.2 Data Source For Ground Broadcast

Contents of the ground broadcast messages can be put in the following categories:

1. Flight Information Services-Broadcast (FIS-B) – the broadcast distribution of weather and aeronautical information.

2. Traffic information from other surveillance sources (radar, multilateration) – this augments the ADS-B data received directly from the air-to-air link.

3. ADS-B data collected from non-UAT links.

4. Other.

Traffic uplink data is sent during the air-to-air segment of the UAT epoch. FIS-B and “other” information is sent during the ground broadcast segment.

There are many possible configurations for the flow of information for the uplink stations. Not all stations need to be configured the same way. The one chosen will depend on the products being provided. In any case, the UAT equipment is a minor part of the ground system. The system will be primarily defined by the ground communication links (satellite, land line (phone, fiber) or microwave or other dedicated RF link), by the sources of the data for ground broadcast (radar, multilateration, weather observation and forecast), and by the applications which fuse this data and generate the ground broadcast reports.

D.1.2 Downlink: Surveillance

ADS-B data being transmitted by aircraft will be received (in general) at multiple ground receiving stations. This redundancy is readily fused since all stations are receiving the same message contents. Because of the required frame synchronization of all UAT transmitters and receivers, there is ample accuracy in the time-of-arrival stamp on each message to readily associate them and merge them. No averaging or weighting need be done on the contents as they are all the same.

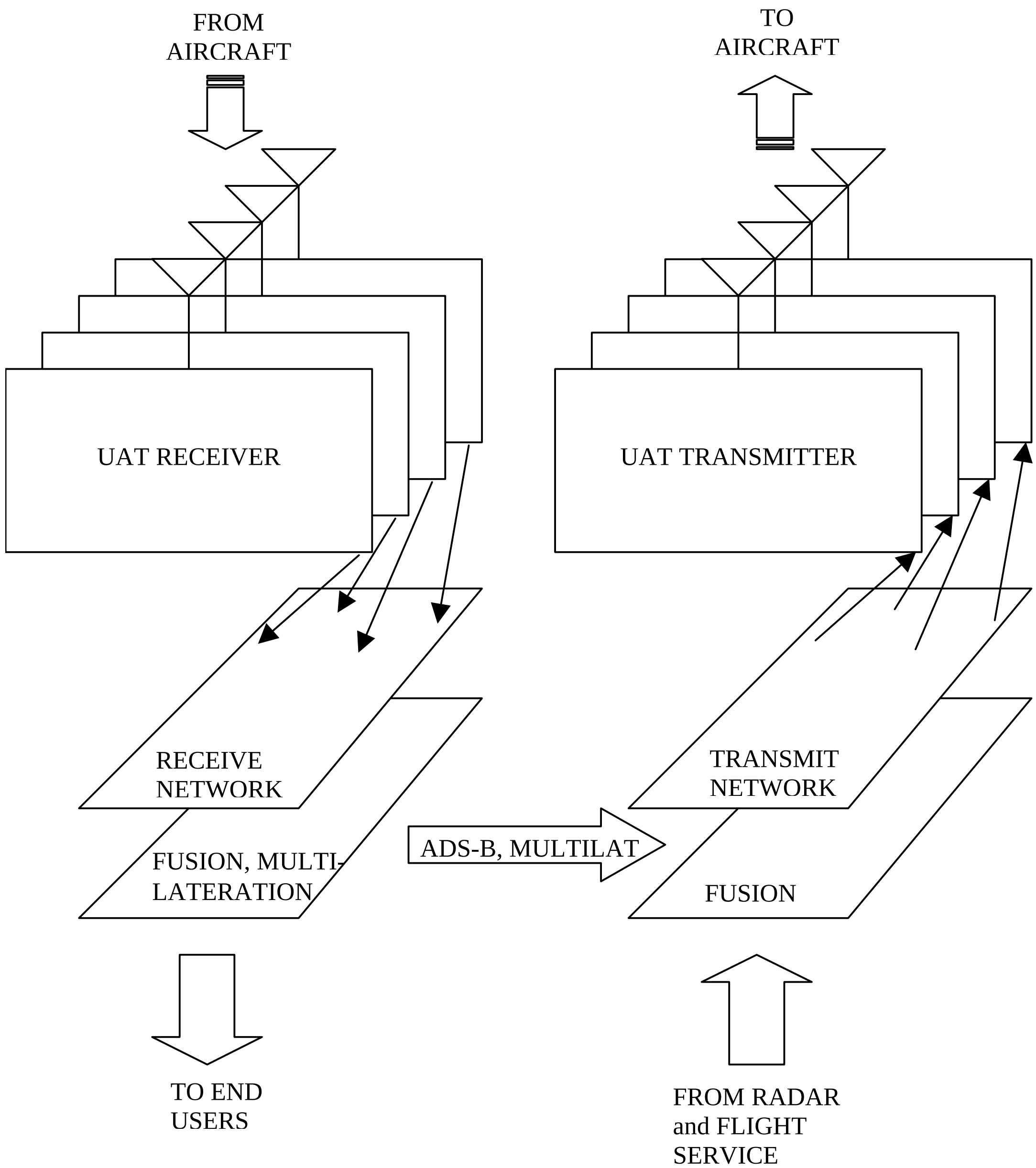
A rough range from the receiving station can be determined from the Transmission Epoch (MSO number) encoded in the Type 0 Long ADS-B message. A more accurate time stamp on arrival and a more accurate receiver synchronization would allow multilateration on ADS-B reports received at multiple ground stations. Either method of independent position verification can be used in a health monitoring check on the reports (a check of the on-board GPS equipment in the aircraft).

D.1.3 Summary of Infrastructure and Implications

Figure D-2 shows a generalized diagram of the components and interconnnect of a ground infrastructure for the UAT data link. Many variations of this general structure are possible. Transmitters and receivers may or may not be co-located. Different sites may have different levels of service. This data link will have to support a transition period for a considerable time period before the fleet is fully equipped. The UAT data link has the necessary flexibility to handle these conditions.

Because of the generality of the data link the system can be expanded as the ground infrastructure is developed and “filled in.” The UAT ground station is adapted to each specific deployment by the application driving it.

The characteristics of the UAT link required to support this general structure are in the areas of time stamps and predictable latency, one second frame synchronization, time division coordination of adjacent ground cells, and a waveform tolerant of self-interference.



<u>Figure D-2:</u> General Form of Ground Infrastructure

D.2 Ground station deployment

D.2.1 Cell layout, time slots, and station ID

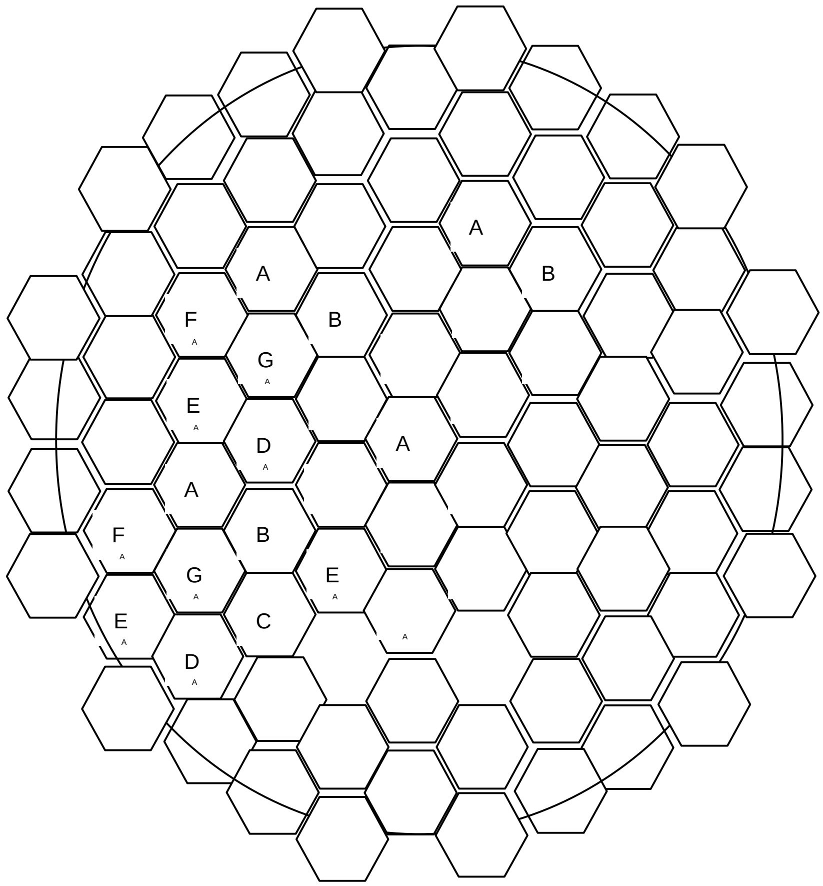
D.2.1.1 Time slots

The UAT data link has 32 uplink time slots available. The separate slots allow nearby stations to operate without interfering with each other. A conservative approach to allocating the time slots is to give one slot to each ground station. In a hexagonal deployment, for example, the nearest station using the same slot as a given station will generally be 6 tiers (cell diameters) away. (A cell and 3 tiers around it totals 37 cells.) Considering propagation loss and the horizon, there is essentially no chance of interference.

In many cases, however, it will be useful to allocate more than one time slot to a given station so it can deliver its entire product. A re-use pattern of 7 time will allow cells re-using a given time slot to be separated by about 2.5 cell diameters.

Continue on with example based on Carl's spreadsheet. Some text below may help.

Signal level separation



D.2.1.2 Slot rotation

One danger of a synchronous system is that other interfering synchronous systems may repeatedly interfere with a given station. In general, the UAT link relies on random interference and is tolerant of occasional missed messages. But if a ground uplink segment is repeatedly masked by another interferer that is synchronized to the UTC second, there can be a serious failure of the data link. For this reason, the transmission times for each assigned time slot will be deterministically rotated.

scheme

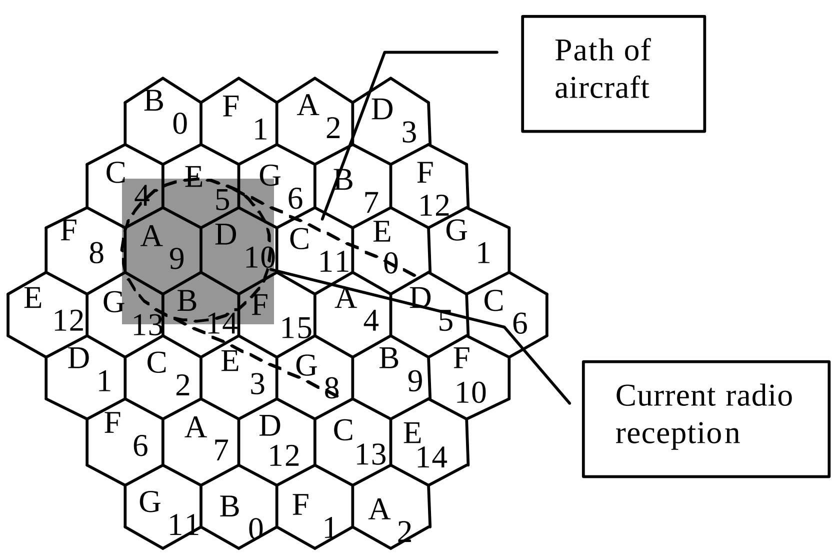
D.2.1.3 Site ID

Each station is assigned a site ID number (Section 2.2.3.2.2.1.8). This number is not unique, having only a 4-bit value. The purpose of the ID is to give a brief (few bits) way of identifying the source of a TIS-B uplink message. This source identification is useful for confidence measures of time synchronization and to counteract spoofing. In sparse areas, only one station with a given ID will be within reception range. In more dense areas, more than one can be received (but not a large number) with the same ID and any range checking can be performed on all stations with that ID to get verification.

As an example, consider a 7-cell reuse pattern of Slot ID. Figure D-3 shows an assignment of the 7 time slots (labeled A through G) and of the 16 Site ID numbers (labeled 0 through 15). To see the repeat pattern in this example, look at a cell with slot label "G" as the center of a 7-cell cluster. A through F are clockwise around it. These clusters are then packed hexagonally. This is just an illustrative example to demonstrate the idea.

The approximate reception area of an aircraft is shaded in the Figure D-3. In the ground uplink segment, the aircraft is solidly receiving data in slots A, B, C, D, and E (labeled A9, B14, C4, D10, E5). It can tell that these stations are within a normal reception range from the location broadcast in the uplink.

Table D-1shows a list of these locations and Site ID's as they can be kept in the aircraft UAT application. The aircraft receives uplinks possibly from two different G slots (G13 and G6). It may get either or neither in any one-second epoch and may get both over many seconds. In any event, it can place them into the table. The same can be said for two F slots (F8 and F15). Due to the trajectory of the aircraft, it has recently been in one of the F slots (F15) as well as other slots (C11, E0, A4, and G8). These are still in the table as well. Entries can be dropped from the table when they are beyond range by some pre-determined amount. At the time shown, there are two entries with Site ID 4 and two with Site ID 8. Note that the time slot (A-G) in the table is for clarity of the example only. It is not important for the range validation process, or for any ground station function once time-of-arrival has been computed.



<u>Figure D-3:</u> Example of Slot and Station ID

Table D-1: Example of Site ID Table

Site ID	Location	Time Slot
9	lat long	A
14	lat long	B
4	lat long	C
10	lat long	D
5	lat long	E
13	lat long	G
6	lat long	G
8	lat long	F
15	lat long	F
11	lat long	C
0	lat long	E
4	lat long	A
8	lat long	G

Each of these ground stations transmits TIS-B messages in the air segment of the UAT frame. Since these are in random MSO's, they can all be received with high probability. In addition, other more distant stations can transmit TIS-B messages and be received. When any TIS-B message arrives with its Site ID (0-15), its apparent distance from the aircraft (from the time-of-arrival) can be checked with *all* entries in the table having that Site ID. If it matches, that message is validated. If not, it can be rejected as unreliable.

It is possible that a legitimate TIS-B message can be rejected from a distant station based on this method, if the station is not on the list. This is not a problem because if the target is important to the aircraft it will be included in the TIS-B uplinks of a nearer station giving good range validation checks. This can be assured by the design of the product coverage for each cell.

D.2.1.4 Sectorized Cells and Co-site Transmission Isolation

In some areas of dense air traffic, a maximum range ground station can experience poor target state update performance due to UAT self-interference. In this event, the area of coverage must be reduced, but it is undesirable to have multiple equipment sites to cover the range. A solution to this problem is to co-locate several units with sectorized radio coverage.

In cases where UAT ground equipment is co-located with other transmitting equipment at a nearby frequency, it is desirable to get as much rejection of that interfering signal as possible. In these cases, the same sectorized antenna discussed above can also help.

In the performance prediction analysis done for the UAT link, areas. … uses an assumed azimuth antenna pattern. It is appropriate for a 3-sector split of a cell. Figure D-4 shows this pattern. The rejection of targets behind and to the sides of the antenna helps the interference problem. Also, the low response behind the antenna can help to reject any interference from a co-site radiator if antennas are appropriately located. Figure D-5 shows two possible location approaches. In Figure D-5(a) the vertical stacking can achieve a high level of isolation. In Figure D-5(b) the 1000-foot spacing gives about 82 dB of isolation at 978 MHz. Need isolation goal –58 dBm in 978 band. This gives a –35 dB SIR for a UAT signal at MTL of –93 dBm. The performance modeling shows this to be an acceptable interference level.

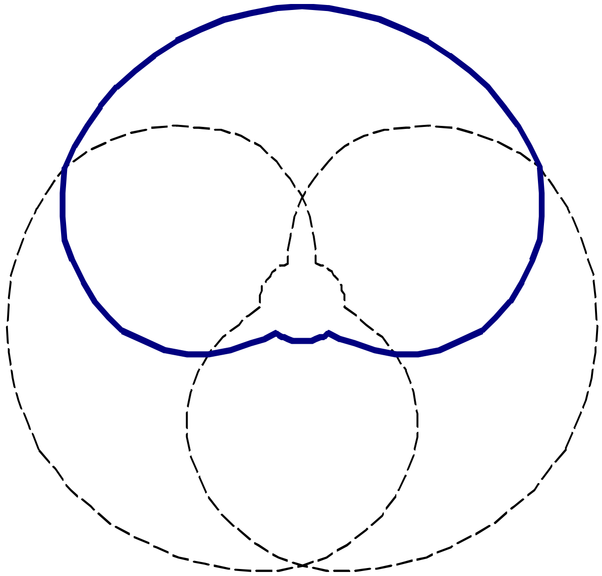


Figure D-4: Sectorized Antenna Pattern (3 sectors)

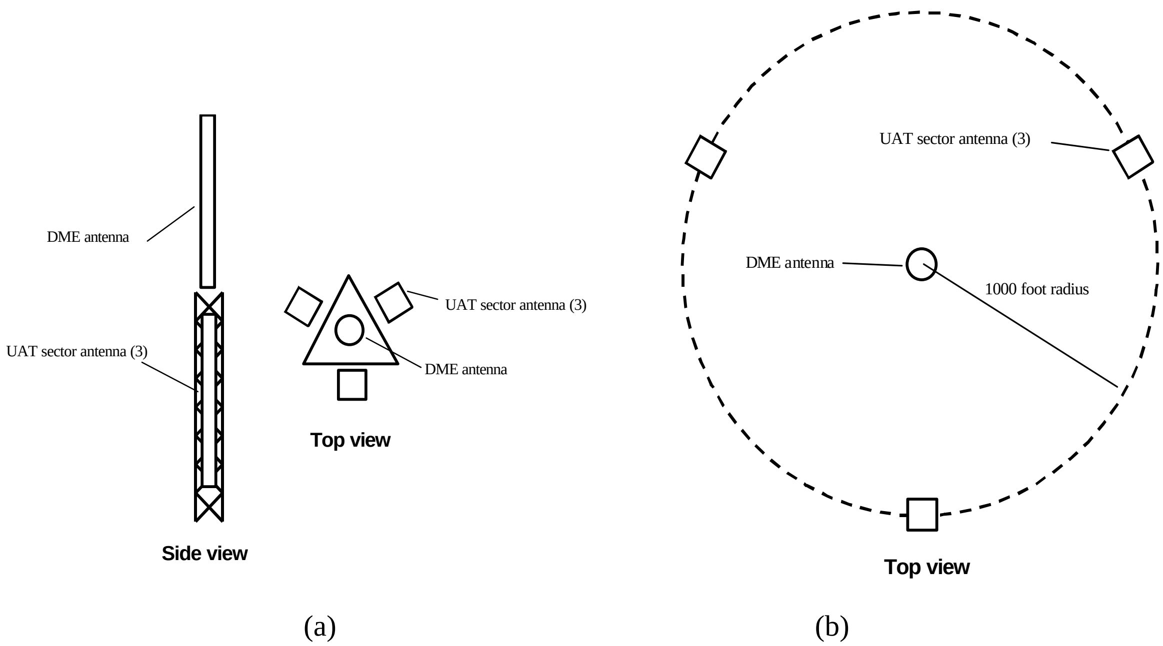


Figure D-5: Possible antenna locations

D.2.2 Eurocontrol requirements

Can meet radar requirements of 5 sec update at 60 NM 12 sec at 60 NM with and only with overlapping ground coverage and fusion

D.3 Installation recommendations

D.3.1 RF interference

There are two sources of interference at the UAT operational frequency of 978 MHz: JTIDS and DME. There has been a considerable amount of analysis, simulation, and laboratory measurement to determine the working limitations of UAT with these other two systems. Most of the issues occur with DME equipment and are discussed below.

D.3.1.1 JTIDS Interference

JTIDS operates in the vicinity of the 978 MHz UAT and the mutual effects of JTIDS and UAT are discussed in XXX. In short, between the spread spectrum nature of JTIDS and the interference rejection of the UAT modulation, the systems exhibit acceptable effects on one another.

D.3.1.2 DME Interference

An important source of interference to the UAT link operating at 978 MHz is DME equipment operating near that frequency. For successful operation of UAT, DME equipment at 978 cannot be co-located. Describe effect in Europe, none in US

For a worst-case of a co-located DME/TACAN at 979 MHz and operating at 10 kW ERP, and for siting to allow at least 1000 foot separation of the antennas, there is in a DME signal level of approximately –10 dBm at the UAT ground station. At 1 MHz from the DME carrier frequency (i.e. at the UAT carrier frequency) the level is down 40 dB from that or –50 dBm. Filter details, wp 8-05 by chris

Other possible techniques to achieve the necessary isolation are a very sharp (e.g. tuned cavity) filter, or adaptive cancellation. In the case of a filter, the approach would be to find a filter for the UAT receiver with acceptable in-band loss for the desired sensitivity to be achieved and then use the 979 MHz rejection of the filter to ease the burden on the antenna separation. In the case of adaptive cancellation, an auxiliary array can be positioned to sample the interferer and the system can adaptively subtract a replica of this sample from the received UAT signal to achieve the best signal-to-interference ratio.

D.3.1.3 DME at 979

Same airport WP-8-05 by chris

Note problem

Note 1000 ft assumption

Note possible mitigation (filter)

Add possibility of adaptive cancellation

D.3.2 Registration

D.4 Miscellaneous topics

D.4.1 Range validation for integrity, anti-spoof

There are several advantages to the synchronous nature of the UAT data link. An application can add confidence to an air or a ground report by comparing the actual time of arrival with a theoretical time. The check can be used to flag a report as a possible spoof, a report from an unsynchronized platform, or a loss of synchronization of own platform. This ability, though not required in the UAT protocol, can increase the confidence of data gathered and reported by that station and of the overall system.

The theoretical arrival time used in consistency checks comes from time of transmission and known distance. All UAT transmissions indicate (directly or indirectly) the location of the transmitting platform. Airborne reports contain latitude, longitude, and height of the aircraft. Ground station uplink messages during the ground segment contain station latitude and longitude. TIS-B reports from a ground station indicate a ground station ID number that allows them to be associated with an explicit location given in the ground segment broadcast. Time of transmission is indicated in the transmission subject to the limitations discussed below. Assuming the receiving application knows its own position, the computation can be made.

There are some uncertainties in computing this theoretical time of arrival. One uncertainty is the degree of the synchronization. The requirement on the timing is that the one-second frame be within XXX of the UTC second. Another uncertainty is the exact time slot. An airborne ADS-B report contains the lower XXX bits of the MSO number. This leaves some ambiguity, but it is large enough to be resolved from practical constraints. Another source of uncertainty is in a ground-based TIS-B report. It contains a 4-bit station ID, but is ambiguous with other ground stations having the same ID. This is mitigated by good re-use strategy in the layout of the ground stations and the fact that the application can be aware of all ground stations within reception range that have that ID and do a range check from all of them.

D.4.2 Multiple ADS-B Links

It is likely that the ADS-B system as it develops in the US will include multiple data links. The UAT data link is capable of supporting a multi-link deployment. Power levels and antenna locations are specified such that air-air as well as air-ground links are established over the coverage area. This allows the ground infrastructure to obtain the UAT ADS-B picture and to supply to the air traffic any non-UAT ADS-B traffic using the TIS-B capability.

D.4.3 Data rates. Latencies

A sample budget

Enroute 3 sec

Terminal 2 sec