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SENSITIVITY ANALYSIS OF DATA LINK ALTERNATIVES FOR LVLASO

By
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FINAL REPORT

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Abstract

In this report, we summarize the results from our research conducted under grant NAG-1-1853. As part of this research, we have modeled the Mode-S system when used to enhance communications among several ground vehicles to facilitate low-visibility landing and surface operations. The model has then been simulated using Bones Designer software. The effectiveness of the model has been evaluated under several conditions: (i) different number of vehicles (100, 200, and 300), (ii) different distributions of interarrival times for squitters: uniform, exponential, and constrained exponential, and (iii) Different safe distances (for collision purpose): squitter length, 1.5*squitter length, and 2* squitter length. The model has been developed in a modular fashion to facilitate any future modifications. The results from the simulations suggest that the Mode S system is indeed capable of functioning satisfactorily even when covering up to 300 vehicles. Certainly, about 10 percent of the squitters undergo collisions and hence the interarrival times for these is much larger than the expected time of 500 msec. In fact, the delay could be as much as 2 seconds. The model could be further enhanced to incorporate more realistic scenarios.

1 Introduction

Low-visibility Landing and Operations System (LVLASO) is currently being prototyped and tested at NASA Langley Research Center. Since the main objective of the system is to maintain the aircraft landing and take-offs even during low-visibility conditions, timely exchange of information between the aircraft and the ground control becomes critical. For safety and reliability reasons, there are several information sources on the ground (e.g., ASDE, AMASS) that collect and disseminate information about the environment to the aircrafts. The data link subsystem of LVLASO is responsible for supporting the timely transfer of information between the aircrafts and the ground controls (and detectors). In fact, if not properly designed, the data link subsystem could become a bottleneck in the proper functioning of LVLASO. Currently, the other components of LVLASO are being designed assuming that the data link has adequate capacity and is capable of delivering the information in a timely fashion.

During August 1-28, 1997, several flight experiments were conducted to test the prototypes of subsystems developed under LVLASO project. The test reults from this experiment were analyzed and documented by us under a different grant (NAG-1-2102).

Under the current grant (NAG-1-1853), we have developed a prototype to simulate the ground traffic at an airport using BoNeS DESIGNER software. This system simulates the load generated from each vehicle and measures the rates of collisions. In particular, it measures the interarrival times of successfully transmitted squitters at the receiver.

This report is organized as follows. In Section 2, we briefly summarize the features of the BoNeS Designer software that we used for simulation. In Section 3, we describe the model that we developed for the Mode S system. In Section 4, we describe the input parameters and the output from an example run. In Section 5, the results from other simulation runs are explained. Finally, Section 6 summarizes the observations.

2 BoNeS Designer Software Tool

BONeS DESIGNER is an integrated software package for modeling and simulating event driven data transfer systems. It can be used for simulation-based design and analysis of a broad range of applications. It provides a graphical environment for modeling a system's structure and function.

The software consists of several modules and optional products. The Data Structure Editor (DSE) is used to specify, edit, document, and store data structures for a model. The DSE supports both encapsulation and inheritance.

The Block Diagram Editor (BDE) is used to create, edit, document, and store graphical models of a system. The simulation manager is used to specify execution parameters, place data collection probes, automatically generate discrete-event simulations of the system model, control simulation execution, and store simulation results. The Post Processor is used to analyze the simulation results, compute statistical and performance measures, and display results in graphical plots.

One of the key features of BoNeS is the number generator module. It can generate random numbers drawn from several distributions: uniform, binomial, poisson, exponential, gamma, geometric, normal, integer uniform, integer empirical, and real empirical. For each distribution, we may specify a number of parameters to control the distribution. For example, for the exponential generator, we specify the mean value and the seed. For uniform generator, we specify the lower and upper bounds of the range and the seed value.

The probes is another interesting feature of this software. Probes can be used to compute such statistical measures as delays, throughput, utilization, and histograms. There are 23 probe modules in the system. In our work, we used the histogram probe. For this probe, we specify the lower and upper boundary values, and the number of bins. The range is then equally divided among the range.

Another useful feature of the system is the execute-in-order modules. This module is used to order the execution of modules in a block diagram. First, the path along the First Out output is executed as far as possible, and then path along the Second Out output is executed. The First Out and Second Out are simply copies of the input. There are also modules that three and four outputs. In our model, we have used up to three outputs.

For more information regarding the features of this software, readers may refer to the User reference manual of the BoNeS Designer. The Alta Group can also be contacted at (800) 9-BONES-7 or at bones-support@lks.csi.com.

3 Model

The main objective of the simulation was to investigate if the Mode S datalink system can be effectively used for updating the positional and other information using short and extended squitters.

The modeling and simulation tool used is BONeS Designer. (For more information, contact Alta Group at 415-574-5800. Also, 1-800-9-Bones-7 for customer support.)

First, we model one vehicle (Single Vehicle). Then, we build a module that can have 100 of these, say 100Veh module. Then, by building another module with multiple copies of 100Veh, we can have a module with as many vehicles as we want (in multiples of 100).

Here, we describe different components of our model. Since it is a hierarchic model, we describe the components first, and then the higher level modules.

3.1 Single Vehicle

In our scenario, a single vehicle is a simple squitter generator. A squitter is generated based on the specified distribution of interval times. According to the chosen distribution, the generator would have specific parameters associated with it. For example, for uniform distribution we specify the lower and upper limits of the uniform range. For an exponential distribution generator, we provide the mean value. In addition, we also specify the random seed for the generator, the traffic stop time (i.e., when the generation should be halted), and the length of the squitter. In addition, for each vehicle a relative order number is assigned. This is necessary whenever more than one vehicle is ready to generate a squitter at any given time and the simulator needs to choose one event at a time to carry out.

In addition to the squitter generator, the single vehicle has a "transmit squitter" block. This block inserts the time of generation and a vehicle ID into each of the squitters. Each vehicle is assigned a unique identifier to identify the source of each squitter. The communication between a single vehicle and the rest of the system is achieved through shared memory, referred to as "Transmit memory."

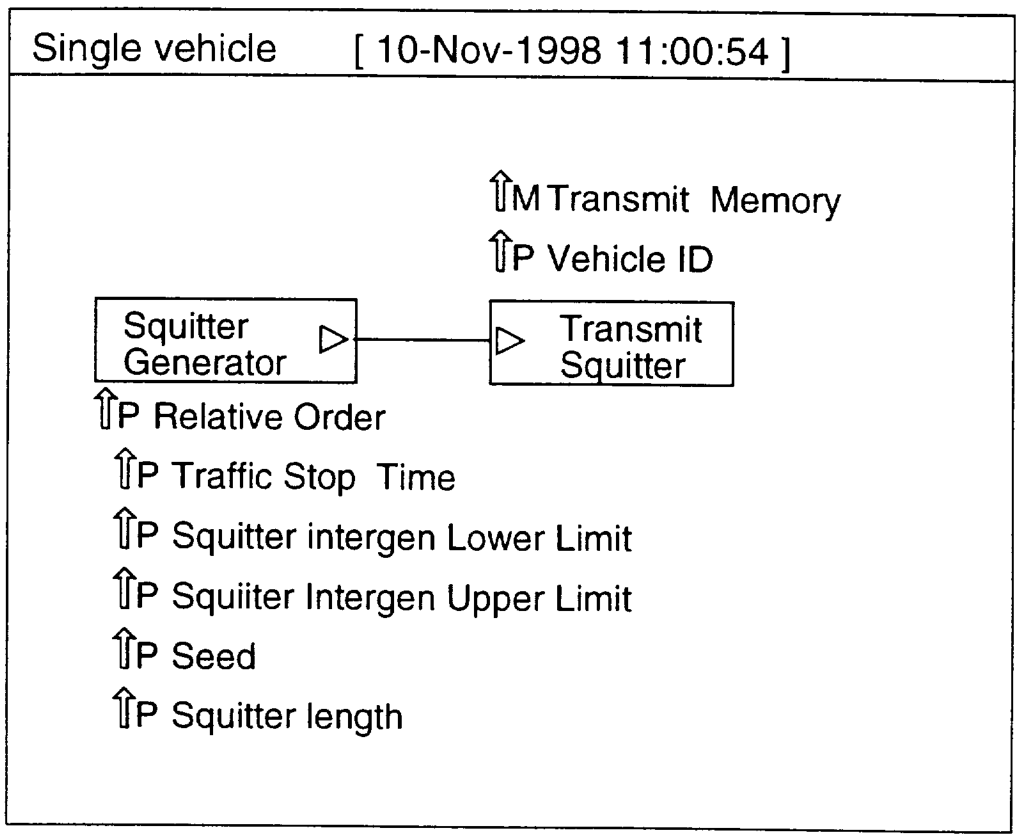

Figure 1: Single Vehicle Model

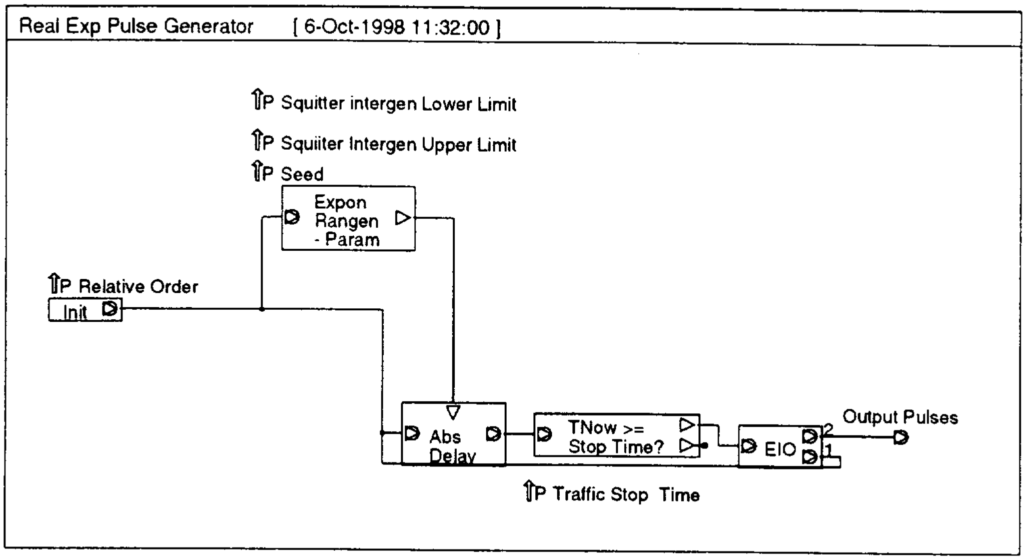

Figure 2: Exponential Distribution – Squitter Generator

3.2 100Vehicles

Using the single vehicle module, we now construct a module containing 100 replicas of the single vehicle. The relative order field of each of the 100 is set so that they are unique. Similarly the vehicle ID field of the single vehicle modules are set. Since we need to assign a unique vehicle ID to each of the single vehicles, we define modules as "First100vehicles", "Second100vehicles," and "Third100vehicles" to build a model with 300 vehicles. The vehicles are numbered from 0-299 respectively.

3.3 300Ground

This module simulates the 300 ground vehicles. It includes the three modules "First100vehicles", "Second100vehicles," and "Third100vehicles" described above.

3.4 Multipath Effect

This is optionally introduced into the model by generating a random number (between 0 and 1) and checking whether are not it is less than

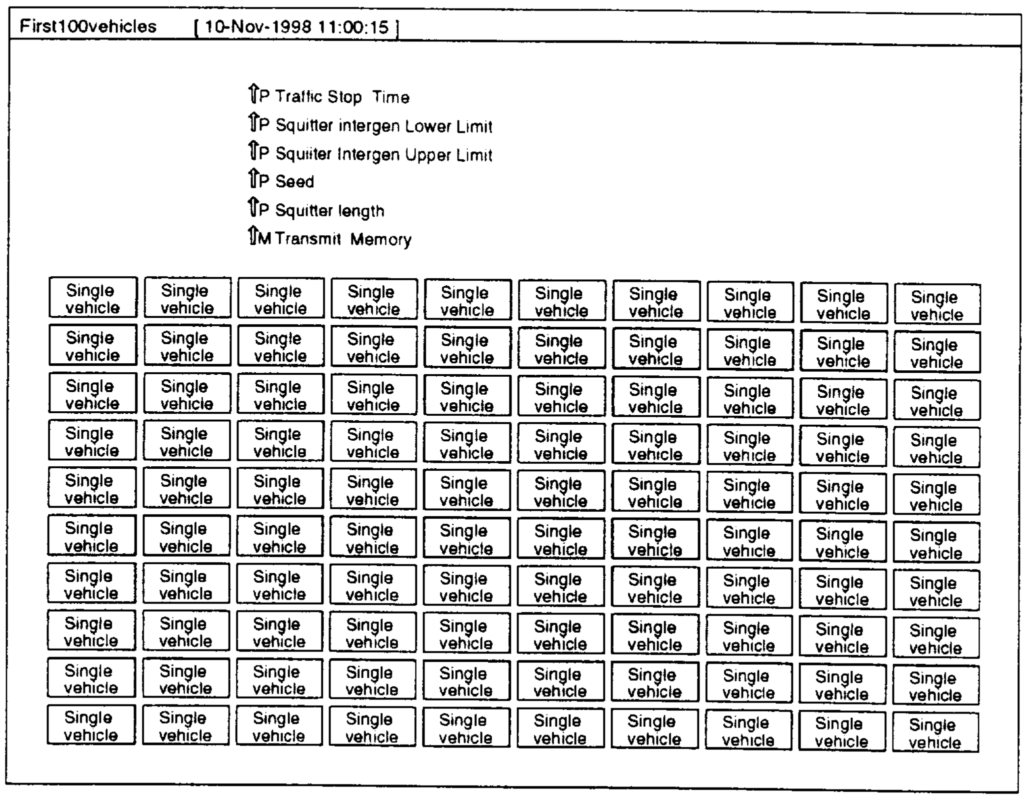

Figure 3: 100 Vehicle Model

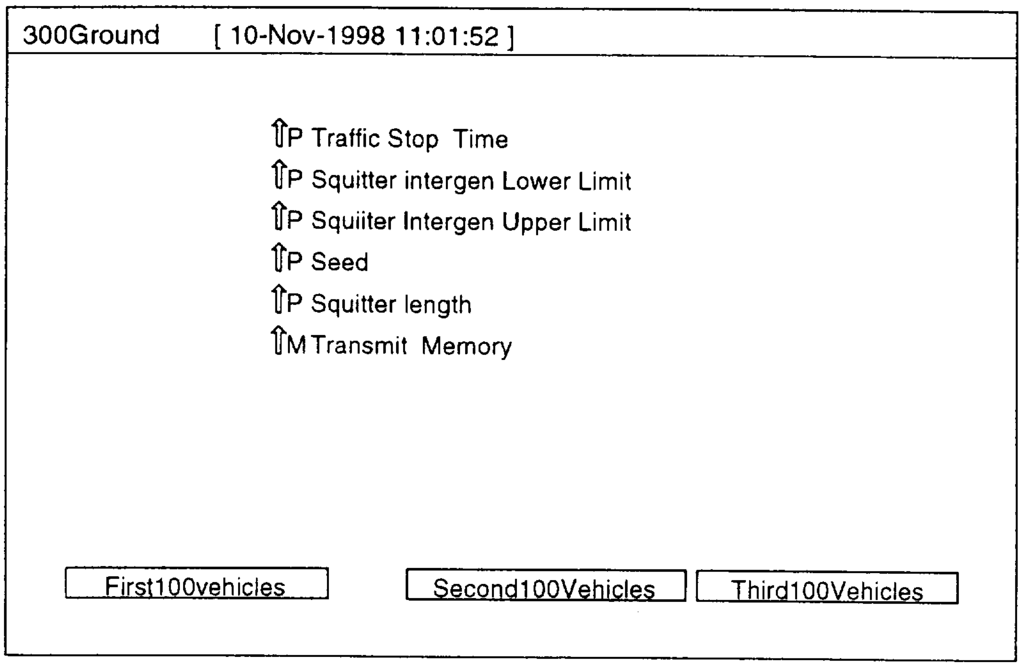

Figure 4: 300 Vehicle Model

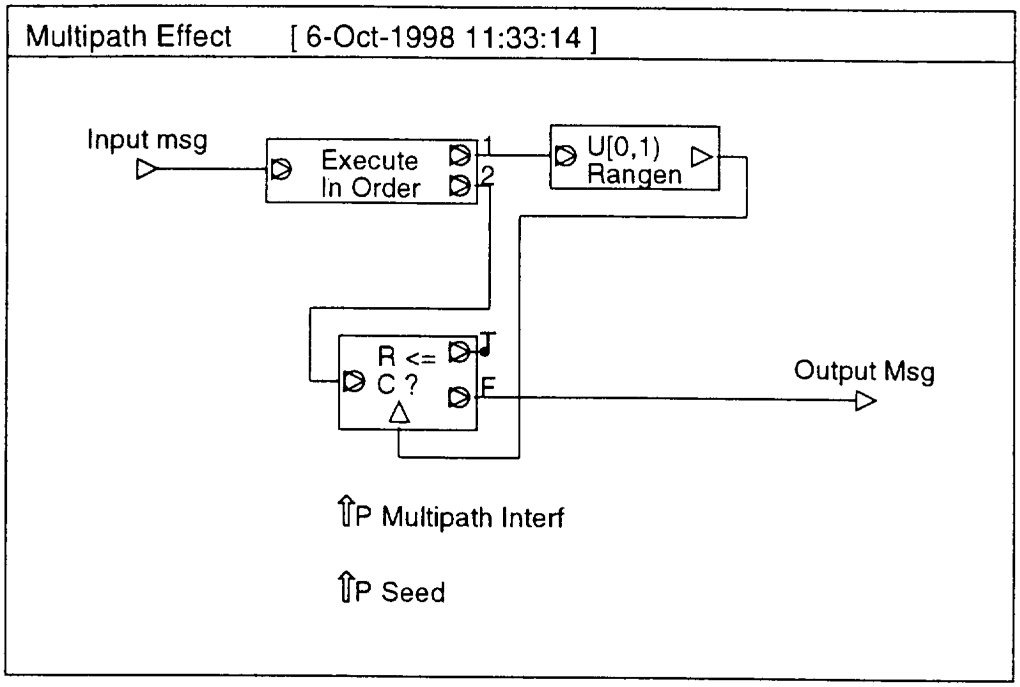

Figure 5: Multipath Effect Module

a prefixed value. If so, we assume that there was no multipath effect. Else, the packet is assumed to have had the effect and hence discarded.

3.5 BitErrorCheck

This module is similar to the above multipath effect module. We generate a random number (between 0 and 1), and decide whether or not the received squitter message has been subjected to bit errors. If so, the packet is discarded. Else, it is forwarded to the next stage.

3.6 InterSuccessTime

This module computes the interarrival times for successfully received squitters from the selected source at the receiver (antenna).

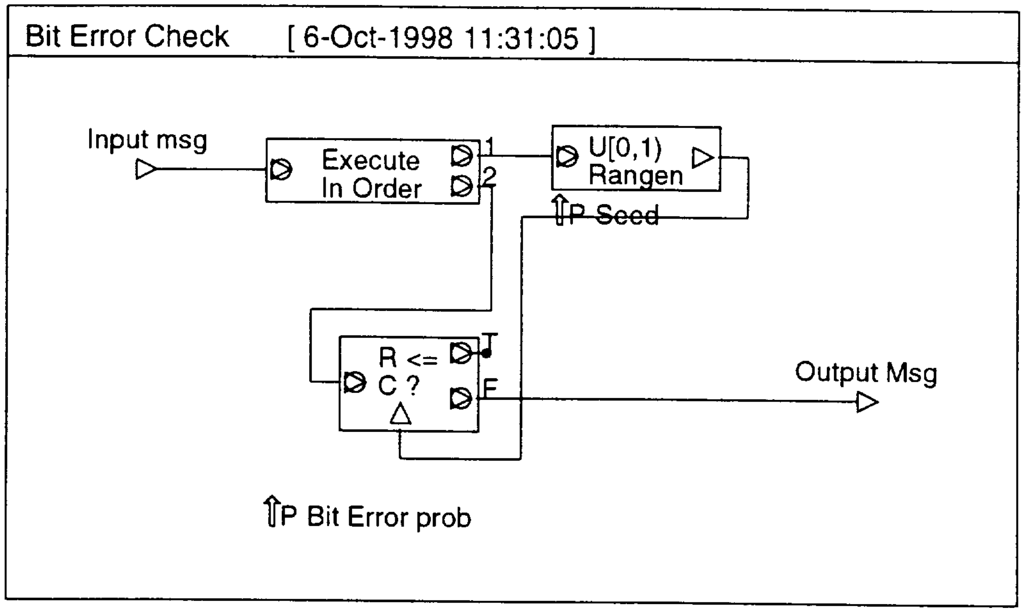

Figure 6: Bit-Error-Check Module

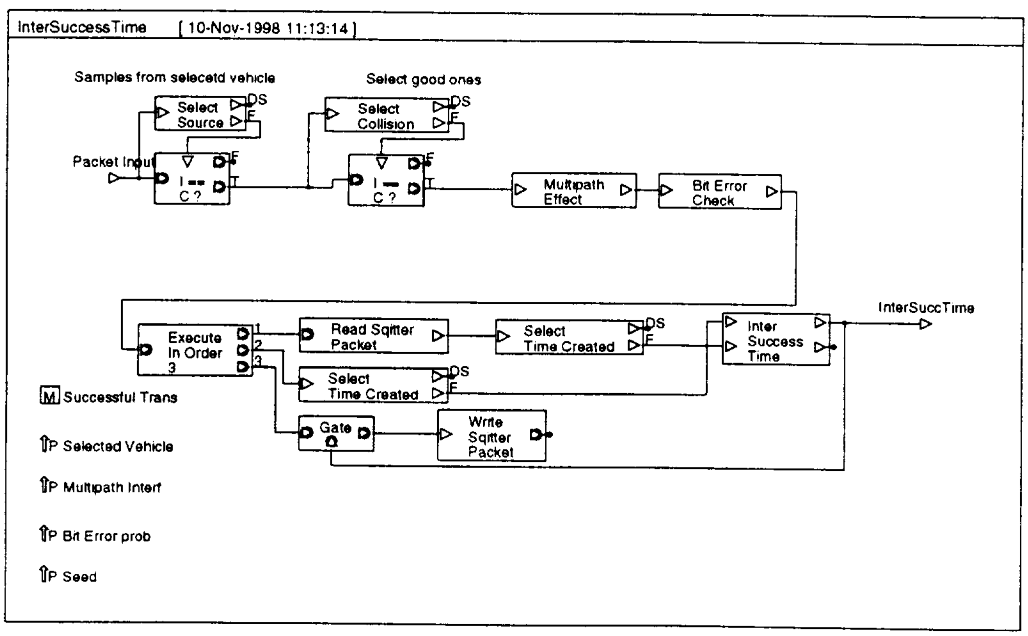

Figure 7: Bit-Error-Check Module

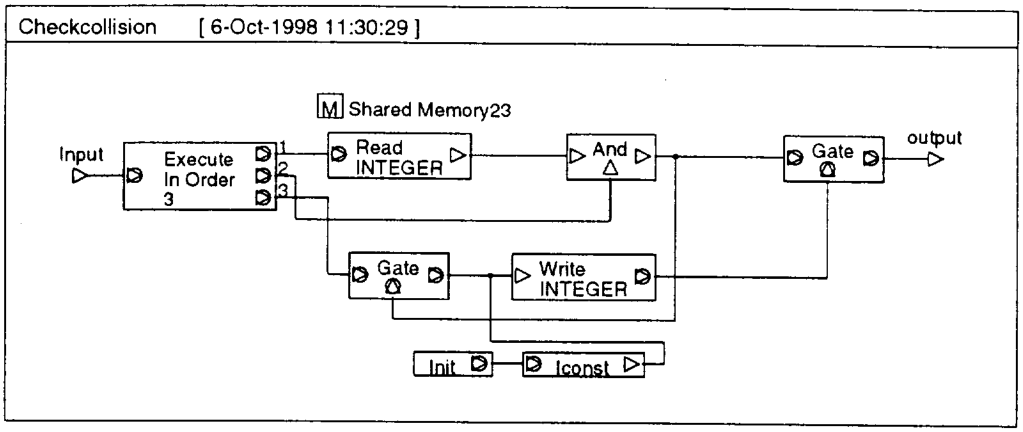

Figure 8: Collision Check Module

3.7 Check Collisions

This module checks for possible collisions among the squitters.

3.8 Comprehensive300ModeSReceiver

This is the highest level module simulating the system. Its first module, "Active Squitter Packet" reads a squitter from the shared memory. The memory contains the last packet transmitted by a station. The packet contains the vehicle ID, the creation time, and the length of the squitter.

The creation time field is then selected by 'Select Time Created" block. This time is then compared with the previous squiter time. If the time difference is less than the "safe distance" then it is said to be involved in a collision. When a collision is detected, a collision bit is set in the squitter packet.

Similarly, the model also checks the antenna visibility range. This is checked by comparing its source with the visibility of the antenna under consideration. If the received packet's source is not in its visibility range, it is immediately discarded.

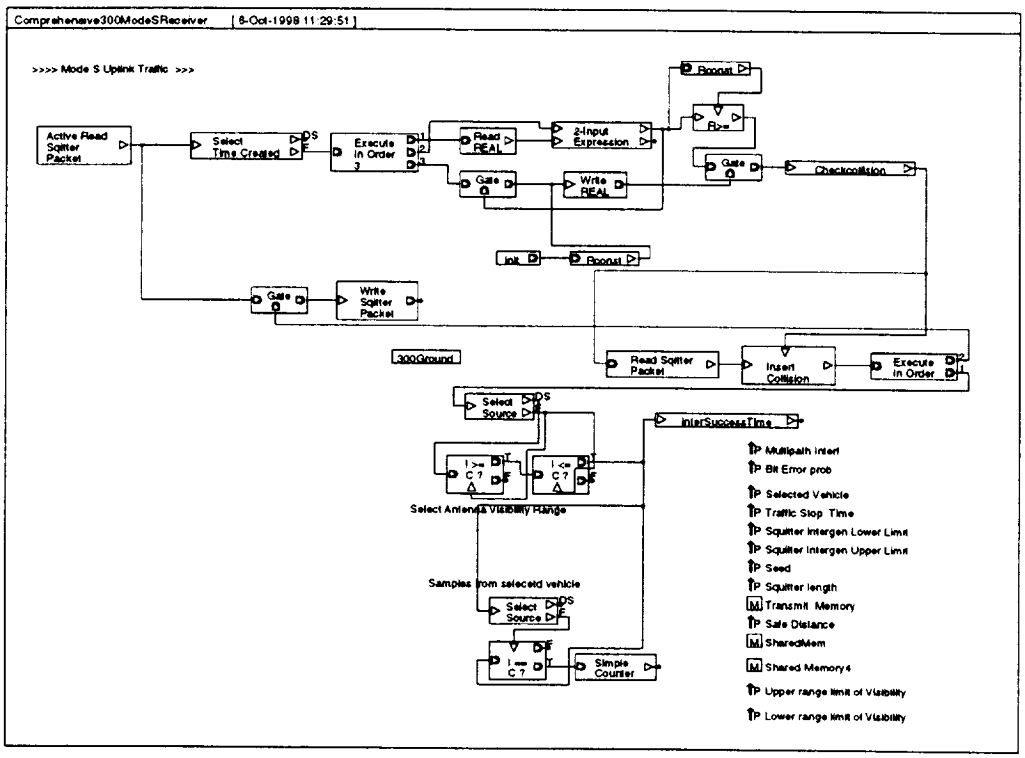

Figure 9: Comprehensive 300-Vehicle Mode S Receiver Model

3.9 Probes

Probes can be placed at any point in the top-level module. We measured the inter-arrival times between successful squitters from a selected station. In other words, we just selected the behavior of squitters from a chosen vehicle at the receiver. This is done by selecting the source field of the squitter packet. When it equals the chosen vehicle ID, it is propagated further, else discarded. We chose a histogram probe with 100 buckets spanning the whole range of intersuccessful squitter times.

4 Example Run

For example, we simulated 300 vehicle model with uniform distribution of squitter generations (between 30000-70000 units or 0.3 sec to 0.7 sec; In the simulation and all the tables in this report, all time units are equal to 10 microseconds. So 30000 in the parameter list as begin of uniform distribution indicates 300000 microseconds or 0.3 seconds). Also note that we assume the long squitters to be occuring 2/sec or once in 0.5 sec). We observed vehicle 99's performance at the receiver. Since it was an extended squitter, its length was 12 units or 120 microseconds. The simulation was carried over 200 Munits of time or 200 seconds. The results are as in Table 1. In this run, the safe distance for non-collisions was assumed to be 1.5*Squitter length or 180 microseconds. So whenever two squitters were generated within a period of 180 microseconds, they were assumed to overlap, and hence in error at the receiver. As you see in the table, this is a parameter and can be changed at the time of a run. We changed this parameter and made several runs also.

Similarly, assuming exponential distribution of inter-squitter times at a station, we made a run. One example run is shown in Table 2. Here, the safe distance was assumed to be just the squitter length or 120 microsec. The last bucket in the statistics captures all values beyond the threshold.

TABLE 1:

Parameters:

```
300 vehicles Uniform Distribution
99       /*Vehicle ID selected for observation */
2.0E8    /* Traffic Stop Time; when to stop generation */
30000  /* Begin of uniform distribution range for intersquitter time */
70000  /* End of the range */
Global Seed
12.0     /* Squitter length */
1.5 * Squitter length  /* Safe distance */
Traffic Stop Time  /*When to stop simulation */
1234567  /* Seed for the random number generator */
```

Results

Inter Squitter Time of Successful Received Squitters	Frequency
31000	135
33000	156
35000	171
37000	108
39000	142
41000	172
43000	165
45000	169
47000	159
49000	151
51000	148
53000	153
55000	132
57000	144
59000	140
61000	170
63000	169
65000	134

67000	144
69000	162
71000	4
73000	12
75000	8
77000	7
79000	6
81000	13
83000	6
85000	19
87000	20
89000	16
91000	15
93000	13
95000	16
97000	22
99000	16
101000	17
103000	17
105000	9
107000	17
109000	10
111000	15
113000	14
115000	12
117000	9
119000	12
121000	15
123000	11
125000	11
127000	10
129000	6
131000	6
133000	3
135000	3
137000	4
139000	3
141000	2
143000	1

145000	3
147000	2
149000	1
151000	1
153000	3
155000	1
157000	2
159000	3
161000	3
163000	5
165000	2
169000	1
171000	1
173000	1
175000	2
179000	2
183000	1
191000	2
195000	1
199000	1
201000	6

TABLE 2:

Parameters:
Pure Exponential distr
99
2.0E8
Ave 50000
Global Seed
12.0
Squitter length
Traffic Stop Time
1234567

Results:
Total squitters generated: 3983

Inter Squitter Time of Successful Received Squitters	Frequency
1000	133
3000	145
5000	121
7000	115
9000	122
11000	115
13000	86
15000	89
17000	66
19000	88
21000	104
23000	88
25000	92
27000	85
29000	74
31000	71
33000	73

35000	61
37000	67
39000	75
41000	52
43000	65
45000	60
47000	58
49000	61
51000	59
53000	44
55000	49
57000	44
59000	55
61000	47
63000	46
65000	37
67000	35
69000	36
71000	37
73000	27
75000	34
77000	47
79000	27
81000	23
83000	31
85000	19
87000	29
89000	24
91000	22
93000	21
95000	18
97000	17
99000	26
101000	16
103000	23
105000	20
107000	14
109000	16
111000	20

113000	16
115000	15
117000	19
119000	7
121000	18
123000	13
125000	14
127000	13
129000	14
131000	12
133000	8
135000	17
137000	10
139000	11
141000	13
143000	8
145000	9
147000	15
149000	12
151000	12
153000	4
155000	4
157000	6
159000	5
161000	7
163000	7
165000	12
167000	8
169000	5
171000	2
173000	3
175000	8
177000	4
179000	4
181000	7
183000	4
185000	4
189000	3
191000	4

193000	2
195000	5
197000	4
199000	1
201000	113

5 Results

To evaluate the behavior of the Mode S system, we made several runs with the system. The actual tables of results are included in the appendix.

From Table 3, we may notice that even when we generate all squitters within an interval of 0.49-0.51 seconds, almost all are received within 0.51 sec. Only a small percentage are involved in collisions and retransmissions.

In Table 4, we assumed that the squitters are generated with a wider range of intersquitter times. Here, the times are 0.4-0.6 sec. This has resulted in many more collisions and reattempts than the earlier one with generation times between 0.49-0.51 sec. In addition, increasing the safe distance from squitter time to 1.2*squitter time has also contributed to increased collisions.

In Table 5, the squitter generation range has been further widened to 0.2-0.8 sec. But the time between successful squitters remained within 0.8 sec for most of the squitters. The safe distance was kept at squitter time. From here and Table 4 we conclude that the safe distance has much more influence than the squitter generation range on the overall collision statistics.

Table 6 shows results when bit error rates, multipath interference, and visibility range are considered together. In addition, the safe distance was assumed to be 1.5*squitter length. The generation time was in the range 0.35-0.65 sec. Clearly, there were more errors resulting in longer intersquitter arrival times at the receiver. In fact there was a value larger than 3 seconds. This may not be acceptable when the vehicles are moving and position is not updated in 3 seconds.

Table 7 shows results obtained with uniform distribution of squitter generation in the range 0.4-0.6 sec. The safe distance was 1.5*squitter length. Clearly, there are many more collisions and the worst interarrival time was larger than 2 seconds. Significant number of interarrivals fell beyond the 1 second tolerance level.

6 Summary

As part of the research under the grant, we have developed a model to simulate the performance of Mode S datalink in the LVLASO context. We have considered different distributions for generation of (long) squitters. We have included the safe distance, distance beyond which two squitters are assumed to be collision free, as a parameter in the model. We have also considered random bit errors by generating random errors in the squitters. We have also incorporated the visibility range as a parameter. From the simulations, we make the following conclusions:

- The behavior of the system was not significantly different for the 100, 200, or 300 vehicles. It displayed acceptable behavior in all the three cases. From this we conclude that the system has not saturated with 300 vehicles and can easily support them. We propose to conduct more simulations to see when the peak will be reached.
- The safe distance factor has significant effect on the performance of the system. Safe distance basically determines the threshold time between creation of messages from two different sources using the same channel, i.e., the Mode S. Depending on the area of coverage for an antenna, the safe distance could be 1 to 2 times the length of a squitter. In Ethernet environment, safe distance is considered to be twice the length of the packet size. Longer the safe distance, higher the possibility of collisions, and hence more distributed is the interarrival time of successful squitters at the receiver from any source.
- The distribution of the generation of squitters at the sources did not effect the performance significantly. Surprisingly, when the generations are done more periodically, there were less collisions. In general, higher the variations in the intersquitter generation times, higher were the variations in the interarrival of successful squitters at the receiver.
- The model is quite flexible and can be tailored to any specific environment or experiment. The BoNeS software in which the model has been developed is quite modular and makes it easy to inherit properties of a lower layer module into a higher level module.
- The model facilitates capturing output at any component. Currently, we collected data corresponding to the histogram of interarrivals of successful squitters for a chosen station. Other probes could be inserted to observe the behavior of collisions, bit errors, multipath effects, etc.

Under a different grant (NAG-1-2102), we have analyzed the experimental results obtained from the flight tests of LVLASO prototype conducted at Atlanta during Aug. 1-28, 1997. These results also indicate that the data link is capable of handling the traffic satisfactorily. The interarrival times for the long squitters was observed to be as in Figure R11 (reproduced from the Final Report of NAG-1-2102). However, the number of vehicles present during the testing was less than 100. So its performance when 300 vehicles are present, as in our simulation results shown here, cannot be extrapolated from these results.

Figure R11 : Interarrival Times of Long Squitter Arrivals (NASA)

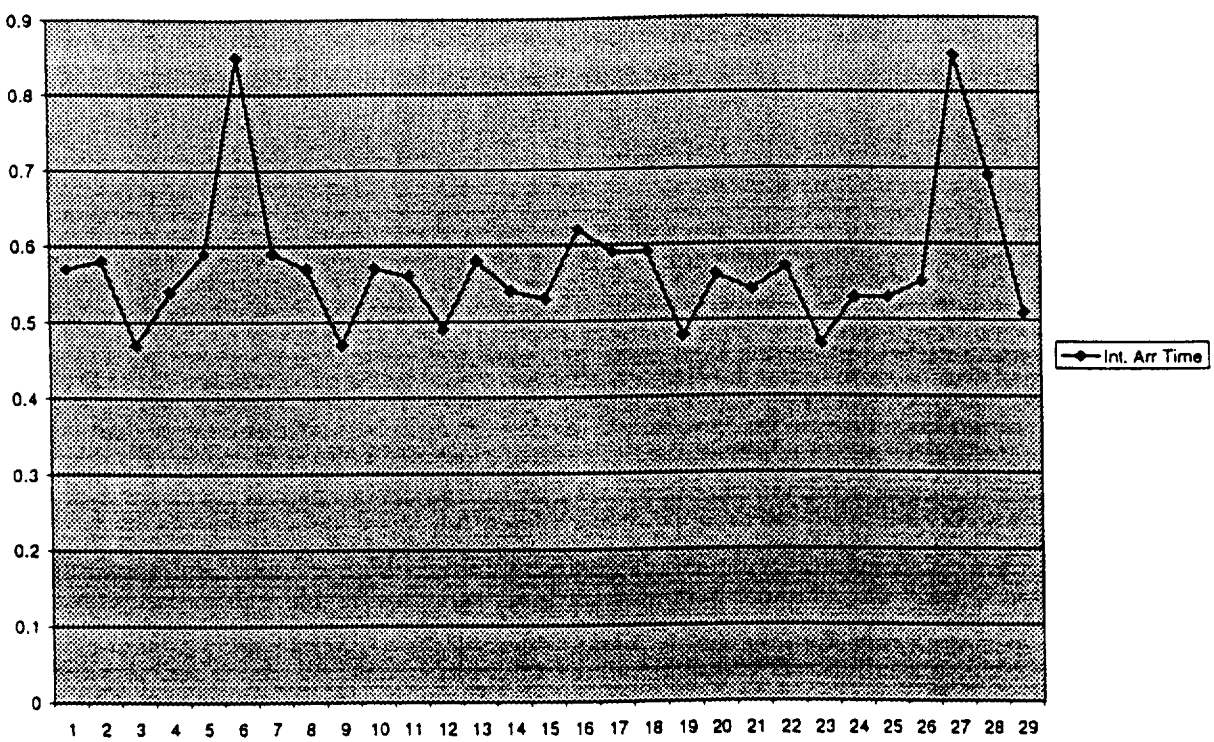

Table 3:

300 vehicles

Y-Axis Title: 'Number in Bin'
X-Axis Title: 'Center of Bin'

Exponential distr 300veh
99
2.0E7
49000
51000
Global Seed
12.0
Squitter length
Traffic Stop Time
1234567

X Title: 'Center of Bin'
Y Title: 'Number in Bin'

Y0 == data1

X	Y0
49000	232
51000	133
99000	1
101000	2
149000	1
153000	1
199000	2
201000	1

Table 4
Exponential distr 300veh
99
2.0E7
40000
60000
Global Seed
12.0
1.2*Squitter length
Traffic Stop Time
1234567

X Title: 'Center of Bin'
Y Title: 'Number in Bin'

Y0 == data1

X	Y0
41000	173
43000	6
45000	7
47000	6
49000	7
51000	5
53000	5
55000	6
57000	1
59000	4
61000	80
81000	3
83000	1
85000	1
93000	1
101000	7
107000	2
109000	1
113000	1

121000	3
123000	1
141000	2
143000	1
145000	1
161000	4
165000	1
169000	1
177000	1
181000	1
183000	1
187000	1
201000	6

Table 5:
Exponential distr
99
2.0E7
20000
80000
Global Seed
12.0
Squitter length
Traffic Stop Time
1234567

X Title: 'Center of Bin'
Y Title: 'Number in Bin'

Y0 == data1

X	Y0
21000	123
23000	7
25000	8
27000	5
29000	17
31000	11
33000	5
35000	5
37000	10
39000	6
41000	8
43000	7
45000	11
47000	3
49000	7
51000	3
53000	5
55000	7
57000	6

59000	9
61000	5
63000	3
65000	6
67000	6
71000	3
73000	2
75000	2
77000	4
79000	6
81000	76
85000	2
87000	1
89000	1
91000	1
97000	1
101000	5
107000	1
115000	1
121000	1
123000	3
133000	1
137000	1
143000	2
149000	1
151000	1
161000	1
171000	1
173000	1
201000	1

Table 6:
Exponential distr
99
2.0E8
35000
65000
Global Seed
12.0
1.5*Squitter length
Traffic Stop Time
1234567
Visibility lower: 250
Visibility upper: 50
Multipath interf: 0.05
Bit prob. error: 0.01

X Title: 'Center of Bin'
Y Title: 'Number in Bin'

Y0 == data1

X	Y0
37500	444
42500	404
47500	467
52500	425
57500	456
62500	448
72500	9
77500	16
82500	40
87500	62
92500	68
97500	87
102500	78
107500	52
112500	56

117500	42
122500	19
127500	10
132500	6
137500	10
142500	11
147500	11
152500	7
157500	5
162500	8
167500	7
172500	1
177500	3
182500	2
192500	5
197500	1
202500	1
207500	2
227500	2
232500	1
312500	1

Table 7:

300 vehicles Uniform
99
2.0E9
40000
60000
Global Seed
12.0
1.5*Squitter length
Traffic Stop Time
1234567

X Title: 'Center of Bin'
Y Title: 'Number in Bin'

YO == data1

X	YO
41000	3055
43000	3014
45000	3027
47000	3043
49000	3028
51000	3022
53000	2926
55000	2957
57000	3017
59000	2947
81000	17
83000	51
85000	95
87000	132
89000	168
91000	220
93000	243

95000	295
97000	355
99000	402
101000	364
103000	299
105000	315
107000	297
109000	212
111000	181
113000	140
115000	111
117000	69
119000	26
123000	1
125000	1
127000	2
129000	6
131000	10
133000	5
135000	13
137000	21
139000	33
141000	33
143000	34
145000	47
147000	39
149000	45
151000	36
153000	36
155000	40
157000	36
159000	25
161000	20
163000	14
165000	20
167000	18
169000	5
171000	3
173000	1

175000	5
177000	1
179000	1
181000	2
187000	5
189000	3
191000	5
193000	2
195000	7
197000	6
199000	2
201000	49