HIGH RESOLUTION SATELLITE COMMUNICATION SIMULATION

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ABSTRACT

The purpose of this paper is to develop and demonstrate Simulation of Satellite Communications (SIMSATCOM), a high resolution, stochastic simulation of satellite communications for evaluating the effectiveness of message transmission and receipt by specified senders and receivers. SIMSATCOM is designed to operate as a stand-alone simulation, but may be adopted as a high resolution module for a large scale simulation such as JWARS.

1 INTRODUCTION

The Joint Warfare System (JWARS) office in Arlington, Virginia was interested in determining whether it would be adequate to model satellites aggregately instead of as entities. There are many types of satellites that JWARS needed to consider. I developed the SIMSATCOM high resolution communication simulation model to provide insight into the geosynchronous satellite portion of this concern. SIMSATCOM models the Milstar satellites that are in an inclined geostationary orbit approximately 22,400 nautical miles above the earth. (USSPACECOM 1997)

SIMSATCOM was designed to operate as either a stand alone simulation model or as a feeder simulation for a larger simulation. The stand alone implementation provides the user with a wealth of data that allows the analyst to answer a variety of questions. For example, the analyst could investigate the effects of increasing satellite capacity or perform a trade-off analysis to determine if it would be better to buy more anti-jam capability or channel capacity for a satellite system. One approach for performing this analysis is to adjust the simulation parameters and conduct runs to determine if the number of good messages transmitted changes significantly as the parameter values are modified.

One of the strengths of SIMSATCOM is its ability to support analysts. The analyst is provided with an exhaustive listing of all of the data that is used in every simulation routine for each time step. This exhaustive listing of the data is practical because the scope of this aggregate satellite simulation provides a limited set of events. This data is stored in MS Excel worksheets that are used as data "placeholders". These placeholders store the data in a format that enables the analyst to easily use any portion or combination of the data to support a study.

2 SYSTEM DESIGN

The systems design for SIMSATCOM is Visual Basic for Applications code that interacts with MS Excel worksheets. The user initiates SIMSATCOM by defining inputs for the simulation on the "inputs" worksheet and then going to the main module in the VB Editor and executing that module. The simulation uses other worksheets as data placeholders that can be used by the analyst after the simulation is run. One advantage of using MS Excel is that any analyst familiar with MS Excel can run the simulation and manipulate the output as necessary. The simulation also has several predefined graphs to support analysis. An example of the type of graphs are the number of messages generated by priority, the average number of messages generated, or the cumulative number of channels in use over time. The analyst can supplement these predefined graphs with user defined customized graphs that would provide insight into a specific study question.

The user inputs the following parameters on the input page prior to starting the simulation: they are the average number of messages (lambda values) for each message type; the number of satellites; the maximum number of channels for each satellite; the anti-jam ability for each ground station type; the priority wait time for each message type; maximum time to wait to retransmit for each message type; the number of jammers; the "perJtot" value; the jammer latitude / longitude (optional, if input, turn off reset jammers procedure); and the satellite information. After the user inputs these parameters, the initialization portion of the simulation begins. At this step the simulation will randomly generate the jammer locations; set the number of satellites and the number of channels on each of the satellites; and assign random locations for each of the jammers. However, if the user desires to employ fixed locations for the jammers, the user can disable this action prior to the simulation execution.

After the initialization, the new message generation process begins. The simulation uses a Poisson distribution to generate the number of messages sent for each message type for each time step. The Poisson random number generator uses the parameters that were input by the user. Several Uniform random numbers are also generated to create the following data for the new message: a new location for the sender and receiver; the sender and receiver type, which indicates the type of equipment the sender and receiver use to counteract jamming; the number of bits, which corresponds to the appropriate type of message; to determine if the message is transmitted using the low or medium data rate if the message is transmitted using satellites "3" or "4". (Law and Kelton 1991)

The simulation next identifies which satellite(s) will transmit the data. The satellite(s) that transmit depend on the sender and receiver locations. If the sender and receiver locations are not in the same transmission area for a single satellite, then a crosslink is required, meaning that more than one satellite is required to transmit the message. If a crosslink is necessary, both satellites must be available for the transmission to occur.

Jamming of the message may also occur at both the uplink and downlink locations of the transmission. There are three possible outcomes from the jamming process in the simulation. A message is either "totally jammed" which means that the message was completely jammed; "partially jammed" which means that the recipient received the message but the message was not comprehensible; or "good" which means that the message was not jammed and the message was transmitted cleanly.

If there are available channels on the appropriate satellites and jamming does not occur on the transmission, then the message is transmitted. Otherwise the message waits in the retransmission queue for the appropriate time to retransmit.

After a message is sent an acknowledgment message is transmitted. This acknowledgment message informs the sender that the message was received successfully and a retransmission is not necessary. If the acknowledgment message is not received by the sender, then the sender assumes that the message was not transmitted successfully and will retransmit the message again after a set period of time (an input by the user, based upon the message type). The sender will only try to retransmit a message for a set period of time, after which the message transmission process stops.

3 PLACEHOLDER WORKSHEETS

SIMSATCOM has seven principal worksheets that are used in the model. The following section describes the MS Excel worksheets that are used as data placeholders. These worksheets contain all of the data for analyst's use. The analyst could easily write a macro in MS Excel to aid in manipulating the data for their use.

3.1 Simulation Control

Once the user begins the simulation, the various worksheets begin to accumulate data. The "sim" worksheet (Figure 1) is the primary worksheet used in the simulation. It contains all of the information used in determining whether the message was sent successfully or not. It contains the location of the sender and receiver, the type of message, the priority of the message, whether it was jammed, and whether an acknowledgment message was sent. The top portion of the sheet contains input and information placeholder data. The information placeholders include the *act row* cell which shows the next available row on the worksheet (currently row 194 in Figure 1); the *cum time* cell which is the current time; and the *cum msgs* cell which denotes the number of messages that have been transmitted. The *rate msg type* cells are the lambda values from the "input" sheet. These values are the Poisson distribution input parameters, which are the average number of messages for each message type. These values are used in generating the number of messages sent for the current time step utilizing the Poisson distribution shown in Equation 1.

$$F(x) = \begin{cases} 0 & \text{if } x < 0 \\ e^{-\lambda} \sum_{i=0}^{x} \dfrac{\lambda^i}{i!} & \text{if } 0 \le x \end{cases} \quad (1)$$

act row	194				
			input	rate msg type	sent
				lambda 1	2
				lambda 2	3
cum time	15			lambda 3	1
cum msgs	147			lambda 4	3

Time (in secs)	msg#	msg type?	bits to trans	Send Lat	Send Long	Recvr Lat	Recvr Long	send type	recv'r type	priority code	rand # for data rate	sat type sender	sat type recvr	crosslink? 0-no 1-yes
0	0	0	0	1	1	1	1	0	0	0		1	1	0
1	1	2	4532	-81	253	-35	126	4	10	2	0.414644	3	2	1
1	2	2	27933	64	236	66	111	2	20	3	0.56177	3	2	1
1	3	3	28363	-68	348	-31	211	3	4	3	0.706453	4	3	1
1	4	3	14339	14	148	-89	30	4	19	3	0.704454	2	1	1

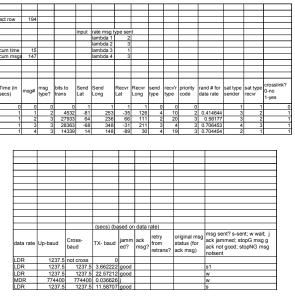| data rate	Up-baud	Cross-baud	TX- baud (secs) (based on data rate)	jamm ed?	ack msg?	retry from retrans?	original msg status (for ack msg)	msg sent? s-sent; w wait; j ack jammed; stopG msg g ack not good; stopNG msg notsent
LDR	1237.5	not cross	0					
LDR	1237.5	1237.5	3.662222	good				s1
LDR	1237.5	1237.5	22.57212	good				w
MDR	774400	774400	0.036626					w
LDR	1237.5	1237.5	11.58707	good				s

Figure 1: "sim" Sheet Extract

The next part of the "sim" worksheet contains the message information used in the model. Each row represents a message and the information that accompanies

it. The first column represents the time step; the second column is the message number. A negative message number indicates that the message is an acknowledgment message to the corresponding message with the absolute value of that number. The *message type* column indicates the type of message that is being transmitted. The possible values for this column are "1" (strategic message), "2" (tactical message), "3" (logistics message), or "4" (administrative message). The number of bits to transmit corresponds to the type of message transmitting. The next four columns are the sender and receiver latitude and longitude locations.

The next two cells, the *send type* and *recv'r type*, are used for the anti-jamming capability of the ground station. The value is a random integer between 0 and 20. The higher the number, the better the anti-jam capability (hence lower chance of being jammed). The explanation of Figure 4, the "type" worksheet provides additional information.

The *priority code* is currently set to the same value as the *message type*. This assumes that the smaller the message type value, the higher the priority of the message. The *random number for the data rate* is used for the *data rate* cell, which is explained in the next paragraph. The satellite type sender and receiver columns, *sat type sender* and *sat type recvr*, identify which satellites are transmitting the data. Table 1 contains the characteristics and location for each satellite.

Table 1: Satellite Characteristics

Sat. No.	Sat. Type	Longitude	Possible Baud Rate (*data rate* column)
1	A (Milstar I)	0 - 90	LDR
2	A (Milstar I)	90 - 180	LDR
3	B (Milstar II)	180 - 270	LDR / MDR
4	B (Milstar II)	270 - 360	LDR / MDR

To determine whether the LDR, "low data rate", or MDR, "medium data rate" is used the random number generated earlier is compared to 0.15. This value was chosen because the Milstar II satellites have approximately 15% MDR channels (32 channels) and 85% LDR channels (192 channels). (Space and Missile Center 1997) If the random number is less than 0.15 then MDR is input, otherwise the LDR is input.

The next two columns specify data rates. The values for these columns are the number of bits per second that the satellite can transmit. The *Up* column indicates the number of bits transmitting on the uplink. If there is a crosslink, then the value in the *crosslink* column will be the number of bits transmitting on both satellites; otherwise, the value in this column will be *no crosslink*.

The *TX-baud* value is a function of the bit rate and the message size. It is the total number of bits to transmit (located in the *bits to transmit* column discussed previous-

ly) divided by the number of bits per second the satellite is able to transmit.

The *jammed* column indicates whether the message was jammed. The possible values in this column are "good", indicating that the message was transmitted good, "j", indicating that the message was not comprehensible due to jamming, or "pj", indicating that the message was partially jammed (i.e., the message header was comprehensible but the remaining portion of the message was not). Further explanation is given in the "jammer" sheet description.

The *ack msg* column is filled in only if the message is an acknowledgment message. The *retry* message column indicates that the message is a retransmission. If it is a retransmission, then the cell is filled with an "r". The *original message status* column is only utilized in conjunction with an acknowledgment message. The value in this column indicates how the original message was transmitted. It contains either the value "good" or "pj".

The final column, *msg sent*, is the final status of the message. The possible values for this column are "s", indicating that the message was sent "good" and the sender received an acknowledgment message; "s1", indicating that the message was sent "good" but the sender has not received an acknowledgment message; "s2", indicating that the acknowledgment message was sent (this value corresponds only to an acknowledgment message); "s3", indicating that the message was successfully transmitted but was partially jammed; "w" indicating that the message is in a waiting status (i.e., it is currently being processed or in the retransmission queue); "j", indicating that the message is jammed; "stopG", indicating that the message process is complete for this message (The message was sent okay, but the sender never received an acknowledgment message and the maximum time to keep trying to send this message has been reached.); "stopNG", indicating that the message process is complete (In this case the message was never received due to jamming, or not enough channels were available to transmit the message and the maximum time to keep trying to send the message was reached.).

3.2 Satellite Channels

Another principal worksheet used by SIMSATCOM is the "sat chan" worksheet (Figure 2). It contains the number of users that are currently utilizing the specified satellite. The model maintains this sheet to ensure that the satellite is not overloaded. The top portion of this sheet contains the maximum number of satellites and the maximum number of channels for each satellite. The *satellite available* row indicates if the satellite has any available channels to transmit messages. If the value is "False" then all channels are being used at that time. The next row value indicates the row that is available to input new information. The *current time* value indicates the current model time.

		max # sats		4				
		max channel		8				
		sat	1		2		3	4
		max chan/sat	8		8		8	8
		sat avail?	FALSE		FALSE		FALSE	FALSE
Next row	106							
cur time	16							
time	sat1 chan	cum sat1	sat2 chan	cum sat2	sat3 chan	cum sat3	sat4 chan	cum sat4
	1	1	2	2	3	3	4	4
0		0		0		0		0
1	0	1	1	1	1			0
1	0	1	2	1	2			0
1	1	1	3		2			0

Figure 2: "sat chan" Sheet Extract

The *time* column shows the time corresponding to the satellite information in the adjacent columns. The *sat1 chan* column indicates whether a channel is being incremented or decremented on the satellite. The *cum sat* column indicates the cumulative number of channels being used on the satellite. These two columns are repeated for each satellite in the model.

3.3 Time

SIMSATCOM's "time" worksheet (Figure 3) keeps track of two important time calculations for the simulation. It calculates the message number that currently is being transmitted on a particular satellite and how much time remains for each transmitting message. The columns on the "time" sheet are broken into categories by satellite. The first column is the current message transmitting on a channel on the specified satellite. The *time to transmit* column denotes the total amount of time that message will take to transmit. The *remaining time left on message number* column indicates the time that remains to transmit the message.

sat 1			sat 2			sat 3			sat 4		
cur msg # transmitting	time to transmit	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #
39	3.10465	3.104646465	112	3.715556	0.715556	39	3.104646	3.104646	104	21.09495	17.09495
6	21.4505	7.450505051	2	22.57212	8.572121	2	22.57212	8.572121	22	29.08444	17.08444
116	32.1584	29.15838384	147	3.534545	3.534545	6	21.45051	7.450505	15	30.08566	17.08566
38	2.02667	0.026666667	-96	1.616162	0.616162	147	3.534545	3.534545	125	15.92646	13.92646
15	30.0857	17.08565657	22	29.08444	17.08444	-96	1.616162	0.616162	116	32.15838	29.15838
104	21.0949	17.09494949	128	27.60162	25.60162	124	17.61374	15.61374	34	26.61818	15.61818
75	19.7964	12.79636364	98	16.85414	11.85414	112	3.715556	0.715556	36	22.87434	11.87434
36	22.8743	11.87434343	34	26.61818	15.61818	98	16.85414	11.85414	128	27.60162	25.60162

Figure 3: "time" Sheet Extract

3.4 Ground Station Anti-Jam Capability

SIMSATCOM's worksheet that describes the anti-jam capability of the ground station is the "type" worksheet (Figure 4). This worksheet is strictly a placeholder worksheet that contains anti-jam capability of the ground stations. This data is used in the jammer event of the simulation. The current sender and receiver location and the sender and receiver type are from the active row on the "sim" sheet. The proportions represent the anti-jamming capability of the ground station. For example, the sender in Figure 4 is type 8, which has a 0.4 anti-jam capability.

		these are the current lat and long gets updated when run macro send recvr loc			
current	sender lat	-46	sender type		
	long	50	8		
	recvr lat	38	receiver type		
	long	331	1		
Type	proportion of anti-jam capability		Priority wait time for receipt of Ack		
1	0.05		1	6	secs
2	0.1		2	10	
3	0.15		3	15	
4	0.2		4	50	
5	0.25				
6	0.3		Max Time for Retrans		
7	0.35		1	11	
8	0.4		2	30	
9	0.45		3	90	
10	0.5		4	200	
11	0.55				
12	0.6				
13	0.65				
14	0.7				
15	0.75				
16	0.8				
17	0.85				
18	0.9				
19	0.95				
20	1				

Figure 4: "type" Sheet Extract

The probability that the ground station will be jammed is (1 - 0.4) times the probability of jam. The explanation of the "jammer" sheet provides further details.

This sheet also contains the amount of time the sender waits for the receipt of an acknowledgment message prior to retransmitting a message. The values "1", "2", "3", and "4" correspond to the priority of the message, and the wait time for each value is input by the user prior to execution of the model. The maximum wait time for retransmission is also input for each message priority class. This is the maximum amount of time the sender will keep trying to send the message.

3.5 Jamming

Another primary worksheet of SIMSATCOM is the "jammer" worksheet (Figure 5). The simulation uses this worksheet to determine if the transmission was jammed. It contains the number of jammers that are capable of jamming a particular site. The top portion of the sheet contains the current sender and receiver location and the sender and receiver type from the active row on the "sim" sheet. The value *perJtot* is used to determine the portion of the jammed value that results in a partially jammed message, with (1- *perJtot*) resulting in a totally jammed message. The *maximum number of jammers* value is input by the user prior to the start of the model execution.

In the result portion of the worksheet, the top row is a consolidation of the jammers versus the sender and then the receiver. The first column represents the jammer number. The second and third columns represent the location of the jammer. The simulation randomly assigns random locations for each of the jammers, by a uniform random number generator (Law and Kelton 1991). The next column is the maximum range of the jammer. All of these values are input at the reset portion (Step 1) of the flow chart. The *distance from the jammer uplink* column

								perJtot=	0.7		Max # of jammers	
	these are the current lat and long											
current	sender lat	-46	sat type								9	
	long	50	8									
	recvr lat	38										
	long	331	1									
	Jammer Locations						**uplink**					
Barrier	lat	long	Max range of jammer	distance from jammer uplink	prob jam (uL)	perc jam	final P(jam) uL	jam none	jam partial	jam total	rand draw	type jam, 0-none,1-part, 2-total
RESULT					0.99752	0.6	0.598513	0.40149	0.58104		1	0.0711	0
1	-18	221	4336	18340.73617	0							
2	-21	182	7091	845.0255738	0.9858							
3	-57	300	6462	10058.62184	0							
4	-23	125	7636	13570.25114	0							
5	-10	328	4743	10708.9081	0							
6	-5	307	8042	18965.9238	0							
7	40	252	2808	1759.273846	0.60747							
8	-64	272	1948	5578.250762	0							
9	-14	8	5816	3877.799506	0.55545							

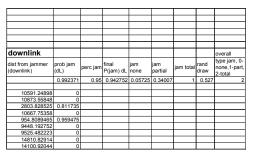| **downlink**								overall
dist from jammer (downlink)	prob jam (dL)	perc jam	final P(jam) dL	jam none	jam partial	jam total	rand draw	type jam, 0-none,1-part, 2-total
	0.992371	0.95	0.942752	0.05725	0.34007		1	0.527	2
10591.24898	0							
10873.55848	0							
2803.828525	0.811735							
10667.75358	0							
954.8089465	0.959475							
9448.192752	0							
9525.482223	0							
14810.82914	0							
14100.92044	0							

Figure 5: "jammer" Sheet Extract

determines how far the jammer is from the sender location. This value is calculated by the following equations: (Meich 1997)

$$dist = 2*\rho*\arcsin(\frac{D}{2*\rho}) \qquad (2)$$

with

$$D = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2} \qquad (3)$$

$$\begin{aligned} x_1 &= \rho*\sin(\phi_1)*\cos(\theta_1) \\ y_1 &= \rho*\sin(\phi_1)*\sin(\theta_1) \\ z_1 &= \rho*\cos(\phi_1) \end{aligned} \qquad (4)$$

$$\begin{aligned} x_2 &= \rho*\sin(\phi_2)*\cos(\theta_2) \\ y_2 &= \rho*\sin(\phi_2)*\sin(\theta_2) \\ z_2 &= \rho*\cos(\phi_2) \end{aligned} \qquad (5)$$

$$\phi_1 = \begin{cases} 90 - latitude1 & if\ latitude1 > 0 \\ 90 + latitude1 & otherwise \end{cases} \qquad (6)$$

$$\phi_2 = \begin{cases} 90 - latitude2 & if\ latitude2 > 0 \\ 90 + latitude2 & otherwise \end{cases} \qquad (7)$$

$$\theta_1 = 360 - longitude1 \qquad (8)$$

$$\theta_2 = 360 - longitude2 \qquad (9)$$

and ρ = 6367 km (the radius of the earth).

If the distance of the jammer to the sender is less than the maximum range of the jammer, the probability of jam for each individual location that is within range of the jammer is determined by the following formula which is from the ACES model (Payne 1996):

$$P_{\text{indiv. jammer}}(jam) = 1-(dist/max\ Range)^2. \qquad (10)$$

Otherwise the probability of jam equals 0. The overall probability of jam is output in the *Result* row. The value of the initial probability of jam is:

$$\begin{aligned} P_{\text{init}}(jam) = &\ 1-(1-Pjam\ (first\ jammer))* \\ &(1-Pjam\ (second\ jammer))*\ldots* \\ &(1-Pjam(nth\ jammer)). \end{aligned} \qquad (11)$$

The *perc jam* value is based upon the type of anti-jam capability of the sender. The anti-jam effectiveness, is taken from the "type" sheet is used to compute the *perc jam* value, which is:

$$perc\ jam = 1 - anti\text{-}jam\ effectiveness. \qquad (12)$$

The final probability of jam is now calculated as:

$$P_{\text{final}}(jam) = (P_{\text{init}}(jam)) * perc\ jam. \qquad (13)$$

The *jam none*, *jam partial*, and *jam total* values are:

$$\begin{aligned} jam\ none &= 1 - P_{final}\ (jam) \\ jam\ partial &= P_{final}\ (jam)*(perJtot) \\ jam\ total &= P_{final}\ (jam)*(1 - perJtot). \end{aligned} \qquad (14)$$

A random number is then generated to determine whether the message is totally, partially or not jammed. If the random number is less than the *jam none* value then the transmission is not jammed and a "0" is entered; if the random number is between the *jam none* and the *jam partial* value then the transmission is partially jammed and a "1" is input. If the random number is greater than the *jam partial* value, then the transmission has been completely jammed and a "2" is input.

For the example, the sender is type 8, which corresponds to an anti-jam effectiveness of 0.4. The *perc jam* is 0.6 and the *final probability of jam* is 0.598 (0.997 * 0.6). The random number that was generated is 0.0711. This value is less than the *jam none* value (0.40149), so a "0" is entered in the *type jam* cell.

Because both the sender and receiver ground stations are susceptible to jamming, a similar calculation is needed for the downlink portion of the transmission. The computations for the downlink columns work similarly to the uplink columns. However, one difference is the calculation of the *type jam* column. This column is

dependent upon the result of the uplink *type jam* column. If the result from the uplink *type jam* column is *jam total* then the overall value for the *type jam* column is also *jam total*. If the uplink is *partially jammed*, the random number generated is only compared with the *jam none* value. If the random number is less than the *jam none* value, the value remains partially jammed (no jamming occurred on the downlink, but the message was partially jammed on the uplink so the overall evaluation is partially jammed); otherwise, the message is totally jammed. If the uplink was not jammed, then the calculation for this column is the same that was used for the uplink computation for *type jam*.

3.6 Retransmission

SIMSATCOM also features a retransmission queue. If a message is not sent successfully, the message goes into the retransmission queue to be sent again. The simulation determines if a message was successful or not by determining if an acknowledgement message was received by the sender in an adequate amount of time. The messages waiting to be retransmitted are recorded on the "Retrans" worksheet (Figure 6). The *time* column indicates the time the message was originally initiated. The *message number* column indicates the message number in the queue. The *message type*, *bits to transmit*, *send lat and long*, *receiver lat and long*, *send and receiver type*, and *priority code* columns are all copied from the "sim" sheet when the message gets initiated. The *wait time* value is input based upon the priority of the message.

next num	162											
				Sender		Receiver						
Time (in secs)	msg#	msg type	bits to transmit	Start Latitude	Start Long	End Latitude	End Long	send type	recv'r type	priority code	wait time	time to try again?	status
												0
2	8	1	2663	-19	223	83	196	8	16	1	6	8	good
2	9	1	3604	-25	257	75	112	13	11	1	6	14	good
2	10	1	2561	-62	74	-44	201	2	20	1	6	14	stopNG

time last try Msg	sat # up	sat # down	rand # (from sim)	jammed?	Max time to try	Time to stop trying
						0
2	3	3	0.852068	good	11	13
8	3	2	0.631439	good	11	13
8	1	3	0.581526	j	11	13

Figure 6: "Retrans" Sheet Extract

The *time to try again* value is the sum of the *wait time* and the *time last try msg* column. The *status* column indicates the status of the retransmission. "stopG", "stopNG" and "good" values indicate that the message will no longer be retransmitted. The value "stopG" means that the original message was sent successfully but the sender never received an acknowledgment message. The "stopNG" value means that the message was never sent due to jamming or no channel was available. The value

"good" indicates that the message and an acknowledgment message were transmitted successfully. The value "w" indicates the message is waiting to be retransmitted. The value "n" indicates that the message will not be retransmitted, (i.e., the message is a retry message and the original message is already in the queue). The *time last try message* column indicates the last time the message was attempted. The *satellite number up and down* columns indicate the satellite number that will transmit the message. The *random number* is the data rate random number from the "sim" worksheet. The *jammed* column indicates the original message jam status. The *maximum time to try* column is the maximum amount of time the sender will try to send the message. The *time to stop trying* is the sum of the initial attempt to send the message (*time* column) plus the *maximum time to try* the message. This value indicates when the model will stop trying to send the message.

3.7 Satellite Information

SIMSATCOM's worksheet that contains the satellite information is called "sat info" (Figure 7). This worksheet contains the number and characteristics of satellites that are used in the simulation. The satellites are modeled after the Milstar I and II satellites. The first column indicates that the Type "A" satellites (modeled after the Milstar I satellite) are "1", "2", "5", and "6" and Type "B" satellites (modeled after the Milstar II satellite) are "3", "4", "7", and "8". The second column indicates the satellite number. The data rate information shown in the next two columns gives the range for the low data rate, LDR, as 75 bits per second to 2,400 bits per second. The average is 1237.5 bits per second. For MDR, the range for transmission is from 4,800 to 1,544,000 bits per second. The average rate is 774,400 bits per second. The average rates are the values used in the calculation on the "sim" sheet for the time to transmit a message.

		Data rates				
	Satellite		low	high	avg	
Type A	1	LDR	75	2400	1237.5	bps
1,2,5,6	2	LDR	75	2400	1237.5	bps
B	3	LDR	75	2400	1237.5	bps
3,4,7,8		MDR	4800	1544000	774400	bps
	4	LDR	75	2400	1237.5	bps
		MDR	4800	1544000	774400	bps

Figure 7: "sat info" Sheet Extract

4 FUTURE RESEARCH AND SUMMARY

All of the information displayed in these worksheets could be hidden from the user, but part of the strength of SIMSATCOM is that all of the data is at the analyst's fingertips. They can take the data directly from the simulation to begin their analysis, or they could write a macro, visual basic for applications code, to collect this

data. The model has a built in module to collect some of the data to be used for analysis. It includes the number of each priority message by type and the number of messages that were sent successfully, partially successful or not successful, as well as accompanying graphs.

SIMSATCOM provides a useful model for answering questions about communications involving geosynchronous satellites. Many features of the simulation are useful for answering a variety of questions. However, there are some areas of the model where it would be beneficial to add additional features to provide further analysis capabilities.

The model is not dynamic in the area of satellite locations. It would be beneficial to modify the model in order for the user to input the location of the satellites and to designate specific areas of responsibility for each satellite. In building this modification, it would be useful to have satellites with different capabilities at specified locations (i.e., different data rates, ranging from low to high, modify the anti-jam capability for each satellite and have specified frequencies on each satellite).

It would also be advantageous to modify a portion of the input locations to a specific area of interest. This could be done with a slight modification of the current model (i.e., add a percentage that would set to a specified area of interest and the remainder to the upper and lower bounds for the input latitude and longitude).

A more sophisticated jamming process could also be added to the model. Different types of jammers with different capabilities would be a beneficial improvement. For example, a microwave radar can cause interference to communication. A simulated microwave radar could be a type of jammer with appropriate frequencies that it could jam. After adding more sophisticated jammers, it would be useful to allow the sender and receiver to select and change frequencies if a specific frequency is jammed.

Once these additions are made, the simulation could be added as a high resolution module to other models. To make this model compatable with another model, the input portion of the model would require modification. The jammers and the output portion of the model would also need to be tailored to the parent model.

Models that require near-earth or semi-synchronous satellites could be designed in a similar fashion. However, the location of the satellites would be dependent on the location of the satellite at the start of the simulation and the time in the model a particular action needs to take place. Specifications specific to the satellites such as sensor capabilities and their corresponding equations would need to be added.

Finally, JWARS, or other broad based simulations, would be able to utilize this model to investigate the satellite aggregation issue. With some modification, it could become the high resolution module for satellite representation.

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