RTCA Special Committee 186, Working Group 5

ADS-B UAT MOPS (DO-282), Revision A

Meeting #15

UAT Ground-Air Performance

Presented by
Larry Bachman, JHU-APL
Mike Castle, JHU-APL

SUMMARY
This Working Paper discusses the probability of reception of Ground Uplink and ground-broadcast TIS-B Messages by Airborne UAT receivers in the Core Europe 2015 traffic scenario (CE2015) at the worst-case self-interference and DME interference points of the scenario, as well as in the low-density scenario.

This Working Paper discusses the probability of reception of Ground Uplink and ground-broadcast ADS-B messages by airborne UAT receivers in the Core Europe 2015 traffic scenario (CE2015) at the worst-case self-interference and DME interference points of the scenario, as well as in the low-density scenario.

Assumptions

The following assumptions were used in this analysis:

- Unless otherwise stated, the baseline for all assumptions is to be found in the RTCA UAT MOPS (DO-282), specifically the modeling and simulation sections of Appendix K in that document.
- The ground transmitter antenna gain is omni-directional in azimuth (0dB), and the elevation gain is based on measured values of a TACAN antenna.
- In order to maintain the appropriate distance from the ground transmitter for each data point, the receiving aircraft is held stationary in each simulation run.
- A common random number seed was used to generate results for the different cases run. The ground transmit power is specified at the transmit antenna. In the CE2015 air traffic scenario, two transmit powers were simulated, 40 and 45 dBm. In the low density scenario, the ground broadcast transmitter has a power of 36.5 dBm.
- Uplinks sent in the ground broadcast segment are transmitted randomly in one of the 32 slots available at the beginning of each second for ground format messages.
- Uplinks sent in the ADS-B segment are broadcast randomly in five transmission windows, each of 19 milliseconds (76 Message Start Opportunities [MSO]) duration. The transmission windows occur within the ADS-B Segment of the UAT Frame beginning at each of the following times after the start of the UTC second:
    - 194 milliseconds (MSO 752) + OFFSET
    - 354 milliseconds (MSO 1392) + OFFSET
    - 514 milliseconds (MSO 2032) + OFFSET
    - 674 milliseconds (MSO 2672) + OFFSET
    - 834 milliseconds (MSO 3312) + OFFSET

  Where OFFSET is randomly determined for each ground transmitter each second as one of the following mutually exclusive values:
    - “ZERO”
    - “20” milliseconds (80 MSOs)
    - “40” milliseconds (160 MSOs)
    - “60” milliseconds (240 MSOs)
    - “80” milliseconds (320 MSOs)
    - “100” milliseconds (400 MSOs)
    - “120” milliseconds (480 MSOs)
    - “140” milliseconds (560 MSOs)

- In the simulation runs, 2 broadcasts per ground transmitter per second are scheduled for ground segment uplinks, and 10 broadcasts per ground transmitter per second are scheduled for the ADS-B segment.

- The altitude for ground transmitters is assumed to be 100 feet.
- Ground transmissions do not interfere with one another.
- Sensitivity values for ground format uplink messages were tuned so that with no interference, there is a 90% message success rate for a signal with –91 dBm power at the antenna (see Figure 1). This is the sensitivity of the receiver to ground uplink messages required by DO-282.

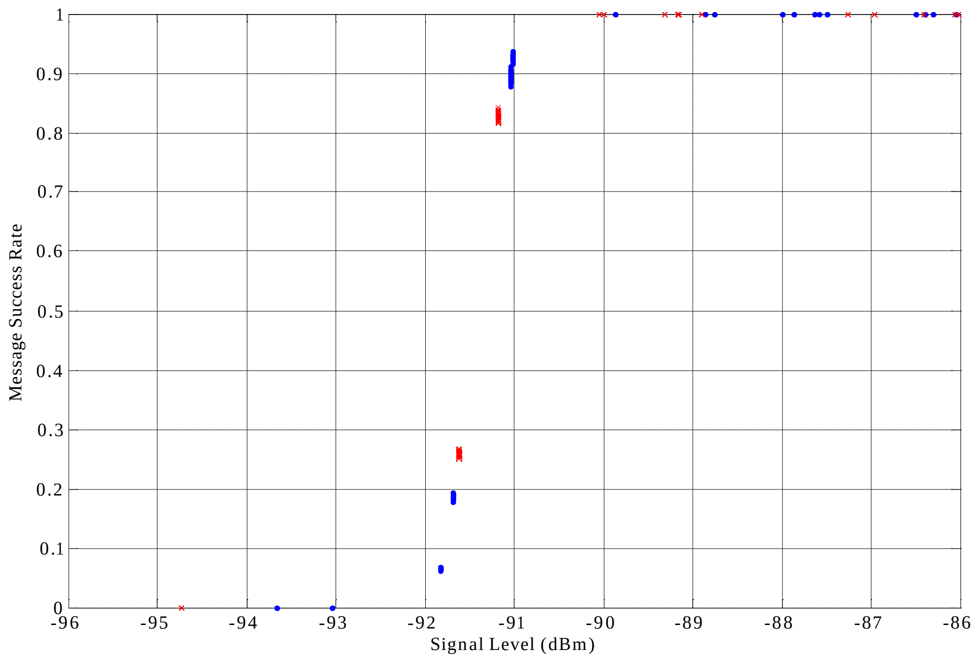

Figure 1 - Message Success Rate as a Function of Range for Ground Message Uplinks with No Interference

Results

In order to produce results in time for this working paper, and considering the number of simulation runs required, the amount of data generated was reduced from that normally used. This enabled the appropriate cases to be analyzed, although the lower statistics produced somewhat larger variability in the results. This may be observed when examining the resulting plots, where the statistical variability is evident when observing the point-to-point differences. These differences give an idea of the uncertainties introduced by the reduced statistics, and these data are more indicative of general trends than exact values.

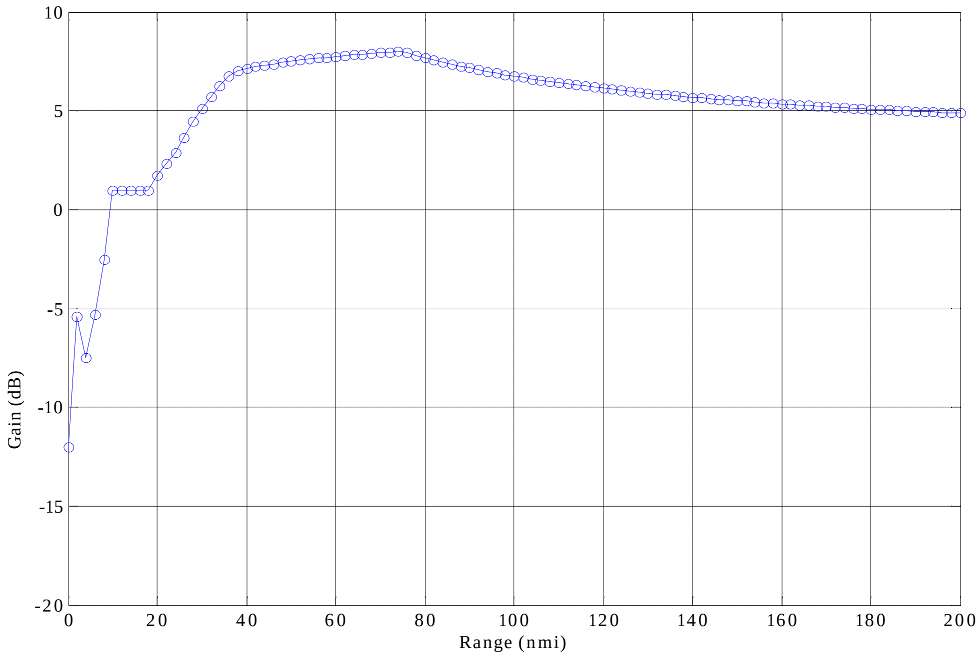

Figure 2 - Ground Transmit Antenna Elevation Gain as a Function of Range for an Airborne Receiver at FL 400

Figure 2 shows the antenna elevation gain patterns for the TACAN antenna used for this analysis. Note that this type of antenna exhibits a sharp null at small distances, with a fairly constant, much more slowly varying gain at distances greater than 20 NM. However, we do expect to see a drop-off in performance at ranges close to the transmitter due to the aforementioned null, and this drop-off is evident in the performance plots.

Figure 3 shows the Message Success Rate (MSR) for a ground station transmitting long ADS-B messages to a receiver over Brussels in the CE2015 air traffic and interference environment. This corresponds to a worst-case UAT self-interference situation. The results are shown as a function of the range of the receiver from the ground station. A Message Success Rate of 0.5 at a particular range means that around half of all of the ground station long ADS-B messages would be received at that range.

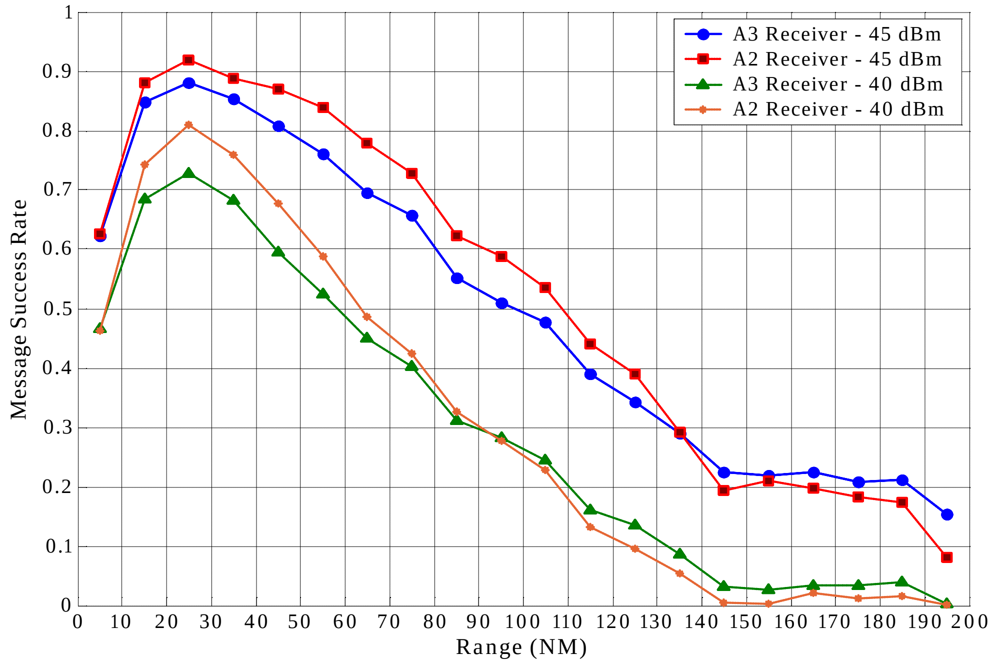

Figure 3 - Message Success Rate as a Function of Range for Receiver at FL400 over Brussels in CE2015, GBT Broadcasting ADS-B Messages at Two Different Power Levels

Figure 4 shows the same information as that shown in Figure 3, but the location of the receiver has been moved to the worst-case DME interference position. The resulting MSR curves are quite similar to those in Figure 3.

Figure 5 shows the performance of an A1 receiver in both positions and GBT power levels. The performance is decreased approximately 10-20% from the performance of the A2 receiver. This decreased performance is because the A2 receiver uses two independent receivers to receive the GBT uplink, whereas the A1 receiver switches its reception capability between top and bottom antennas in successive seconds in the ADS-B message portion of the UAT frame.

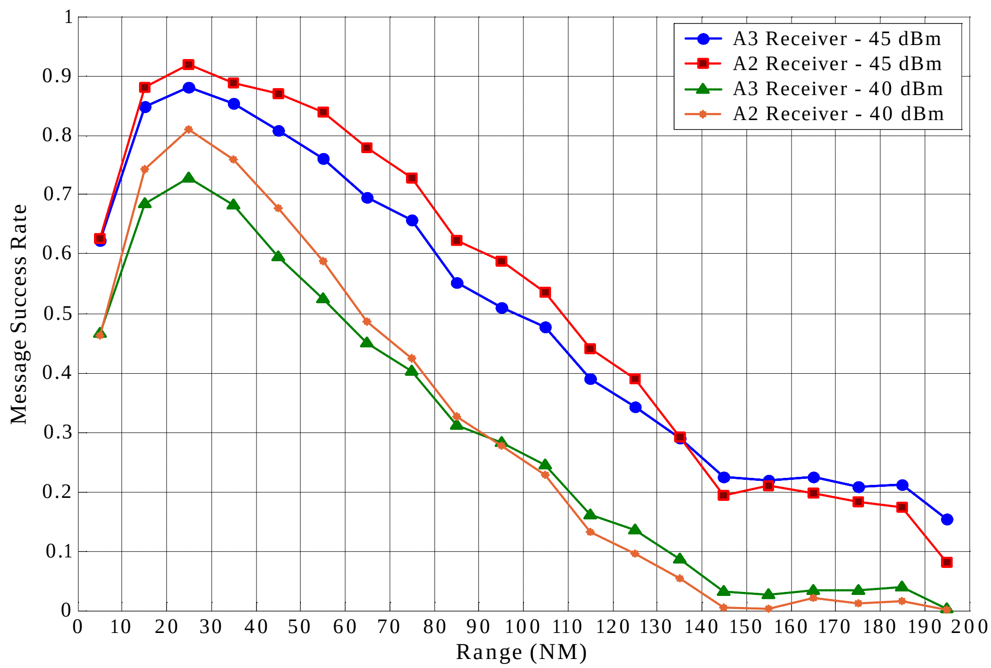

Figure 4 - Message Success Rate as a Function of Range for Receiver at FL400 over worst-case DME position in CE2015, GBT Broadcasting ADS-B Messages at Two Different Power Levels

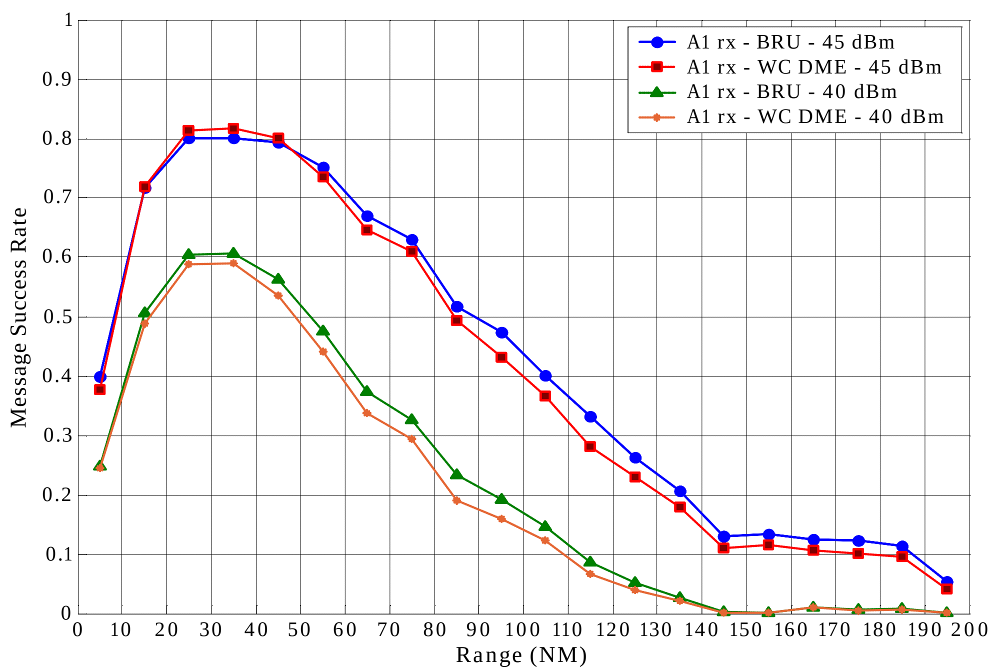

Figure 5 - Message Success Rate as a Function of Range for an A1Receiver at FL400 over both positions in CE2015, GBT Broadcasting ADS-B Messages at Two Different Power Levels

Figure 6 and Figure 7 show the MSR vs. range curves for ground station transmission of ground uplink messages in the ground segment of the UAT frame, for A3 and A2 receivers over Brussels and at the worst-case DME interference location, respectively. Figure 8 shows the performance of A1 receivers in the ground segment at both positions and GBT transmit powers. Since these transmissions are being made in a protected portion of time (no ADS-B aircraft transmissions), the MSR results are better than those shown in Figures 2 and 3. The only sources of interference for these transmissions are co-site, Link 16, and DME/TACANs, but the error correction and interleaving built into the ground uplink message format tends to make it robust to this interference. The curves for A3 equipage (high-end air transport aircraft) in the two locations are quite similar, indicating the robustness against DME/TACAN interference of the receive filter chosen for this equipage class. For the case of both A2 and A1 equipage, both of which use a different receive filter than the A3, the results are worse when the aircraft is located at the worst case DME position.

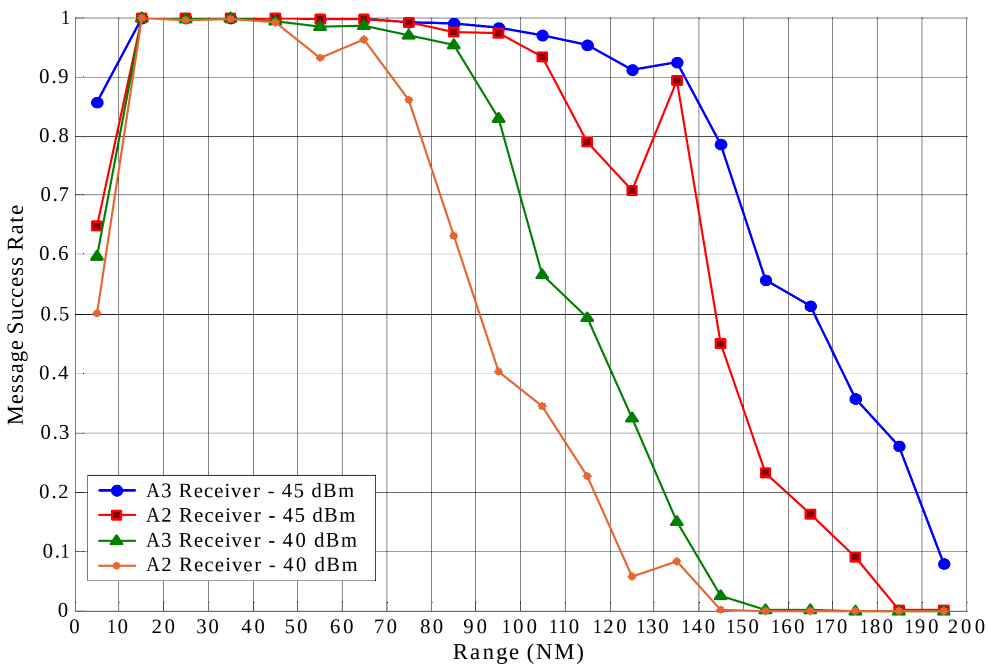

Figure 6 - Message Success Rate as a Function of Range for Receiver at FL400 over Brussels in CE2015, GBT Broadcasting Ground Segment Messages at Two Different Power Levels

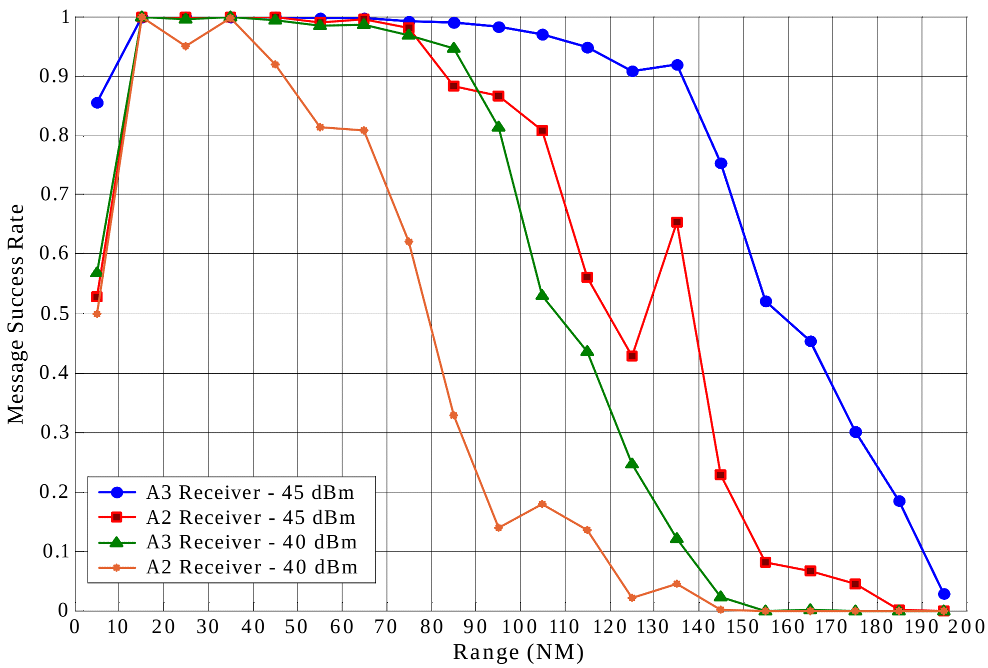

Figure 7 - Message Success Rate as a Function of Range for Receiver at FL400 over worst-case DME position in CE2015, GBT Broadcasting Ground Segment Messages at Two Different Power Levels

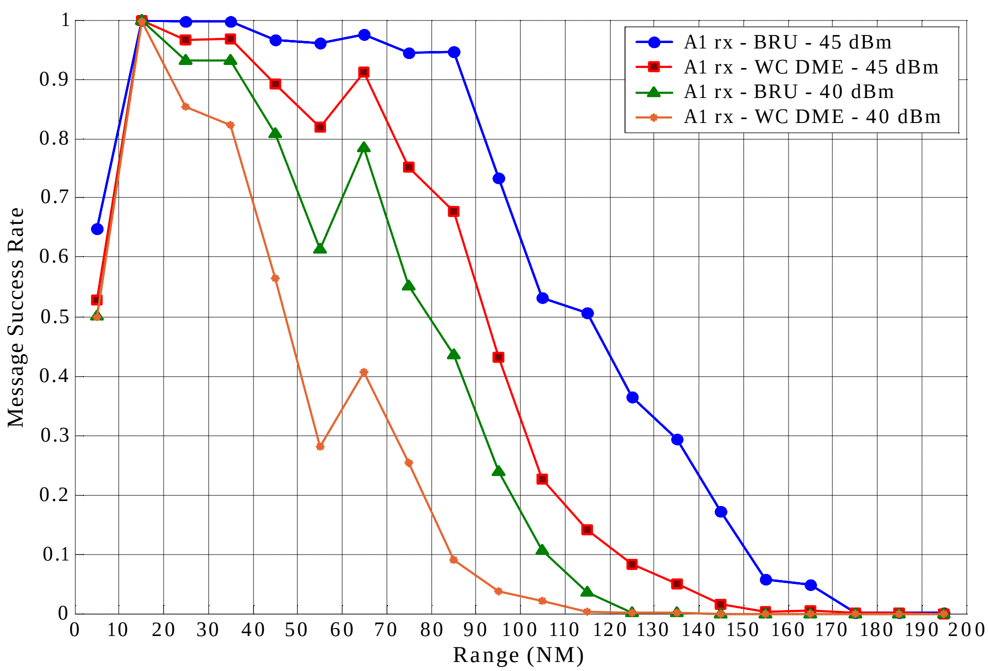

Figure 8 - Message Success Rate as a Function of Range for an A1Receiver at FL400 over both positions in CE2015, GBT Broadcasting Ground Segment Messages at Two Different Power Levels

A comparison of the results in Figures 3-8 is made in Figures 9-13, which compare the various results for the A3 and A2 receivers for different positions, broadcast segments, and GBT transmit powers. Recall that there are two possible locations (over Brussels and worst-case DME), two possible message types (long ADS-B and ground uplink), and two possible GBT transmit powers (45 and 40 dBm). Figure 9 reconfirms that, while the choice of worst-case locations seems to have little effect on ground-air communication success, at ranges less than around 180 NM ground uplink messages are received by A3 equipped aircraft with higher probability than long ADS-B messages. This is most likely due to their being broadcast in a protected portion of the UAT transmission frame.

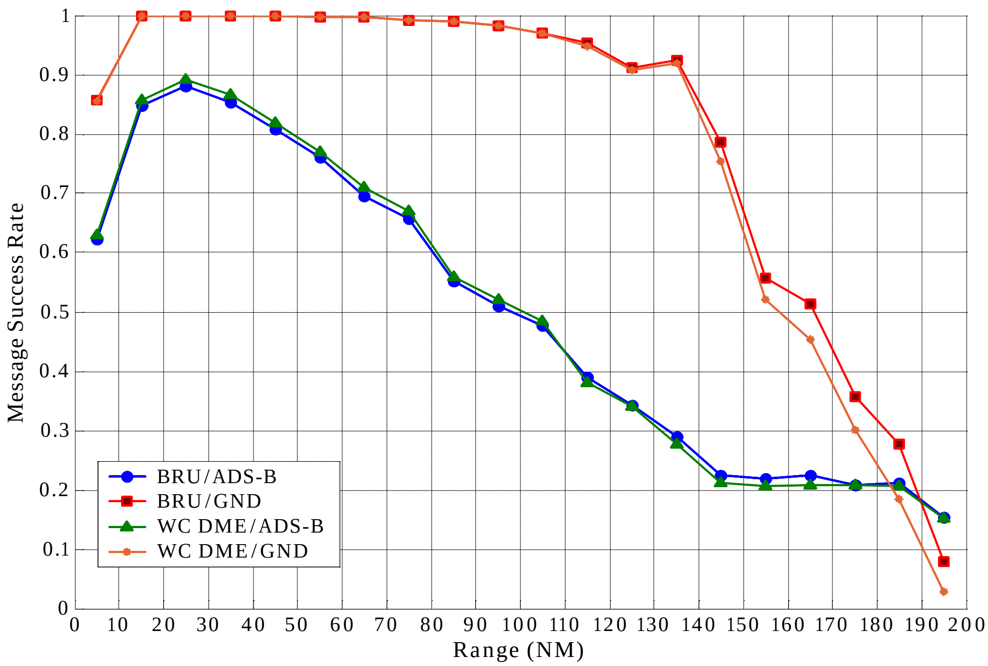

Figure 9 - Message Success Rate as a Function of Range for an A3 Receiver at FL400 in CE2015 for Different Locations Receiving 45 dBm Broadcasts from GBTs in Different Broadcast Segments (same data as Fig. 2-6)

Because the location of the A3 receiver does not seem to have a significant impact on MSR performance, Figure 10 plots the performance for the A3 receiver as a function of uplink segment and GBT transmit power. The trend is the same; ground uplinks generally exhibit a higher MSR than the corresponding ADS-B segment uplinks.

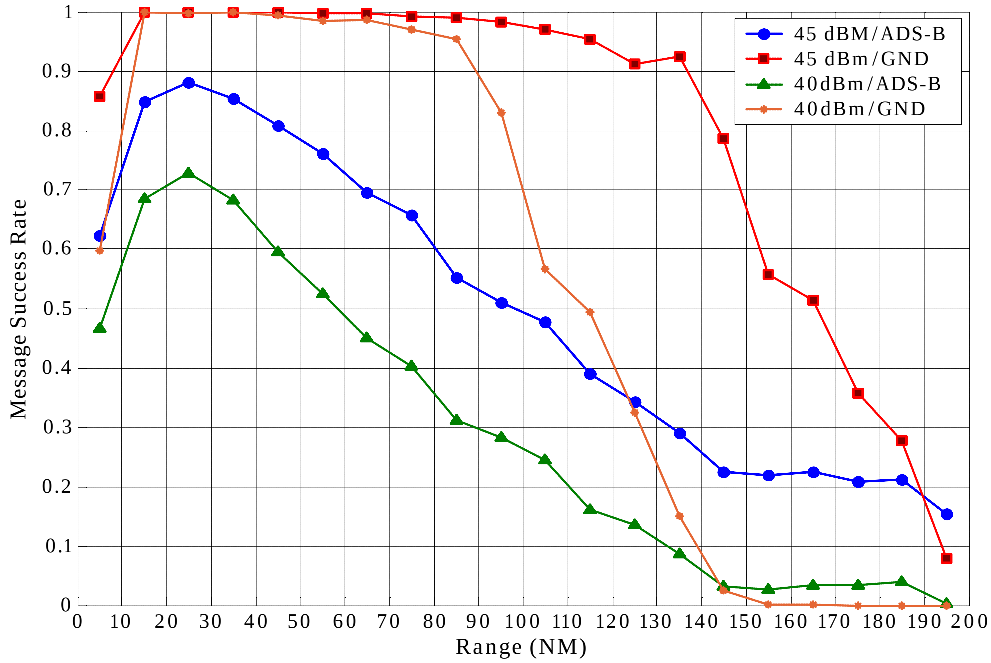

Figure 10 - Message Success Rate as a Function of Range for an A3 Receiver at FL400 over Brussels in CE2015 for Two GBT Transmit Power Levels and Broadcast Segments (same data as Fig. 2-6)

Figure 11 shows the A2 receiver's MSR from messages transmitted by a GBT broadcasting at 45 dBm in both locations and uplink segments. The ADS-B segment performance is almost the same in both locations, as it was for the A3 receiver. However, the MSR for the ground segment is lower in the worst-case DME position than over Brussels. Compared with Figure 9, this shows the filter for the A2 receiver is more vulnerable to DME interference (the dominant limiter in the ground segment). In the ADS-B segment, the performance shown by the A3 and A2 receivers is very similar. Interference from UAT transmissions in this segment tend to reduce MSR values overall and washes out the effect of filter in reducing DME interference.

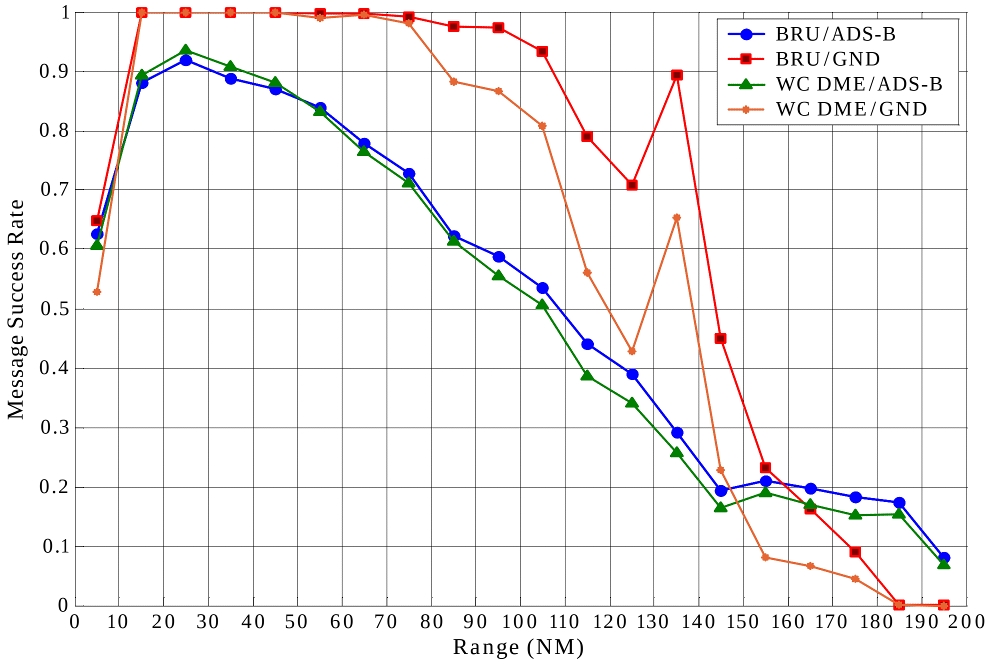

Figure 11 - Message Success Rate as a Function of Range for an A2 Receiver at FL400 in CE2015 for Different Locations Receiving 45 dBm Broadcasts from GBTs in Different Broadcast Segments (same data as Fig. 2-6)

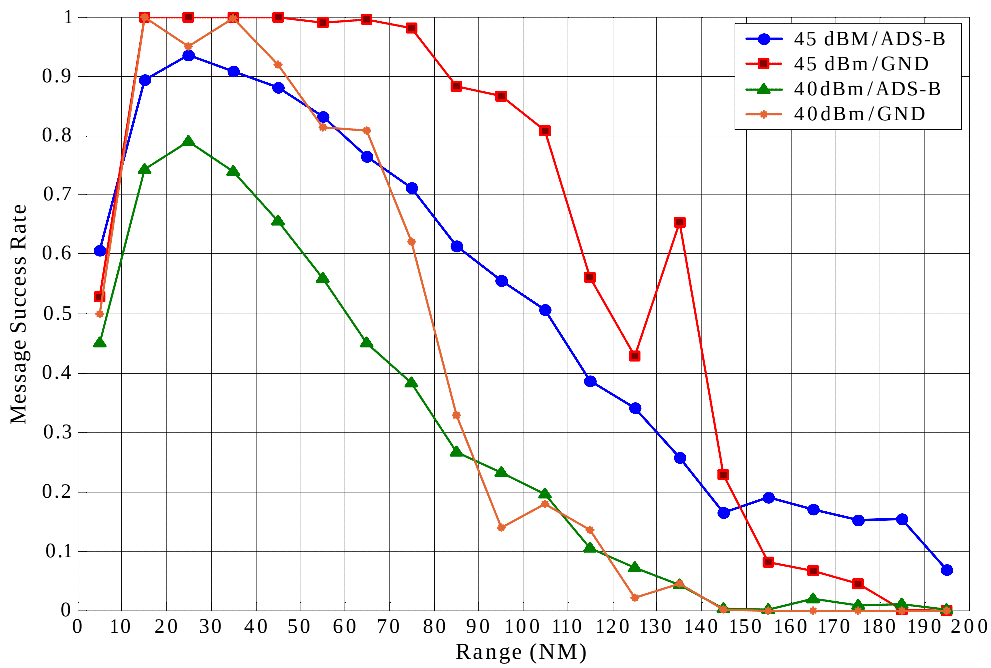

Figure 12 - Message Success Rate as a Function of Range for an A2 Receiver at FL400 over the worst-case DME Position in CE2015 for Two GBT Transmit Power Levels and Broadcast Segments (same data as Fig. 2-6)

As a means of comparing the performance of the GBT transmitters with the airborne transmitters, Figure 13 and Figure 14 below overlay the MSR for an A3 receiver in both Brussels and worst-case DME positions in CE 2015 for both GBT and airborne transmitters. The high power GBT (45 dBm) has an MSR dependence on range very similar to the airborne A3 transmitters. The 40 dBm GBT seems to approximate the midpoint in performance between A2 and A3 transmitters. Recall that the airborne transmit power is randomly selected from a 4 dB range that depends on the equipage. For similar transmitter power levels, GBT transmissions have a relatively higher MSR. It is likely that the assumptions about GBT antenna gain are the reason for this. The GBT uses a TACAN antenna pattern with a boresight gain of 8 dB at about 5 degrees above horizontal. The airborne antennas assume the TLAT antenna gain model. As an example, compare the antenna gains for two transmitters to a receiver 50 NM away at 40,000 feet. The two transmitters are a GBT and an aircraft at 20,000 feet. The GBT has only the TACAN elevation gain, which for this case is 7.5 dB added to the signal. The airborne transmitter has a gain for the top antenna of 1 dB and for the bottom of –1.2 dB, added into an azimuthal component, which averages about 0.5 dB. For cases similar to this with low elevation angles, the antenna gain has little effect on the airborne transmitter, however, the GBT has 6-8 dB antenna gain effectively added to the signal.

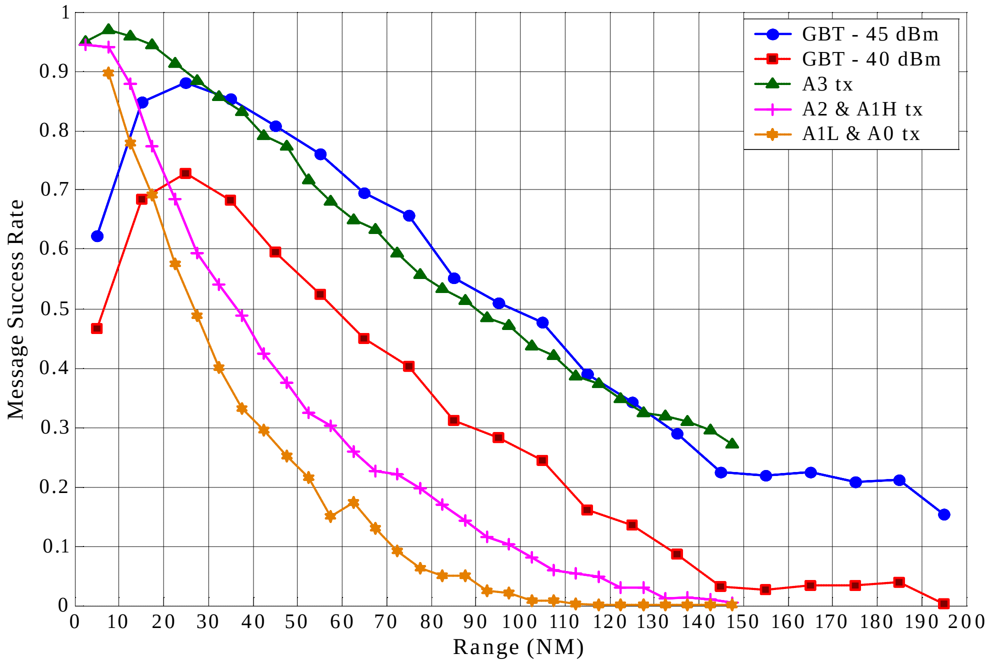

Figure 13 - Comparison of the MSR Rate of the GBT's with the Corresponding Airborne Transmitters for an A3 Receiver at High Altitude over Brussels in CE2015

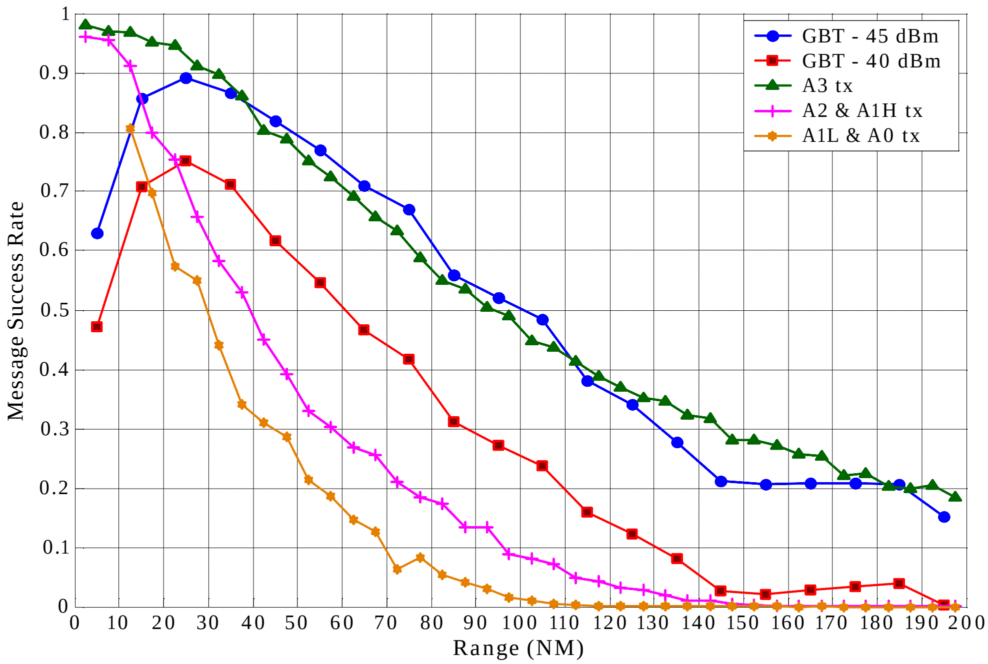

Figure 14 - Comparison of the MSR Rate of the GBT's with the Corresponding Airborne Transmitters for an A3 Receiver at High Altitude over worst-case DME Position in CE2015

Figure 15 shows MSR vs. range for the low-density environment. The only category of aircraft in this high-altitude scenario is the A3, so the results are for an A3 receiver at FL400. Results are shown for both types of ground transmission messages on the same plot. Recall that the GBT transmit power used in the low-density scenario was 36.5 dBm at the antenna.

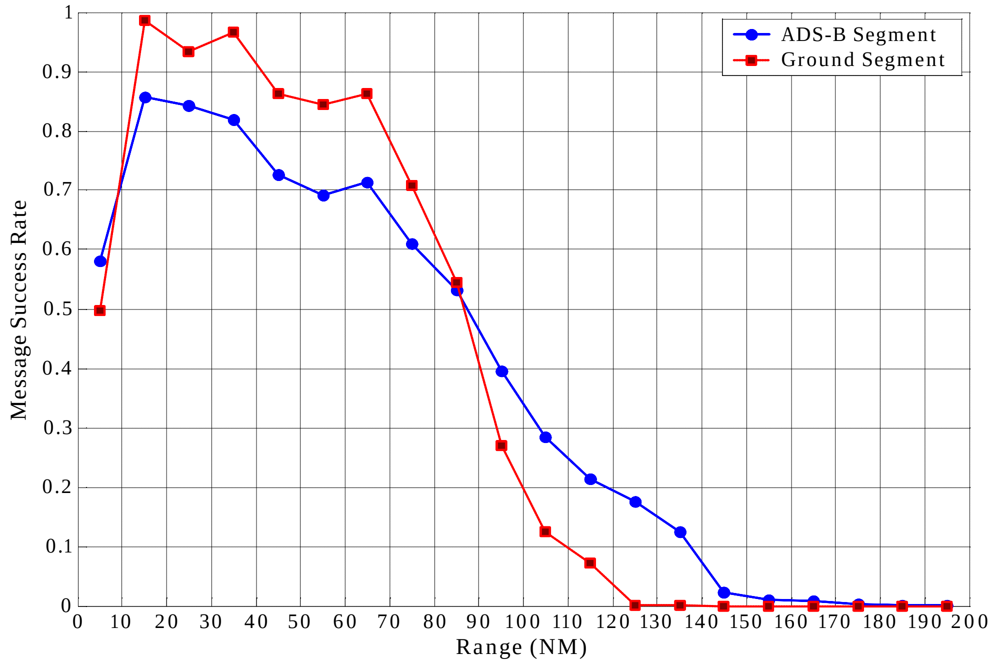

Figure 15 - Message Success Rate as a Function of Range for an A3 Receiver at FL400 in Low Density Environment for ADS-B and Ground GBT Broadcast Segments