

RTCA Special Committee 186, Working Group 5

ADS-B UAT MOPS

Meeting #10

UAT Message Overlap Statistics

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SUMMARY

This paper addresses Action Item 9-10. Issues related to the number of overlapping ADS-B signals that need to be accommodated are discussed. The main finding of the paper is that a receiver that can handle three simultaneous overlapping signals will be able to receive the vast majority of cases. Related test procedures for the MOPS are also discussed.

Introduction

This paper deals with Action Item 9-10, which was to address issues pertaining to the statistics of overlapping ADS-B signals in a multiuser environment. These issues are of interest because they have an impact on receiver design requirements and, hence, on possible MOPS test procedures. The basic question is to determine how many overlapping ADS-B signals a UAT receiver must be able to process. This question is best answered in the context of a hypothetical receiver architecture. The receiver design considered here is shown in Figure 1.

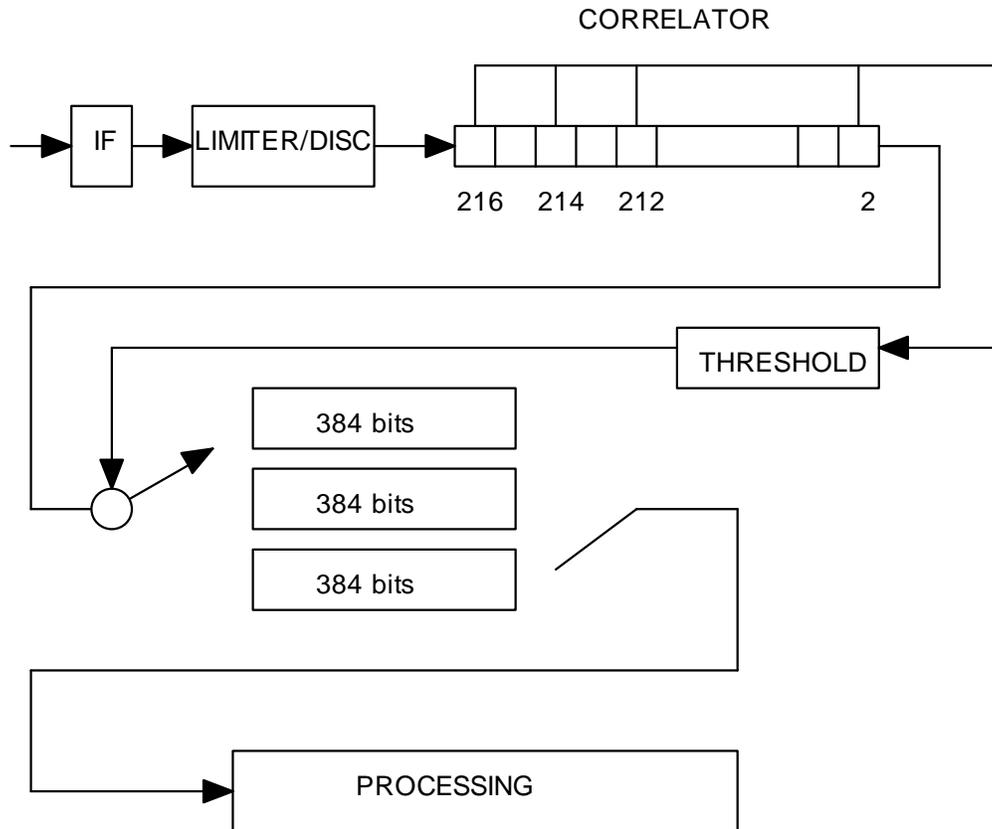


Figure 1. Possible UAT Receiver Architecture

In this design the incoming signal is demodulated into a string of ones and zeroes that is compared to known synchronization sequence in a correlator. A sequences that passes a certain threshold will cause the ensuing bit samples to be placed in one of a number of 384-bit registers. The size of the registers is determined by the size of a long ADS-B message. Such messages are sent as RS(48, 34) code words, so the length of one is just $48 \times 8 = 384$ bits. It is assumed that when one of these registers is filled its contents are immediately passed along to the input queue of a RS decoder and the register is available for another incoming message. Of course, it is possible that the incoming message is a basic ADS-B message whose length is only 240 bits (since it is a RS(30, 18) code word).

The system design is based on the ability of the RS decoder to sort out (with very high probability) which of the two possible types was actually sent. It is also possible that the RS decoder will determine that the message cannot be decoded because there are too many errors or because the whole message was the result of a false alarm.

The question addressed in this paper can be paraphrased as, “How many registers are necessary?” The need for more than one register arises whenever a synchronization occurs while a register is still being filled with bits derived from a previous synchronization. Such a situation could happen for a number of reasons:

1. A new signal which is significantly stronger than the first signal arrives.
2. The signal being demodulated contains a sequence of bits that is sufficiently like the synchronization sequence to pass the threshold (embedded sync).
3. The first signal was a basic ADS-B message, and a new message arrives soon after it is completed.

The receiver has no way of knowing which of these conditions applies in any given situation. If the receiver *did* know it might be able to take some appropriate action which would obviate the need for more than one register. For example, if it were known that case 1 applied, the best course of action would be to replace the old message with the new one. The second case could occur if some of the information in the message “looked like” the synchronization sequence. This similarity might be relatively static (for example, a way point might persist for long periods of time). Thus, if this case applied, the initial message should not be removed. In the third case, the receiver could pass along an abbreviated message with instructions to the RS decoder to attempt only RS(30, 18) decoding. Because the appropriate actions are much different in each case, it is highly desirable to avoid making a choice prior to the RS decoding process.

Statistical Model

This section will describe the model used to derive an upper bound for the number of registers required to provide a given probability of message processing.

A set of scenarios was modeled in which a number (N) of users were assumed to be transmitting ADS-B messages. Although it is expected that some fraction of the messages will actually be basic ADS-B messages, a full complement of long messages was assumed in order to provide a worst-case analysis. From the point of view of any particular receiver, the arrival times of the messages was assumed to be uniformly distributed over the 800 ms portion of each second devoted to ADS-B. The power levels of the messages were chosen randomly from the reverse cumulative distribution shown in Figure 2. This distribution was provided by Larry Bachman of JHUAPL during the spring of 2001 and was based on the UAT deployment assumptions being used at the time. The markers represent the APL data, and the line is based on the equation that was used in the model:

$$P(x) = \exp(-0.0046 (x + 104.7)^2) \quad (1)$$

for $x \geq -104.7$. $P(x) = 1$ for $x < -104.7$. In this equation, x is measured in units of dBm. The results of this paper are *not* very sensitive to the exact form of the distribution.

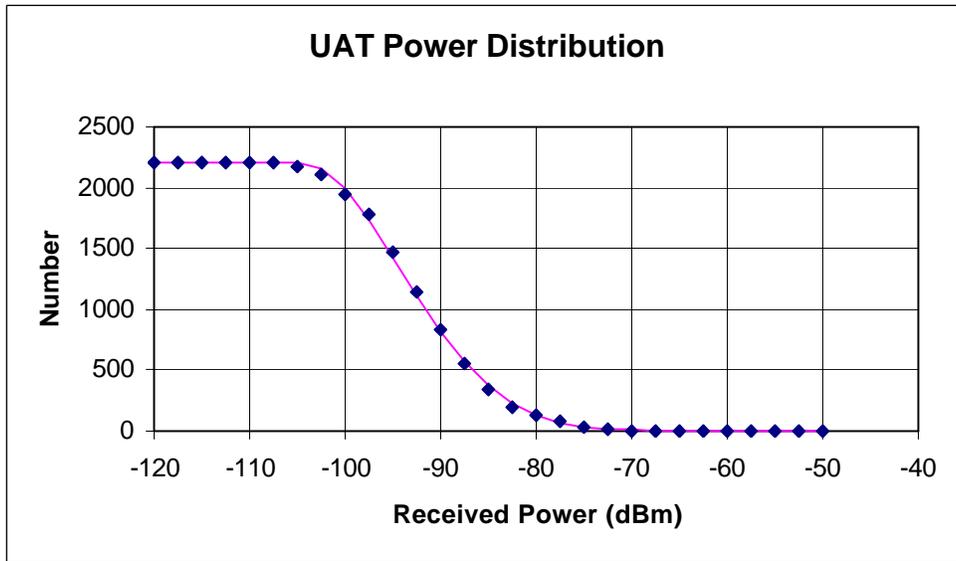


Figure 2. UAT Received Power Distribution (for 2200 users)

A very simplified version of the model assumes that the synchronization portion of each message always succeeds and every message needs to be placed in one register or another. The register requirements would then depend on the arrival sequence of the messages. A number of possibilities are shown in Figure 3.

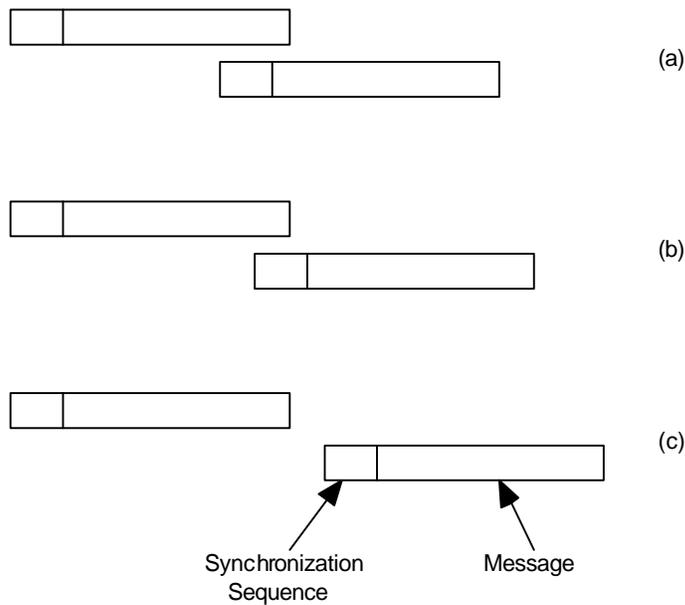


Figure 3. Message Overlap Possibilities

In case (a) of Figure 3, the message portions of two bursts are coincident in time, and they require separate registers. If an additional register is not available, the second message is dropped. In case (b), the message portion of one burst overlaps the synchronization portion of another; thus, they can each use the same register. In case (c), the bursts are entirely separate, and one register will clearly suffice.

In this simplified case the probability of requiring a certain number of registers can be calculated by noting that one message can take precedence over another if it precedes it by a number of bits periods between 1 and 384. If there are N users competing with a given burst, the average number of preceding users is given by

$$I = 384 \times N / 833334 \quad (2)$$

where 833334 is the number of bit periods in 0.8 seconds. The probability of requiring n registers is given by a Poisson distribution, i.e.,

$$P(n) = e^{-I} I^{n-1} / (n-1)! \quad n \geq 1. \quad (3)$$

This theory was compared to the computer simulation and found to be in complete agreement.

In the real world the probabilities will be altered because many of the overlapped signals will not synchronize. For example, many times the second signals in Figures 3(a) and 3(b) will not synchronize because of interference from the first signal. It is necessary to have a model of synchronization performance to account for these effects. The simplified model of synchronization performance used in the simulation is as follows:

1. If the desired signal power is greater than the power of any individual interferer overlapping the synchronization sequence, then the synchronization will succeed.
2. If the desired signal power is less than the power of any interferer overlapping its synchronization sequence, then the synchronization will fail if and only if at least 16 bits of the synchronization sequence are overlapped. [The number 16 relates to a synchronization threshold value of 84 (out of a possible 108). When there are 16 bits overlapped by a strong signal (producing a 50% BER), the average synchronization score is $3 \times 20 + 3 \times 16 / 2 = 84$.]

These criteria overestimate the probability of synchronization. The criteria fail to properly take into account cases where there are multiple interferers. Also, criterion 1 is clearly optimistic even when there is only one interferer. Overestimating the synchronization probability will once again tend to overbound the number of registers required.

With these rules in place, the number of registers required to accommodate all potential messages can be determined by simulation. The results for various values of N are plotted in Figures 4 through 11 as the curves labeled "real." These show the average

number of messages per second that require the specified number of registers. For comparison, the results of equation (3) are shown as the curves labeled “ideal.”

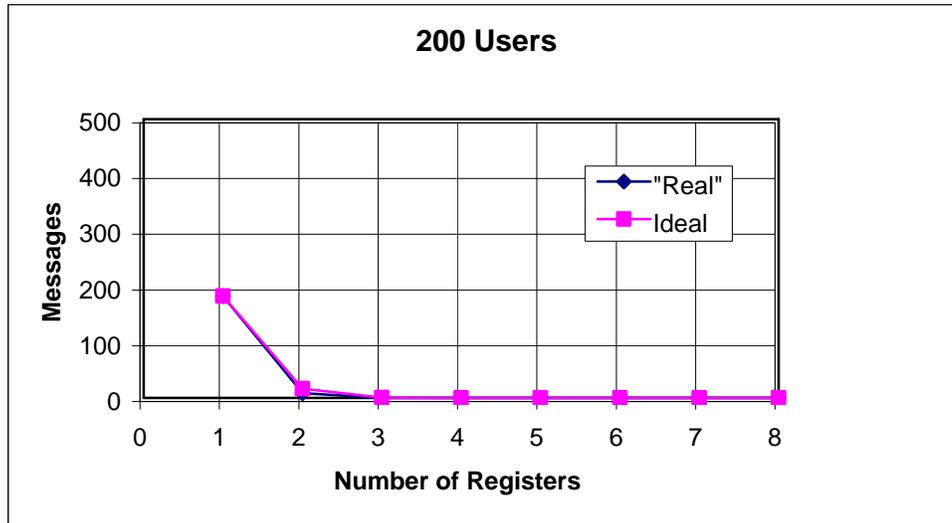


Figure 4. Simulation Results for 200 Aircraft

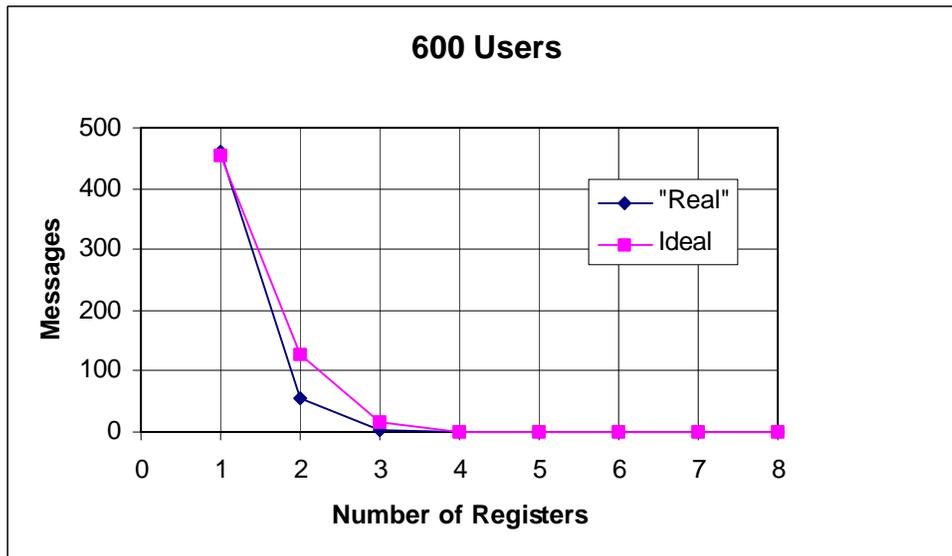


Figure 5. Simulation Results for 600 Aircraft

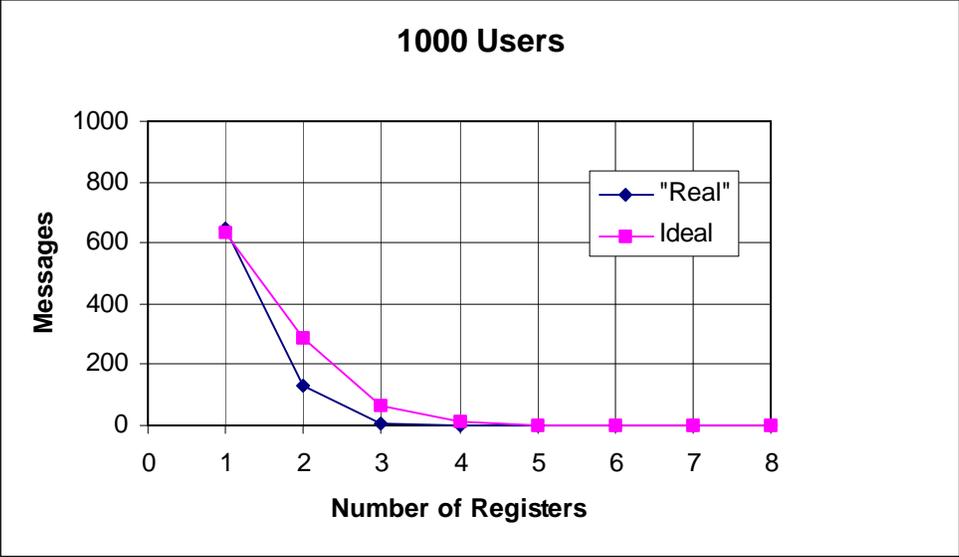


Figure 6. Simulation Results for 1000 Aircraft

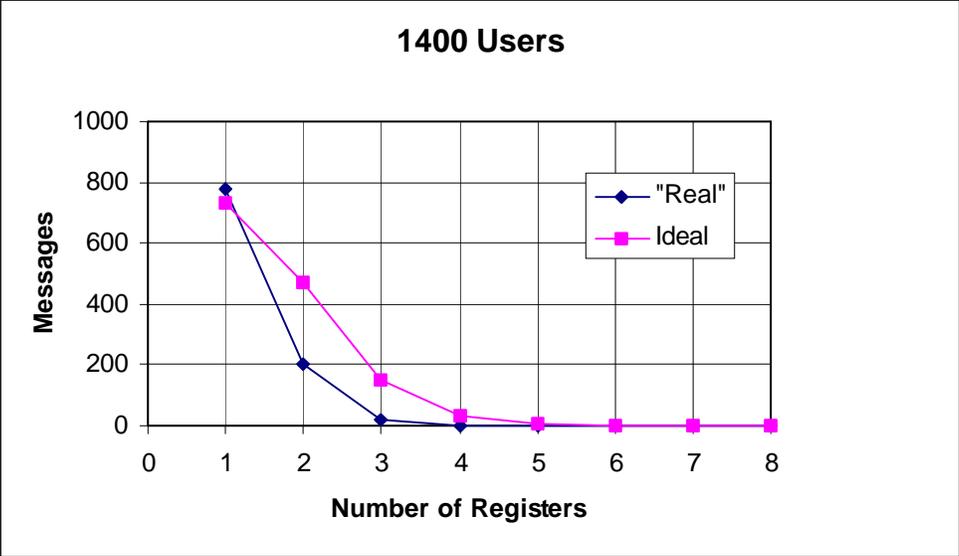


Figure 7. Simulation Results for 1400 Aircraft

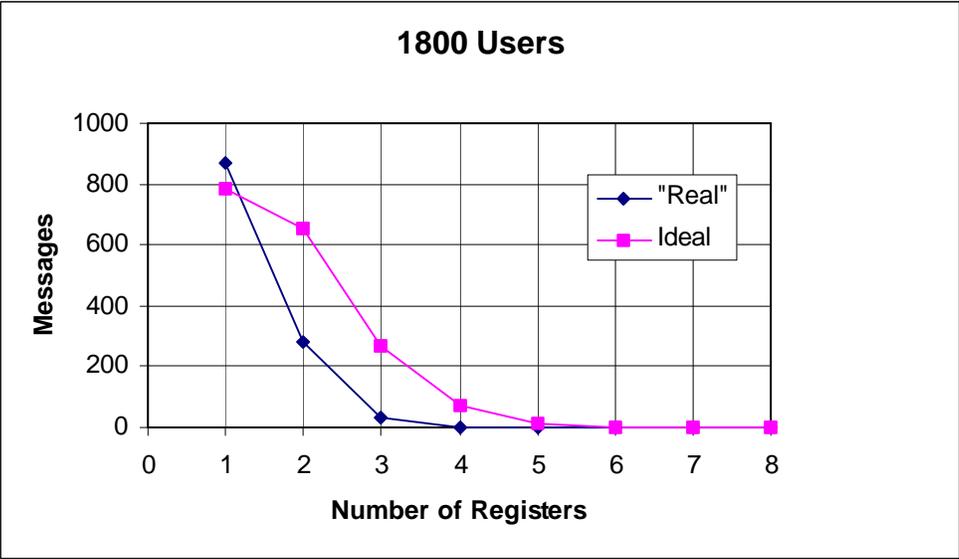


Figure 8. Simulation Results for 1800 Aircraft

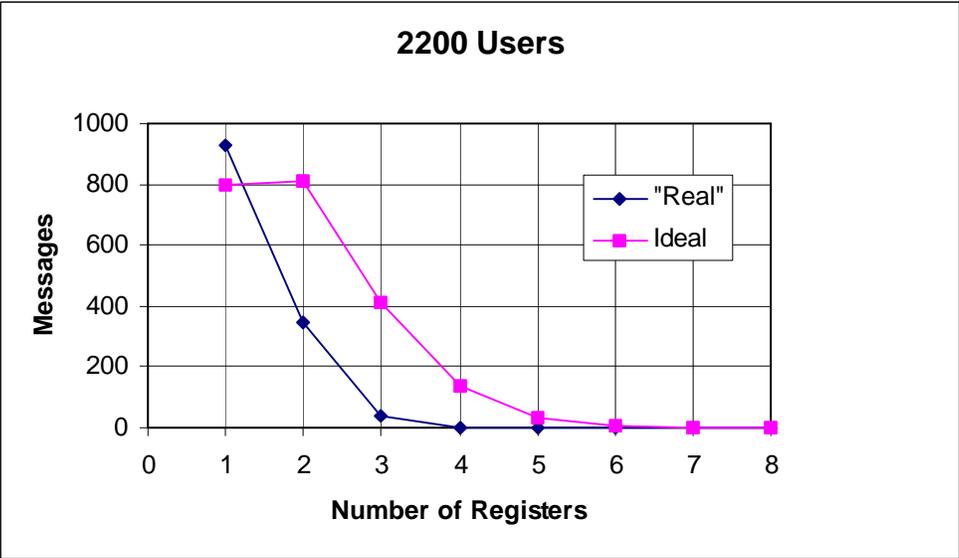


Figure 9. Simulation Results for 2200 Aircraft

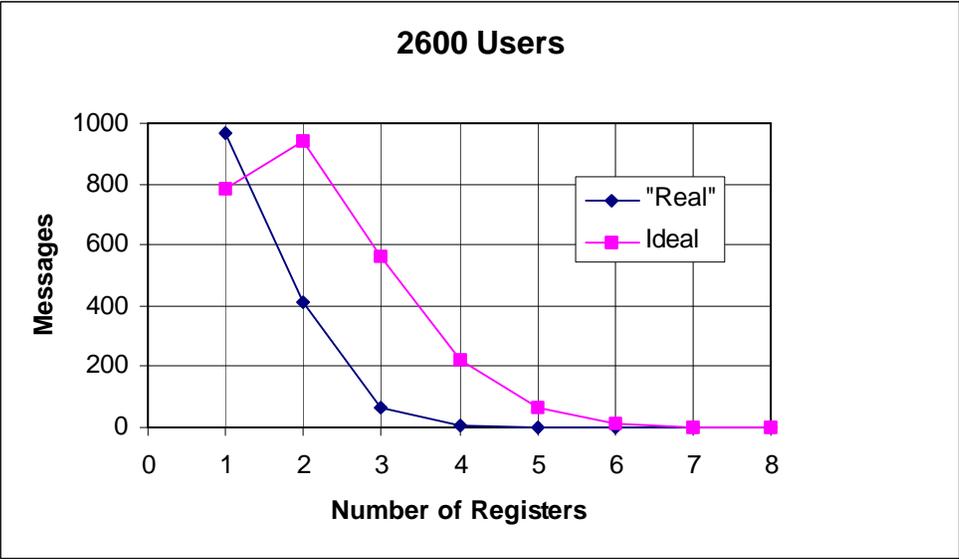


Figure 10. Simulation Results for 2600 Aircraft

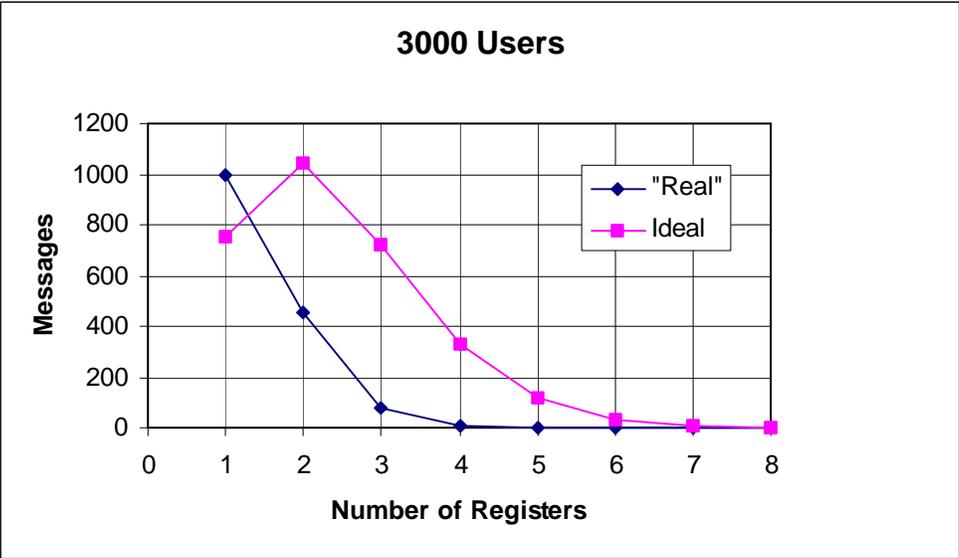


Figure 11. Simulation Results for 3000 Aircraft

Discussion

There are various trends that can be seen in the graphs. For instance, as the number (N) of users increases, the fraction of the messages that actually synchronize decreases. The number of successful synchronizations versus N is plotted in Figure 12. This is evidence that the system is beginning to saturate. These graphs do not, however, take into account the messages that successfully synchronize but do not survive the error correction process. That information is irrelevant to this discussion because it has no impact on the number of registers used.

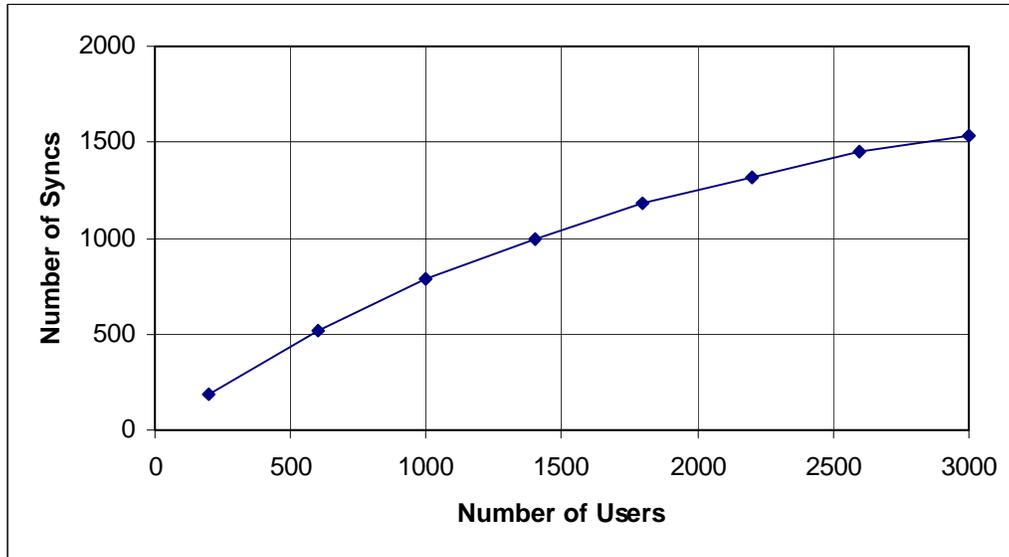


Figure 12. Overall Synchronization Performance

A second trend that can be seen in the results is that the “real” distributions tend to be much more peaked at the value 1 than the ideal curves. This happens because the signals with multiple overlaps are the ones most likely to be pruned due to synchronization failures. More realistic models of synchronization performance would probably result in distributions with even more peaking. It is interesting to note that as the number of users increases the shapes of the “real” distributions become very similar.

The most important issue for this paper is the fraction of potentially successful messages that are rejected if the number of registers is limited. In Figure 13, this fraction is plotted versus N , assuming 1, 2, or 3 registers are available. The curves tend to flatten out as the number of users increases. This seems to be due to the fact that the shapes of the curves become similar as N increases. (The irregularities in the curves are related to the limited number of cases studied. These curves are based on simulations of 10 seconds’ worth of UAT transmissions.) For $N = 2200$, which is the number used for the LA 2020 scenario, the values are 0.30 for one register, 0.034 for two registers, and 0.0022 for three registers. The use of three registers reduces the probability of rejection to a negligible level.

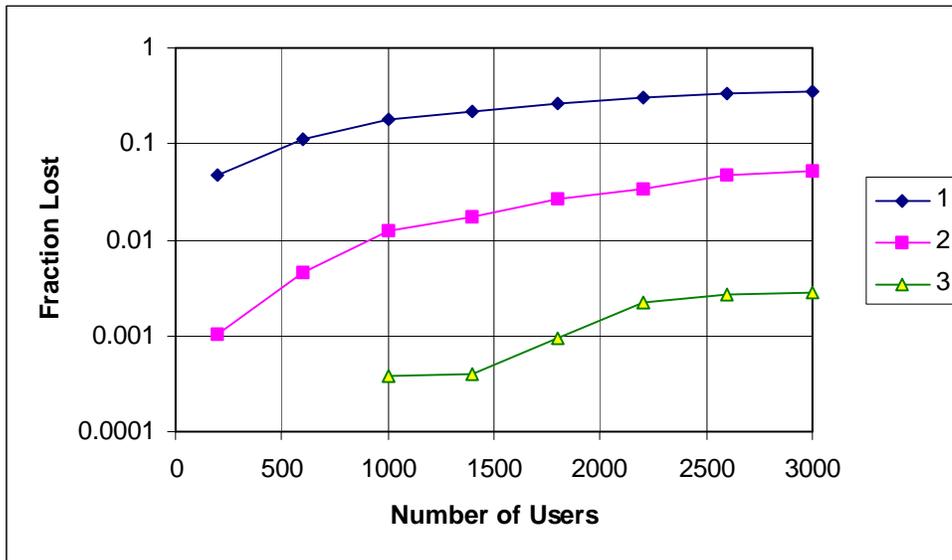


Figure 13. Fraction of Rejected Messages
(Parameter is the Number of Registers)

Effect of Up Link Messages

In normal the operation of the UAT system, the ADS-B bursts and the up link bursts are supposed to be transmitted in different time intervals separated by relatively large guard times. Nevertheless, there is a system requirement to continually search for both types of messages simultaneously. If that is the case, then there is some possibility that a receiver can “synchronize” with an up link message during the time usually reserved for ADS-B messages. This could happen due a false alarm or because something close to the up link synchronization sequence is embedded in an actual ADS-B message. Either way, the potential up link message will occupy some receiver resources that would otherwise be available for ADS-B.

Suppose, for example, that at least one of the registers shown in Figure 1 is actually 4416 bits in length instead of 384. Such a register is just long enough to contain an entire up link message ($4416 = 6 \times 8 \times 92$). Whenever there is an up link synchronization detected the message is placed in such a register, which is then not available for duty receiving ADS-B information. Thus, if the total number of registers is 3, then the effective number available for ADS-B is reduced to 2 for as long as it takes to fill the long memory. If the up link threshold is set at a value that yields about 1 false alarm or embedded synchronization per second, then the average fraction of time spent on extraneous up link message processing is $4416/833334 = 0.0053$. This can be converted into a revised estimate of the probability of rejecting an ADS-B message. For $N=2200$ and a total of three registers, the revised probability is $0.0053 \times 0.034 + 0.9947 \times 0.0022 = 0.0024$. In other words, the effects of false up link synchronization phenomena appear to be negligible if the false alarm rate is reasonably small.

Test Procedures

It is desirable to have in the MOPS a simple set of test procedures that will ensure that the overlap requirements are met. The following procedures are suggested.

For these tests, it is assumed that a special ADS-B test burst (TB) can be generated. The test burst will be the length of a long ADS-B message and will contain as part of its data stream a valid ADS-B synchronization sequence starting at approximately 200 bits after the end of the actual synchronization sequence.

In all the tests, there will be 4 partially overlapping test bursts (TB1 through TB4), separated by 150 microseconds provided to the receiver under test. The timing is shown in Figure 14. The powers of these signals will be manipulated to generate different results.

Test 1. Power of TB1 and TB4 at -50 dBm. Power of TB2 and TB3 at -65 dBm. TB1 and TB4 should be successful. TB2 and TB3 should not.

Test 2. Power of TB1, TB3, and TB4 at -65 dBm. Power of TB2 at -50 dBm. TB2 should be successful. TB1, TB3, and TB4 should not.

Test 3. Power of TB1, TB2, and TB4 at -65 dBm. Power of TB3 at -50 dBm. TB3 should be successful. TB1, TB2, and TB4 should not.

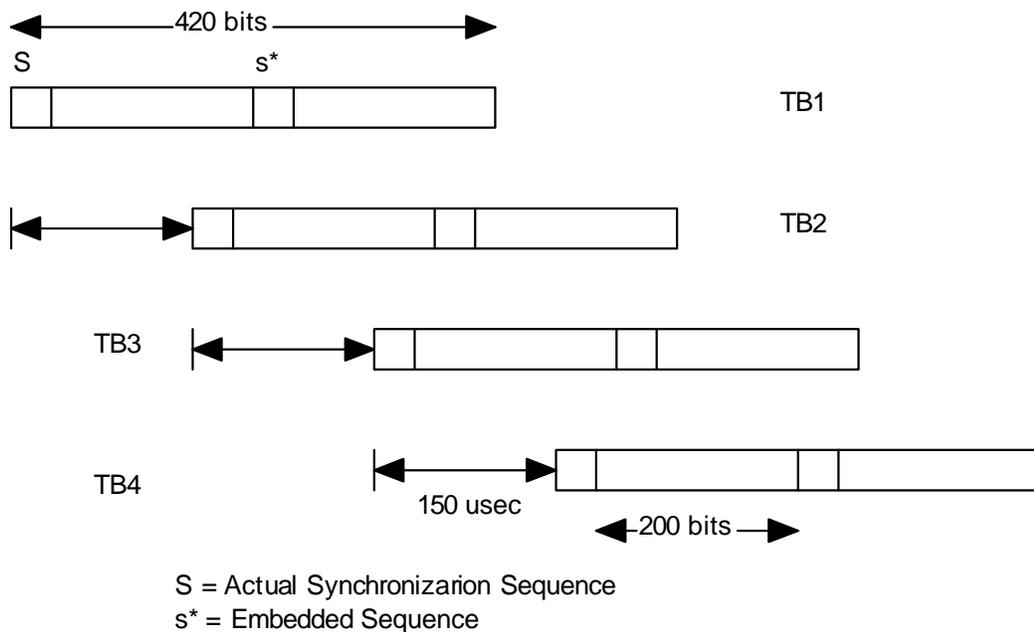


Figure 14. Timing of Test Signals

Summary

Performance has been simulated using a simplified system performance model based on using a separate memory register to process each incoming message. (This is not meant to imply that an actual UAT implementation needs to be designed this way.) When the number of messages being received exceeds the number of registers, new messages are dropped. Using this rule, it appears that ability to handle three overlapped signals will cover almost all cases.

Test procedures designed to cover the appropriate overlap cases have been suggested.