TN
90/64

FAA WJH Technical Center
00026335

COPY 1

Aeronautical Mobile Satellite Service (AMSS) Capacity Analysis and Protocol Performance Simulation Results

FEDERAL AVIATION ADMINISTRATION
AUG 14 1992
TECHNICAL LIBRARY

July 1992

DOT/FAA/CT-TN90/64

This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.

U.S. Department of Transportation
Federal Aviation Administration

Technical Center
Atlantic City International Airport, N.J. 08405

technical note technical note

NOTICE

This document is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the objective of this report.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/CT-TN90/64		

4. Title and Subtitle	5. Report Date
AERONAUTICAL MOBILE SATELLITE SERVICE (AMSS) CAPACITY ANALYSIS AND PROTOCOL PERFORMANCE SIMULATION RESULTS	July 1992
	6. Performing Organization Code: ACD-330
7. Author(s): Thomas F. Dehel (CTA)	8. Performing Organization Report No.: DOT/FAA/CT-TN90/64
9. Performing Organization Name and Address: CTA Incorporated, English Creek Center, The Courtyard, Suite 204, McKee City, N.J. 08232	10. Work Unit No. (TRAIS)
	11. Contract or Grant No.: T0704F
12. Sponsoring Agency Name and Address: U.S. Department of Transportation, Federal Aviation Administration, Technical Center, Atlantic City International Airport, N.J. 08405	13. Type of Report and Period Covered: Technical Note
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The Federal Aviation Administration (FAA) is supporting the development of standards for the use of satellite communications in aviation. As part of this support, the FAA has conducted an analysis and simulation of the Aeronautical Mobile Satellite Service (AMSS) to determine the capacity of this system to meet data requirements and to determine the message transit delay of the system under a range of conditions. The results show that a minimum AMSS ground station (which can receive four 600 bits per second (bps) R-channels and transmit on one 600 bps P-channel) will be able to support about 60 aircraft with a message (e.g., ADS position report) update rate of 5 minutes. The transit delay results show that, under the system projected bit error rate of $1x10^{-5}$ and 15 percent channel occupancy, the transit delay will be 75 seconds or less for 99.9 percent of the messages and 40 seconds or less for 99 percent of the messages. Voice call setup delays were also determined; the transit delay time for a voice call setup message is 48 seconds or less for 99.9 percent of the calls. However, if the system BER drops to the lower end of the expected range (i.e., $1x10^{-4}$), then the probability of delivery of data messages drops below 99.9 percent.

17. Key Words	18. Distribution Statement
AMSS Communication Satellite ADS	This document is available to the U.S. public through the National Technical Information Service, Springfield, Va. 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	76	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

	Page
EXECUTIVE SUMMARY	vii
1. INTRODUCTION	1
1.1 Background	1
1.2 Test Overview	1
2. DISCUSSION	2
2.1 Test Conduct	2
2.1.1 AMSS Capacity Analysis	2
2.1.2 Message Transit Delay Simulation	2
3. RESULTS	4
3.1 AMSS Capacity Analysis Results	4
3.1.1 AMSS R-Channel Capacity Results	4
3.1.2 AMSS T-Channel Capacity Results	5
3.2 Message Transit Delay Results	5
3.2.1 R-Channel Message Transit Delay Results	5
3.2.2 T-Channel Message Transit Delay Results	7
3.2.3 Comparison of ADSSIM Results to SATSIM	7
3.2.4 Effect of BER on R-Channel Message Delay	8
3.2.5 P-Channel Considerations	8
4. CONCLUSIONS	8
5. RECOMMENDATIONS	9
6. REFERENCES	9
APPENDIXES	
A - AMSS Capacity Results	
B - AMSS Transit Delay Results	

LIST OF ILLUSTRATIONS

Figure		Page
1	R-Channel Capacity Required for 1 SU Message (600 BPS Channel)	11
2	R-Channel Capacity Required for 2 SU Message (600 BPS Channel)	12
3	R-Channel Capacity Required for 3 SU Message (600 BPS Channel)	13
4	R-Channel Capacity Required for 1 SU Message (1200 BPS Channel)	14
5	R-Channel Capacity Required for 2 SU Message (1200 BPS Channel)	15
6	R-Channel Capacity Required for 3 SU Message (1200 BPS Channel)	16
7	T-Channel Capacity Required for 5 SU Message (600 BPS Channel)	17
8	T-Channel Capacity Required for 7 SU Message (600 BPS Channel)	18
9	T-Channel Capacity Required for 10 SU Message (600 BPS Channel)	19
10	T-Channel Capacity Required for 5 SU Message (1200 BPS Channel)	20
11	T-Channel Capacity Required for 7 SU Message (1200 BPS Channel)	21
12	T-Channel Capacity Required for 10 SU Message (1200 BPS Channel)	22
13	R-Channel Transit Delay for 1 SU Message (600 BPS Channel)	23
14	R-Channel Transit Delay for 1-3 SU Message (600 BPS Channel)	24
15	R-Channel Transit Delay for 1 SU Message (Cumulative, 600 BPS Channel)	25
16	R-Channel Transit Delay for 2 SU Message (Cumulative, 600 BPS Channel)	26
17	R-Channel Transit Delay for 3 SU Message (Cumulative, 600 BPS Channel)	27
18	R-Channel Transit Delay for 1 SU Message (Cumulative, 1200 BPS Channel)	28
19	R-Channel Transit Delay for 2 SU Message (Cumulative, 1200 BPS Channel)	29
20	R-Channel Transit Delay for 3 SU Message (Cumulative, 1200 BPS Channel)	30
21	Comparison of ADSSIM to SATSIM Results	31
22	Effect of Bit Error Rate on Transit Delay	32

LIST OF TABLES

Table		Page
1	AMSS Analysis/Simulation Accomplishments	1
2	Relationship of T-Slot Delay to P-Channel Rate	4

EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA) is supporting the development of standards for the use of mobile satellite communication in aviation. As part of this support, the FAA has conducted an analysis and simulation of the Aeronautical Mobile Satellite Service (AMSS) to determine the capacity of this system to meet data requirements and to determine the message transit delay of this system under a range of conditions. The results show that a minimum AMSS ground station (which can receive 600 bit per second R-channels) will be able to support about 60 aircraft with a message (e.g., ADS position report) update rate of 5 minutes. The transit delay results show that, under the projected system bit error rate of $1x10^{-5}$ and 15 percent channel occupancy, the transit delay will be 75 seconds or less for 99.9 percent of the messages and 40 seconds or less for 99 percent of the messages. Voice call setup delays were also determined; the transit delay for a voice call setup message is 48 seconds for 99.9 percent of the calls. However, if the channel bit error rate drops to the lower end of the permitted range (i.e., $1x10^{-4}$), then the probability of delivery of data messages drops below 99.9 percent.

1. INTRODUCTION.

1.1 BACKGROUND.

This test report provides the results of analysis and simulation of the Aeronautical Mobile Satellite Service (AMSS) to determine the ability of the AMSS subnetwork to support projected air traffic control (ATC) applications (e.g., Automatic Dependent Surveillance (ADS) message transmission and voice call setup message transmission). This simulation focuses on the performance of the AMSS subnetwork, primarily on the link layer protocol. The simulation and analysis effort was conducted according to the "AMSS Capacity Analysis and Protocol Performance Simulation Plan," Federal Aviation Administration (FAA) Technical Note, DOT/FAA/CT-TN90/35, dated October 1990.

1.2 TEST OVERVIEW.

Table 1 summarizes the progress of this analysis and simulation effort.

Table 1, item 1, capacity analysis, was conducted for R-channel loading of 15 percent and T-channel loading of 100 percent. The number of channels required for different loading conditions can be calculated by a simple ratio and is described later in this report.

Table 1, item 2, R-channel message transit delay, was simulated for channel bit rates of 600 and 1200 bits per second (bps), representing the near term capabilities of the satellite communications equipment. R-channel delay results were calculated using the 8-s retry timer because the AMSS system description has been amended to incorporate this.

Table 1, item 3, T-channel message transit delay, also was simulated for channel bit rates of 600 and 1200 bps, representing near term capabilities of the satellite communications equipment.

Table 1, items 4 and 5, were not described in the original test plan because the enhanced version of the simulation software, SATSIM, was not available when the test plan was written. These simulations are described in section 3.2.3 and 3.2.4.

TABLE 1. AMSS ANALYSIS/SIMULATION ACCOMPLISHMENTS

Test Plan Reference	Description
5.1	AMSS Capacity Analysis
5.2.1	R-Channel Transit Delay
5.2.2	T-Channel Transit Delay
N/A	SATSIM Comparison to ADSSIM
N/A	Bit Error Rate (BER) Analysis

2. DISCUSSION.

2.1 TEST CONDUCT.

2.1.1 AMSS Capacity Analysis.

The message capacity of an AMSS R- or T-channel was calculated using equations and tables contained in the Inmarsat SDM. The equations and tables were encoded using the BASIC software language (provided in [1]) and were used to calculate the number of R- or T-channels required to support air-ground data communications, such as ADS. Since there is a range of requirements for ADS messages length and update rates, ranges of parameters were used. The inputs to the capacity calculation program were:

a. Number of AES (10, 25, 50, 100, 200, 300)

b. ADS update interval (5 minutes (min), 2 min, 1 min, 30 s, 10 s)

c. Channel bit rates (600, 1200, 2400, 10500 bps)

d. ADS message length (1, 2, 3, 5, 7, 10 signal units (SU's))

Note: Under the current AMSS architecture, user messages of 33 octets or less would be sent as up to three R-channel SU's; messages of 34 or more octets would be sent as five or more T-channel SU's. Mr. Colliver's paper recommends use of a convergence protocol resulting in a basic ADS message length of 30 octets; without the convergence protocol a total of 76 octets would be required to transmit a basic 10 octet ADS message [2].

e. Channel options (R- or T-channel).

The number of R-channels required to accommodate the ADS application was calculated with the channel loading at 15 percent. The number of T-channels required for ADS was calculated with the T-channel loaded to 100 percent. One hundred percent loading is greater than the expected T-channel loading of 70 to 80 percent, however, using 100 percent provides an upper bound on the results. The results can be adjusted to any channel loading (this is discussed later in the report).

2.1.2 Message Transit Delay Simulation.

The Boeing ADSSIM software (described in [3]) provides a simulation of AMSS which outputs message transit delay for messages of 1, 2, or 3 SU's over the R-channel under a given channel occupancy condition. The model assumes that the channel occupancy is random, and it provides a Monte-Carlo simulation of the R-channel protocol. The Boeing ADSSIM model was used to generate message transit delay time for the AMSS R-channel and was also used as part of the approximation for transit delay over the T-channel.

After the simulation plan was written, a revised version of ADSSIM, called SATSIM, was provided by Boeing. SATSIM permits the user to vary the BER of the channels being simulated. SATSIM results are provided for comparison with ADSSIM results.

2.1.2.1 R-Channel Simulation.

The following parameters were used to simulate R-channel operation:

a. R-channel occupancy (5, 10, 15, 20, and 25 percent).

b. Channel bit rates (600, 1200 bps).

c. Retransmission Timer (8 s, 15 s for voice setup).

d. Number of SU's (1, 2, 3).

e. Maximum number of retry attempts (5).

f. Reliable Link Service (RLS).

Other parameters which are requested by the ADSSIM model were given values appropriate for the goals of this simulation. These are:

g. Time to route from Ground Earth Station (GES) to destination (0 s) (to eliminate effects outside the AMSS subnetwork).

h. Number of SU's in P-channel queue (6) (6 is the minimum selectable number, chosen to minimize the effect of other traffic).

i. Mix of message sizes on channel (1 SU - 34 percent, 2 SU - 33 percent, 3 SU - 33 percent; data were also taken with 80 percent of the channel loading consisting of messages of the same length as the message being simulated.

j. Link and miscellaneous processing delays (0.5 s).

The model was run to simulate the transmission of 20,000 messages and the transit delay times were recorded. The 20,000 transit time delay calculations for each set of input conditions were stored on a disk and ordered by transit delay time. Messages which were not delivered were flagged to indicate nondelivery. From the ordered list, the transit delay times were plotted as a cumulative probability density function; the percentage of messages delivered was provided as an output of interest.

2.1.2.2 T-Channel Approximation.

The ADSSIM program contains a T-channel approximation which does not take into account the time delay of the T-channel time slot request message. To account for this delay, a model of the T-channel protocol was constructed which uses the ADSSIM R-channel model for transmission of the time slot request message in addition to other approximations.

The T-channel message transit delay is approximated by the following simplified formula:

(R-chan req time) + (time to 1st assigned slot) + (Tx time)

= total delay for T-channel

In this approximation, the "R-channel request time" is the time to transmit one SU message on the R-channel; these results are provided in the R-channel simulation described in section 4.2. The "time to first assigned slot" is dependent on the P-channel rate, as described in the International Maritime Satellite Organization (INMARSAT) SDM. This is shown in table 2.

TABLE 2. RELATIONSHIP OF T-SLOT DELAY TO P-CHANNEL RATE

P-Channel Rate	Minimum Delay to T-slots
600 bps	3.0 s
1200 bps	2.0 s
2400 bps	1.8 s
10500 bps	1.6 s

The "Tx" time is the time required to transmit the burst at the given channel rate, which can be calculated from table 4 in the INMARSAT SDM [4].

In order to assure that the simulation provides a minimum bound for the performance of the T-channel, the model uses minimum time delay to the T-channel timeslots assigned. This simplification is discussed further in the analysis. Work is currently in progress which will define T-channel delays more accurately.

3. RESULTS.

3.1 AMSS CAPACITY RESULTS.

The data used to generate the graphs in this section are included as tables in appendix A.

3.1.1 AMSS R-Channel Capacity Results.

Figure 1 shows the plot of the number of R-channels (loaded to approximately 15 percent) that would be required to accommodate the specified ADS update rates and number of aircraft. The results are plotted with the number of ADS aircraft on the abscissa and the required number of R-channels on the ordinate. Six different ADS update rates are plotted on the same graph; the update rates are shown adjacent to their respective lines. Figure 1 applies to the 600 bps R-channel rate for ADS messages which are contained in one SU. One R-channel SU contains 11 octets of user data, however, some or most of this capacity may be used for protocol header information for OSI compliant communication. It may be necessary to send an ADS message in two or three R-channel SU's; the capacity required is proportionately increased and is shown in figures 2 and 3. These figures show that the required number of channels increases quickly as the message length is increased or the update rate is decreased.

Figures 4 through 6 show the capacity results for 1200 bps rate R-channels. Tabular results for the higher data rate channels are given in appendix A.

An initial GES should support four R-channels [4], but the number can be increased by the GES operator. A Communication Satellite Corporations (COMSAT) GES will initially be equipped with four R-channels, but discussions with COMSAT personnel indicate that this number may be increased to 12 R-channels in the future. Figures 1 through 6 show that a significant number of aircraft (i.e., 60 - 180) can be accommodated by a

single GES's (minimum) four R-channels as long as the message update rate is 5 minutes. Message update rates in the 10- to 60-s range quickly consume the available channel capacity. Four 600 bps R-channels could accommodate only about five ADS aircraft at a 30-s update interval with a three SU message.

There is also a substantial decrease in the number of required channels if the message is limited to one SU, or 11 octets of user data (which includes upper layer protocol). Four 600 bps R-channels could accommodate about 60 ADS aircraft at a 5-minute update interval if the message ADS message was contained in three SU's; if the message were contained in one SU, about 180 ADS aircraft could be handled.

3.1.2 AMSS T-Channel Capacity Results.

Figure 7 shows the plot of the number of T-channels loaded to 100 percent that would be required to accommodate a specified number of aircraft at various message update rates. Loading to 100 percent is considered extreme since the expected T-channel loading is in the 70 - 80 percent range; therefore, the results here represent a bound on the minimum number of channels required. The results can be adjusted for any channel loading by dividing the number of channels required by the desired channel loading.

The results presented in figure 7 apply to the 600 bps T-channel rate for ADS messages which are contained in five SU's. A five SU T-channel message contains 34 octets of user data; however, some or most of this capacity may be used for protocol header information for OSI compliant communication. Specifically, overhead may be required for OSI network, transport, session, presentation, and application layers. Even the use of a convergence protocol to reduce overhead will still necessitate some overhead octets. It may be necessary to send an ADS message in more T-channel SU's; the capacity required for the seven SU case (representing 50 octets) is shown in figure 8, and the channel capacity required for the 10 SU case (representing 74 octets) is shown in figure 9.

Figures 10 through 12 show the capacity results for 1200 bps rate T-channels loaded to 100 percent. Tabular results for higher data rate channels are given in appendix A.

3.2 MESSAGE TRANSIT DELAY RESULTS.

The data used to generate the graphs in this section are provided in appendix B tables.

3.2.1 R-Channel Message Transit Delay Results.

Figure 13 shows the message transit delay results for the 15 percent occupied 600 bps R-channel with the transmitted message consisting of a single SU. The cumulative probability is shown along the ordinate and the transit delay is shown on the abscissa. The results show that 50 percent of the messages are delivered in 3 s, 95 percent of the messages are delivered in 16 s, 99 percent of the messages are delivered in 30 s, and 99.9 percent of the messages are delivered in 54 s. The ADS message delivery time requirement has only been specified in relatively broad terms (5 s - 1 minute [5]). The transit delay times shown in figure 13 cover this range, however, the short delay times (in the 5 - 15 s range) will not be met by a fraction of the messages transmitted. For example, if the ADS message delivery requirement is 15 s, then 5 percent of the messages transmitted will not meet this.

The important assumption made in the ADSSIM simulation of the R-channel is that the messages on an R-channel are transmitted at a random time with respect to one another. This may be true of passenger telephone call setup messages or a pilot's request for an altitude reassignment, but it probably will not be true for ADS message transmission. The transmission of basic ADS message will be periodic. However, since there is no current method to coordinate transmission start times for ADS, each aircraft's transmission will appear random to other aircraft. Therefore, the assumption of random message transmission may be valid for this case.

Figure 14 shows the results for the 15 percent loaded 600 bps R-channel with the transmitted message consisting of two or three SU's (the one SU case is included for reference). The message delivery time increases more dramatically at the higher probability end of the curve; this is expected since messages consisting of more SU's are more likely to have collisions on the R-channel.

The Federal Aviation Administration (FAA) may, in the future, use ADS reports from aircraft in oceanic sectors for routine applications (flight following) or critical applications (aircraft separation). These applications will demand messages delivered in a specified time with a specified high probability of success. The remainder of the data are plotted in figures 15 to 20, showing the change in the "high probability" transit delay time (95, 99, and 99.9 percent cumulative probabilities) with respect to R-channel occupancy.

Figure 15 shows the high probability transit delay time data as a function of channel occupancy for the 600 bps R-channel with a message length of one SU. Figure 15 shows curves for three sets of data: the 95, 99, and 99.9 percent probability of success. The data are plotted in this manner to emphasize the importance of specifying a probability of success along with a transit delay time. Figure 16 gives the same data for two SU messages, and figure 17 gives the same data for three SU messages. It should be noted that increasing the message length from one to three SU's on an R-channel with 15 percent occupancy increases the mean delivery time by only 2.2 s, but the 95 percent cumulative probability delivery time increases by 8.4 s, the 99 percent cumulative probability delivery time increases by 8.8 s, and the 99.9 percent cumulative probability delivery time increases by 21.4 s.

It should be noted in figure 17 that at 20 percent and above channel occupancies, the probability of delivery is less than 99.9 percent. This result is important if the requirement for message delivery is 99.9 percent. Figures 18 - 20 show the high probability delay time results for the 1200 bps R-channel.

3.2.1.1 R-Channel Voice Call Request Message Delivery.

The AMSS call setup protocol for an air-to-ground voice call is initiated by the transmission of a call request SU on the R-channel. The call request is transmitted as a Direct Link Service (DLS) message, but other protocol features cause retransmission if the request is not acknowledged. The basic timer for the retransmission is 15 s. The data in appendix B indicate the delay time that will be experienced by the call request SU on a 15 percent occupied 600 bps R-channel. The results show that the median (50 percent cumulative probability) time for a call setup SU to be delivered is 2.91 s on a 600 bps R-channel, the 95 percent cumulative probability delivery time is 23.3 s, the 99 percent cumulative probability delivery time is 44.2 s, and the 99.9 percent cumulative probability delivery time is 71.6 s.

Voice channel availability is restricted to an AES with a high gain antenna, therefore, it is likely that a 10500 bps R-channel would be available to transmit the voice call request. For the 10500 bps R-channel, the median time is 0.5 s, the 95 percent cumulative probability delivery time is 16.1 s, the 99 percent cumulative probability delivery time is 31.8 s, and the 99.9 percent cumulative probability delivery time is 48.2 s.

The 95, 99, and 99.9 percent cumulative probability delivery delays exceed the proposed 2-s requirement defined in reference 5. These delays are significant since they will apply to emergency situations (unless some changes are made to AMSS). Currently, all air-to-ground R-channel traffic (including low priority passenger communications) are placed on the same set of R-channels; there is no capability to direct high priority or emergency traffic onto reserved R-channels. A high priority call request SU on an R-channel, such as an emergency voice call request, could collide with a low priority SU from another aircraft, such as a passenger telephone call setup request. The use of dedicated R-channels is one method which would solve this priority problem.

3.2.2 T-Channel Message Transit Delay Results.

A minimum bound on the T-channel transit delay time may be calculated by adding the minimum delay waiting for a timeslot and the transmission duration to the delivery time for a one SU message representing the timeslot request message. The minimum delay for the 600 bps channel is 3 s, and the minimum delay for the 1200 bps channel is 2 s. The transmission delay for a 10 SU message on a 600 bps T-channel is 3.8 s, and the minimum transmission time for a 10 SU message on the 1200 bps T-channel is 1.9 s. (The calculations are made according to table 5 in the SDM [4].) The transit delay for the 600 and 1200 bps R-channels for a single SU are shown in figures 15 and 18. The resultant cumulative probability delivery delays on the 600 bps T-channel is 23.2 s for 95 percent, 37.4 s for 99 percent, and 60.4 s for 99.9 percent. The results for the 1200 bps T-channel are 16.1 s for 95 percent, 27.2 s for 99 percent, and 42.9 s for 99.9 percent.

The results discussed here represent a situation where there is no queuing delay for use of the T-channel. This is overly optimistic. Other work currently in progress indicates that, with 70 percent T-channel loading, some messages may experience a delay of over 20 s in waiting for available time slots on the T-channel [6].

3.2.3 Comparison of ADSSIM Results to SATSIM.

The SATSIM program is similar to ADSSIM but includes the capability to input the BER of the channel being simulated. SATSIM was run for the 600 bps and 1200 bps R-channels for the three SU message length case, with a channel BER set to $1x10^{-5}$. The 95, 99, and 99.9 percent cumulative probability transit delay results for the 600 bps R-channel are shown in figure 21. The figure also includes the ADSSIM results for comparison. The results for the 1200 bps R-channel are included in annex B. The figures show that ADSSIM and SATSIM give similar results, and that a BER of $1x10^{-5}$ has no significant impact on the message delivery delay times except for the 99.9 percent cumulative probability results. A 10 percent increase in transit delay is seen for the 99.9 percent results.

3.2.4 Effect of BER on R-Channel Delivery Delay.

The target BER on AMSS P-, R-, and T-channels is $1x10^{-5}$, however, degradation to $1x10^{-4}$ is permitted by the power control mechanism. Loss of a P-channel is not declared until the BER exceeds $1x10^{-4}$ for a 3-minute averaging time. The effect of BER on the message delivery time (for a three SU R-channel message on a 600 bps channel) is shown in figure 22. The most severe effect is on the 99.9 percent delay time; increasing the BER above $1x10^{-5}$ to $5x10^{-5}$ causes the probability of delivery to drop below 99.9 percent. As the BER increases from $1x10^{-5}$ to $1x10^{-4}$, the 99 percent cumulative probability delivery delay time increases by 5 s, and the 95 percent cumulative probability delivery delay increases by 2 s. The delays increase sharply when the BER exceeds $1x10^{-4}$. At a BER of $1x10^{-3}$, the probability of delivery drops below 99 percent.

3.2.5 P-Channel Considerations.

This analysis was performed to examine the transit delays primarily in the air-to-ground direction. Communications in the ground-to-air direction occurs over the P-channel, which provides sequential transmission of SU's. Since there is no chance of collision with another SU, the main cause of nondelivery is due to uncorrected bit errors, which affects only about 1 SU per 1,000. The transit delay on a lightly loaded channel is then on the order of a few seconds. Heavy channel use can cause SU queuing, which can cause longer delays. One analysis estimated the average ground-air message transit delay at 10 s [7].

4. CONCLUSIONS.

The following conclusions are evident from the analysis and Monte-Carlo simulation of AMSS.

a. AMSS can currently meet a near term requirement to transmit ADS messages in three R-channel SU's (assuming that the ADS message and overhead are 33 octets or less) with a 5-minute update interval if a 40-s or less AMSS transit delay is acceptable for 99 percent of the messages. When the system is operating at $1x10^{-5}$ BER, the 99.9 percent transit delay time is 75 s. However, since the BER is permitted to be as great as $1x10^{-4}$, AMSS cannot guarantee that the probability of delivery will equal or exceed 99.9 percent. If used exclusively for ADS periodic reporting, a single GES with the minimum four R-channels could accommodate approximately 60 aircraft.

b. There are significant system capacity benefits to be gained if the amount of data to be sent and the overhead associated with a routine ADS message are limited to a single R-channel SU. For example, a single GES with four R-channels could accommodate about 180 ADS equipped aircraft with a 5-min update interval if the ADS message was contained in a single R-channel SU, while a single GES with four R-channels could handle about 60 aircraft if the ADS message required three SU's.

c. There are significant delivery time benefits to be gained if the data and the overhead associated with a routine ADS message can be contained within a single R-channel SU. For example, 99.9 percent of the ADS messages contained in a single R-channel SU would be delivered within 53.6 s, while the 99.9 percent cumulative probability delivery time for a three SU message rises to 75 s.

d. There are significant delivery delays of R-channel voice call setup messages which exceed proposed requirements. On the 10500 bps R-channel, 95 percent of the call setup messages are delivered within 16.1 s, 99 percent of the messages are delivered within 31.8 s, and 99.9 percent of the messages are delivered within 48.2 s.

e. AMSS has been designed to operate at the edge of its performance for messages which require 99.9 percent probability of delivery, in both channel occupancy (15 percent) and BER ($1x10^{-5}$). Exceeding these limits decreases the probability of delivery below 99.9 percent.

5. RECOMMENDATIONS.

In view of the results of this study, the following recommendations are proposed:

a. The current AMSS architecture will provide significant improvements over current oceanic HF voice communication and can meet a near term ADS requirement; however, if requirements for reduced aircraft separation standards in oceanic regions necessitate additional communication enhancements to meet ADS and voice call setup requirements, then the AMSS Panel should develop methods to improve performance of AMSS, such as limiting overhead, using dedicated emergency channels, and requiring sequential and coordinated ADS message transmission.

b. That the dynamic control mechanisms which restrict the AMSS R-channel loading to 15 percent and maintain the BER at $1x10^{-5}$ should be analyzed and simulated, since these factors greatly affect the delivery delay times.

c. That the scope of this study should be expanded to include the Aeronautical Telecommunication Network (ATN) - encompassing the effect of upper layer protocols and of the connecting aircraft and terrestrial subnetworks expected to carry ATC data. This simulation would require a more capable modeling tool, such as OPNET. It is expected that the results of simulations which include the operation of proposed OSI protocols at all layers will aid in the selection of useful protocols and quickly eliminate protocols which are too slow or require too much overhead to be useful in an operational environment.

6. REFERENCES.

1. Dehel, Thomas F., Aeronautical Mobile Satellite Service (AMSS) Capacity Analysis and Protocol Performance Simulation Plan, Technical Note, CTA Inc. for the FAA Technical Center, DOT/FAA/CT-TN90/35, October 1990.

2. Colliver, F. W., and Signore, T. L., Provision of Automatic Dependent Surveillance Using a Link-Independent Satellite Subnetwork Access Protocol, AMSSP/3-WP/19, 1990.

3. Judd, Thomas, ADS Delivery Time Analysis, ICAO AMMSP/3, 1990.

4. INMARSAT, System Definition Manual (SDM) for the Aeronautical Mobile Satellite Service (AMSS), London, U.K., 1990.

5. Scales, Walter, et al., Preliminary FAA Requirements for the Aeronautical Mobile Satellite Service (AMSS), ICAO AMSSP/3, 1990.

6. Scales, Walter, A Simplified Monte Carlo Simulation of a T-channel Reservation Process (to be submitted to the ICAO AMSS Working Group).

7. Scales, Walter, Preliminary Estimates of Transit Delay for AMSS Packet Data Service, ICAO AMSSP/WG-A/2-WP/57.

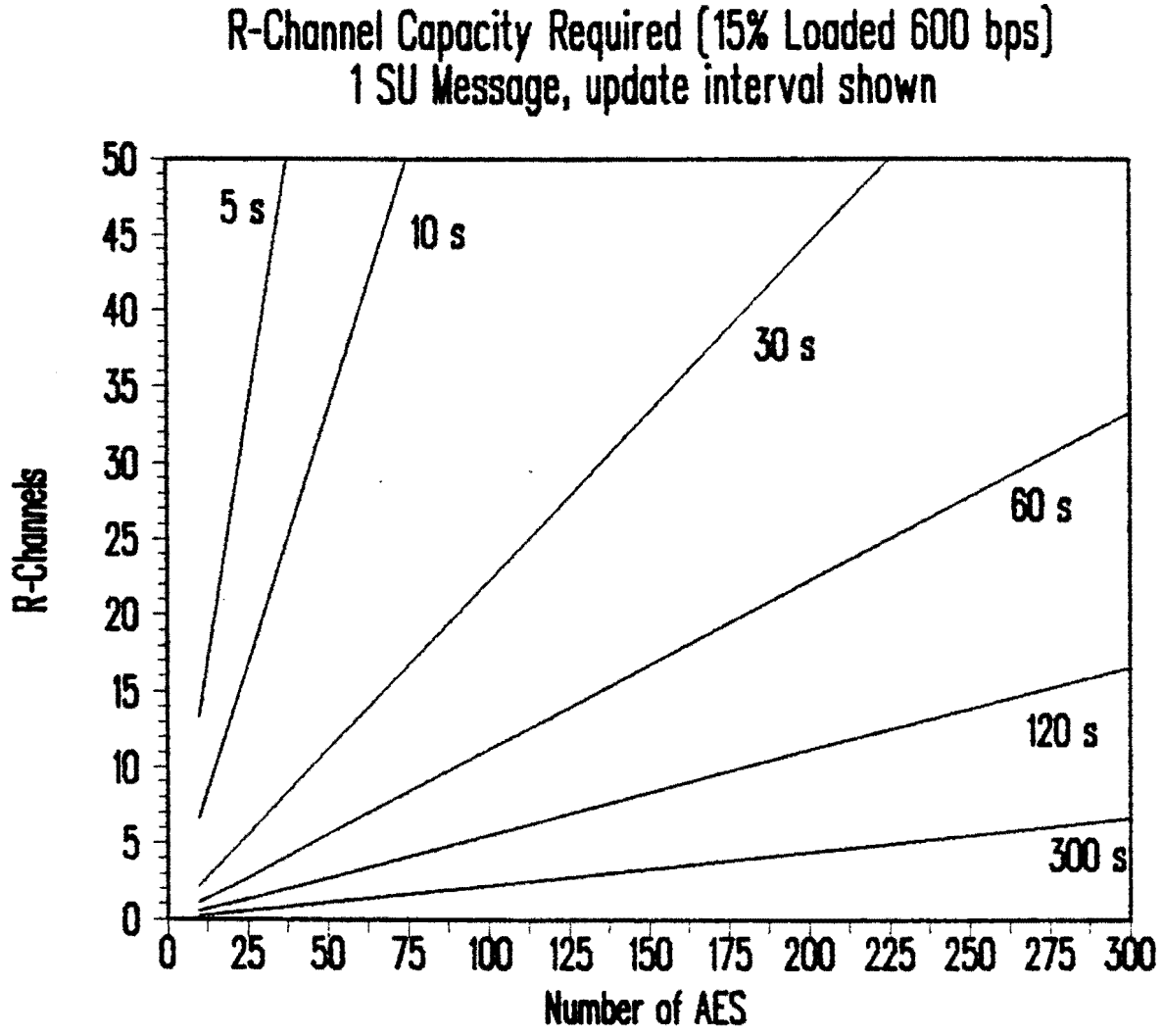

FIGURE 1. R-CHANNEL CAPACITY REQUIRED FOR 1 SU MESSAGE

(600 BPS CHANNEL)

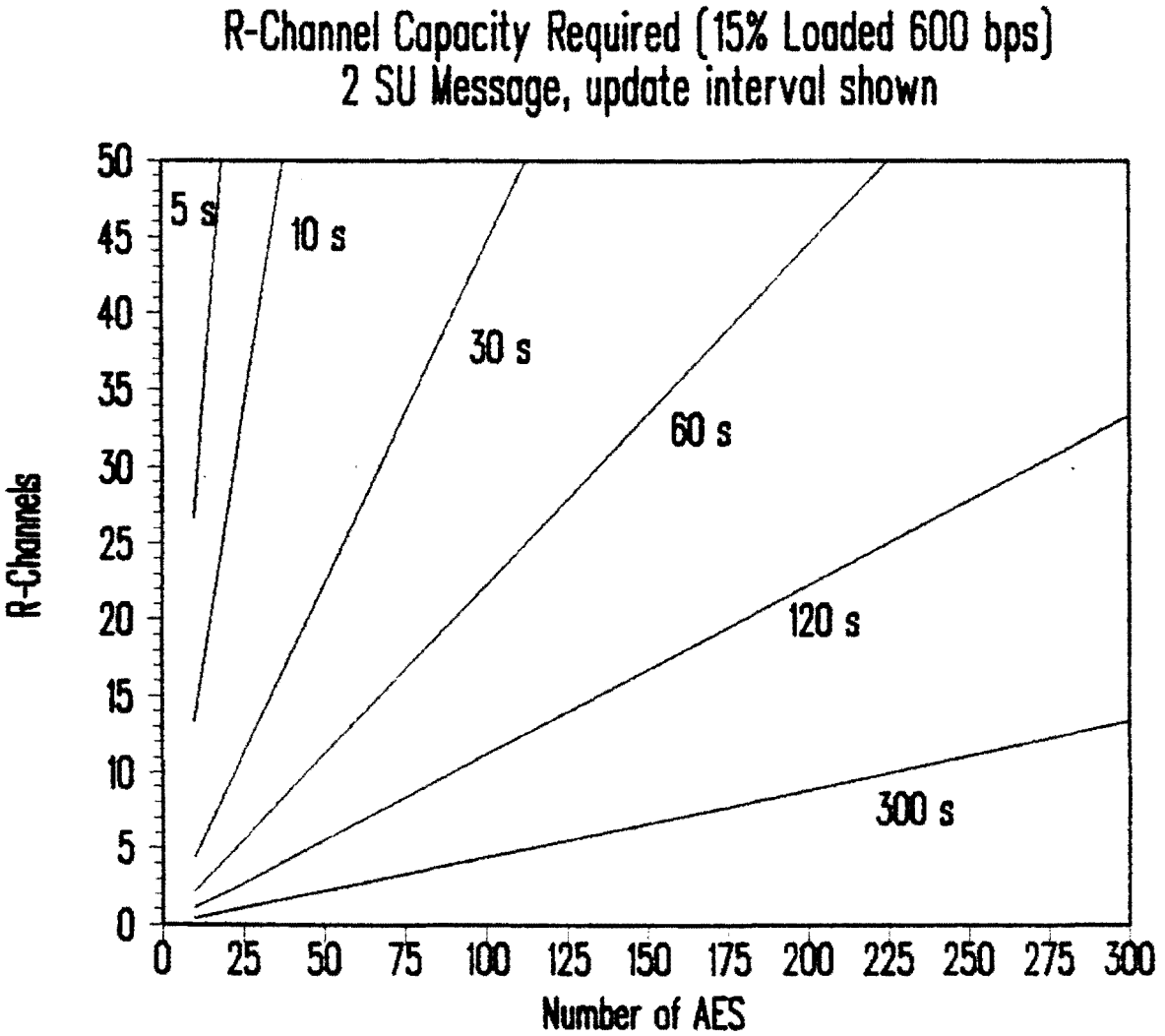

FIGURE 2. R-CHANNEL CAPACITY REQUIRED FOR 2 SU MESSAGE

(600 BPS CHANNEL)

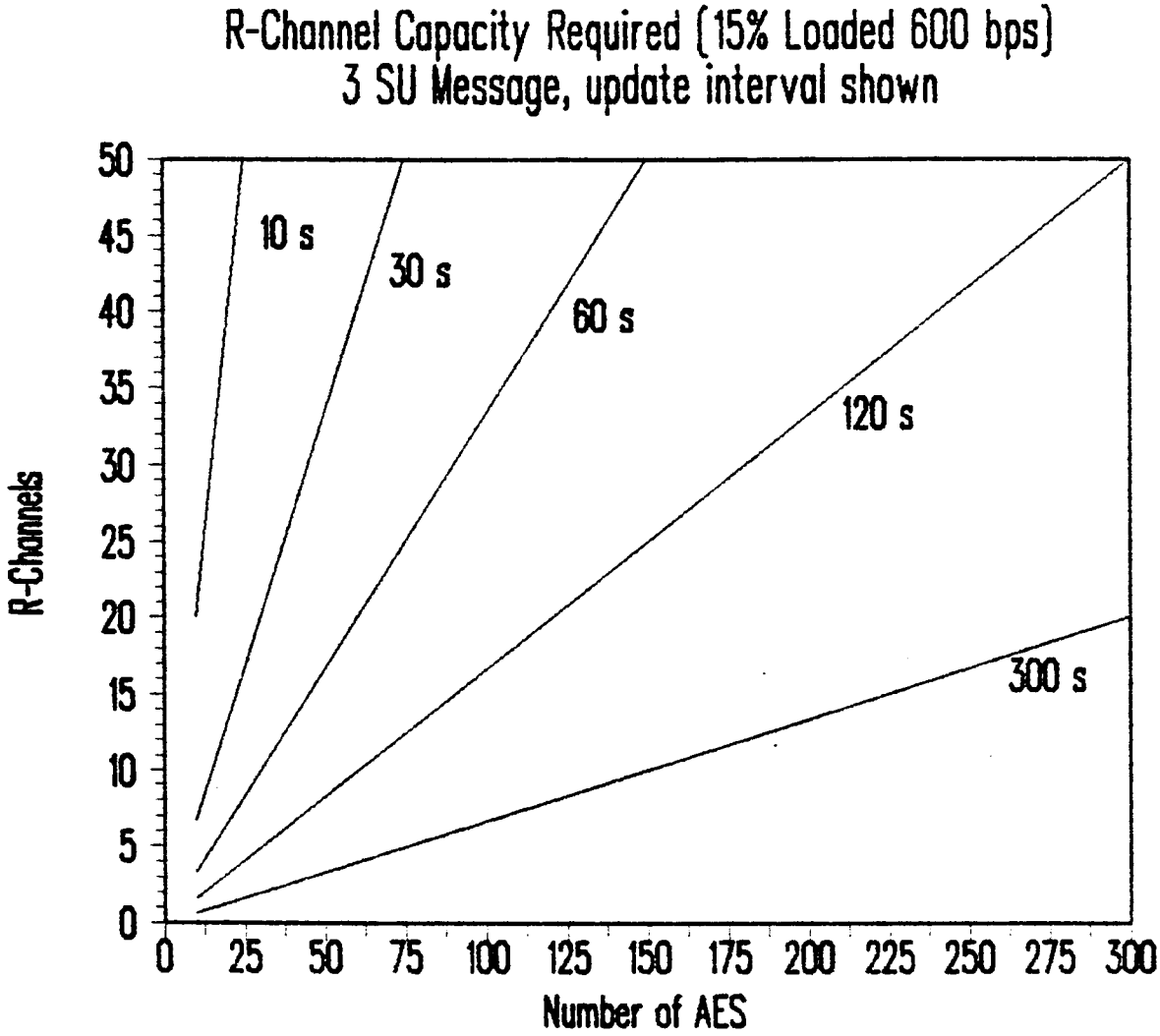

FIGURE 3. R-CHANNEL CAPACITY REQUIRED FOR 3 SU MESSAGE

(600 BPS CHANNEL)

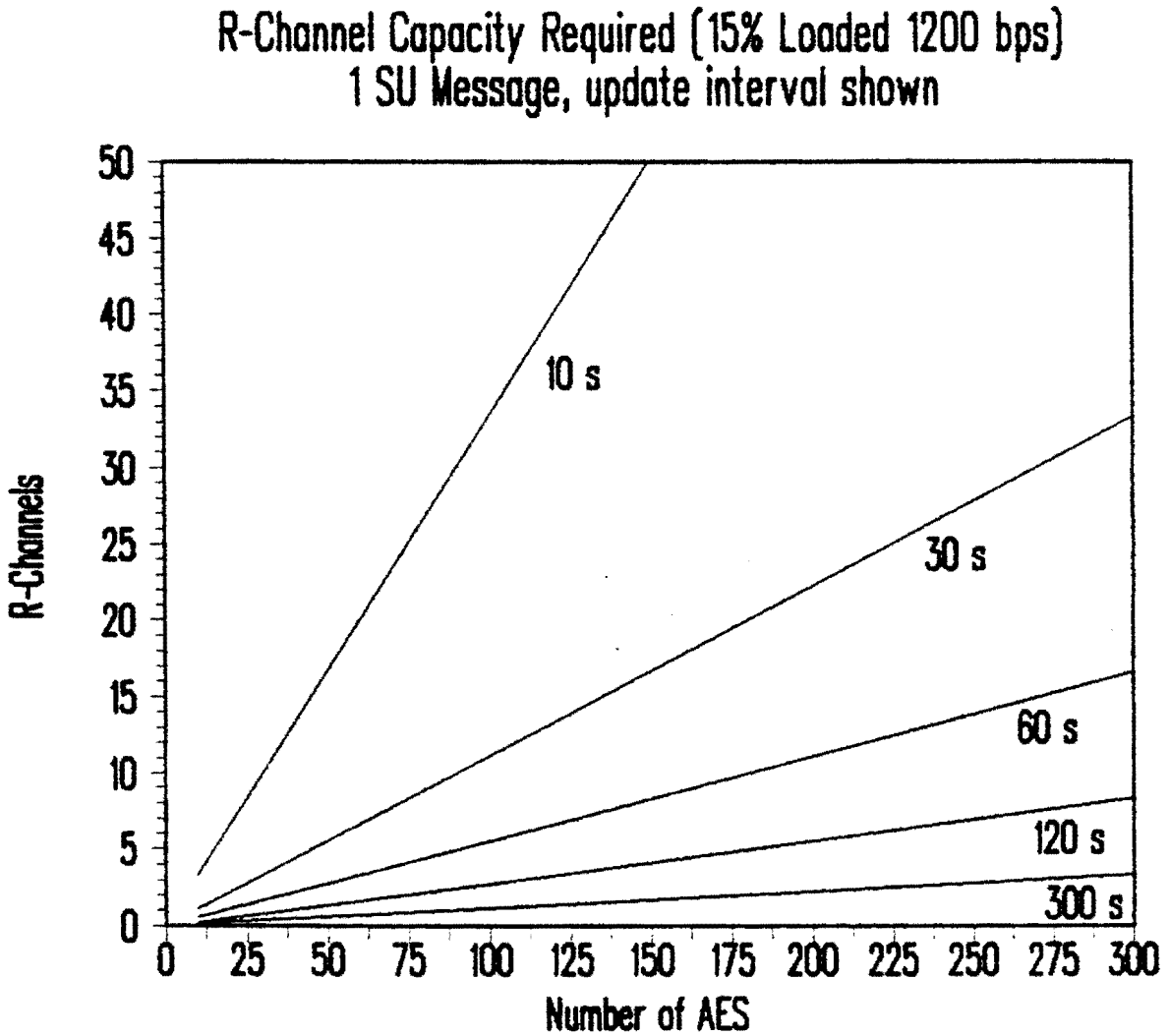

FIGURE 4. R-CHANNEL CAPACITY REQUIRED FOR 1 SU MESSAGE

(1200 BPS CHANNEL)

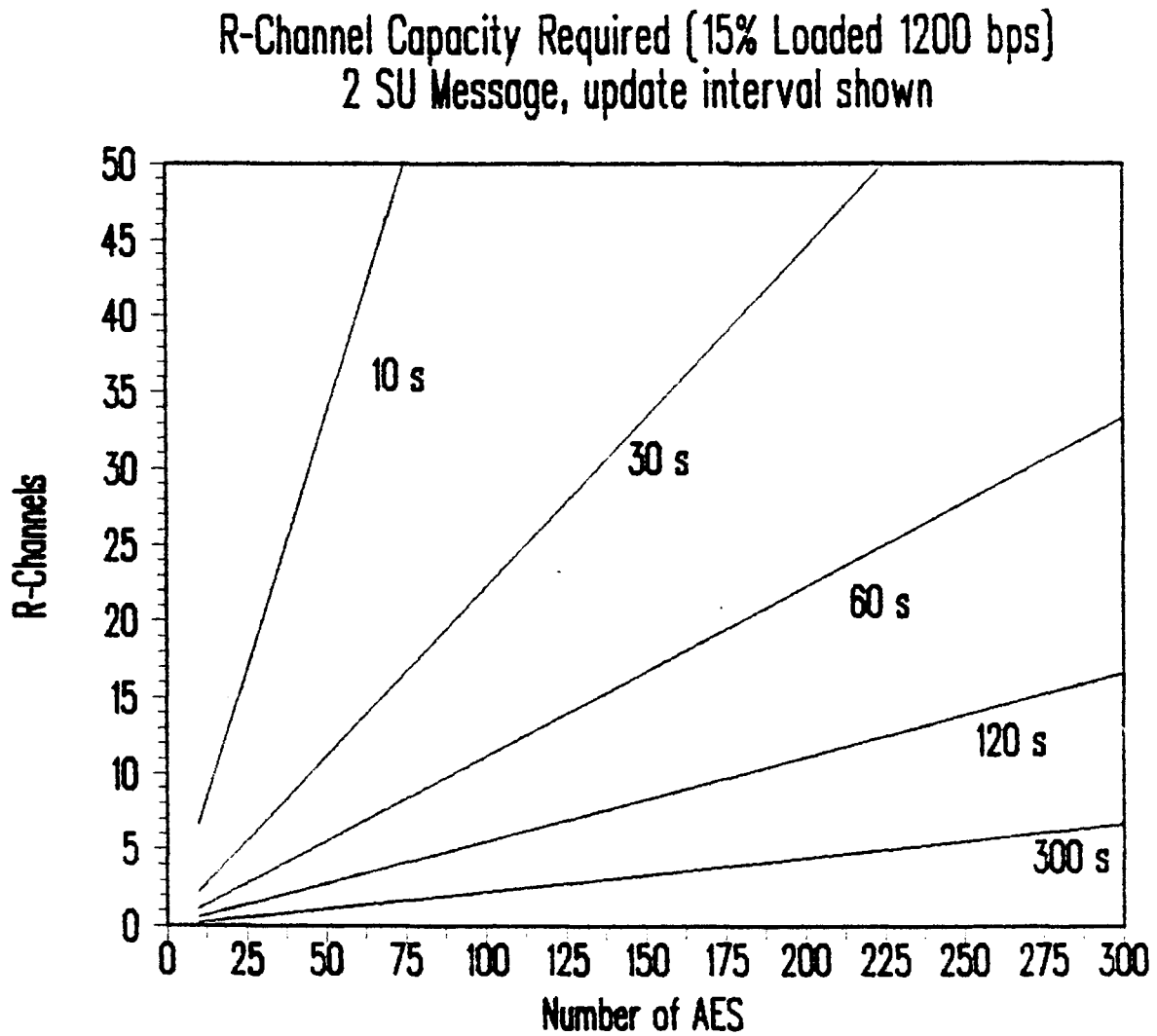

FIGURE 5. R-CHANNEL CAPACITY REQUIRED FOR 2 SU MESSAGE

(1200 BPS CHANNEL)

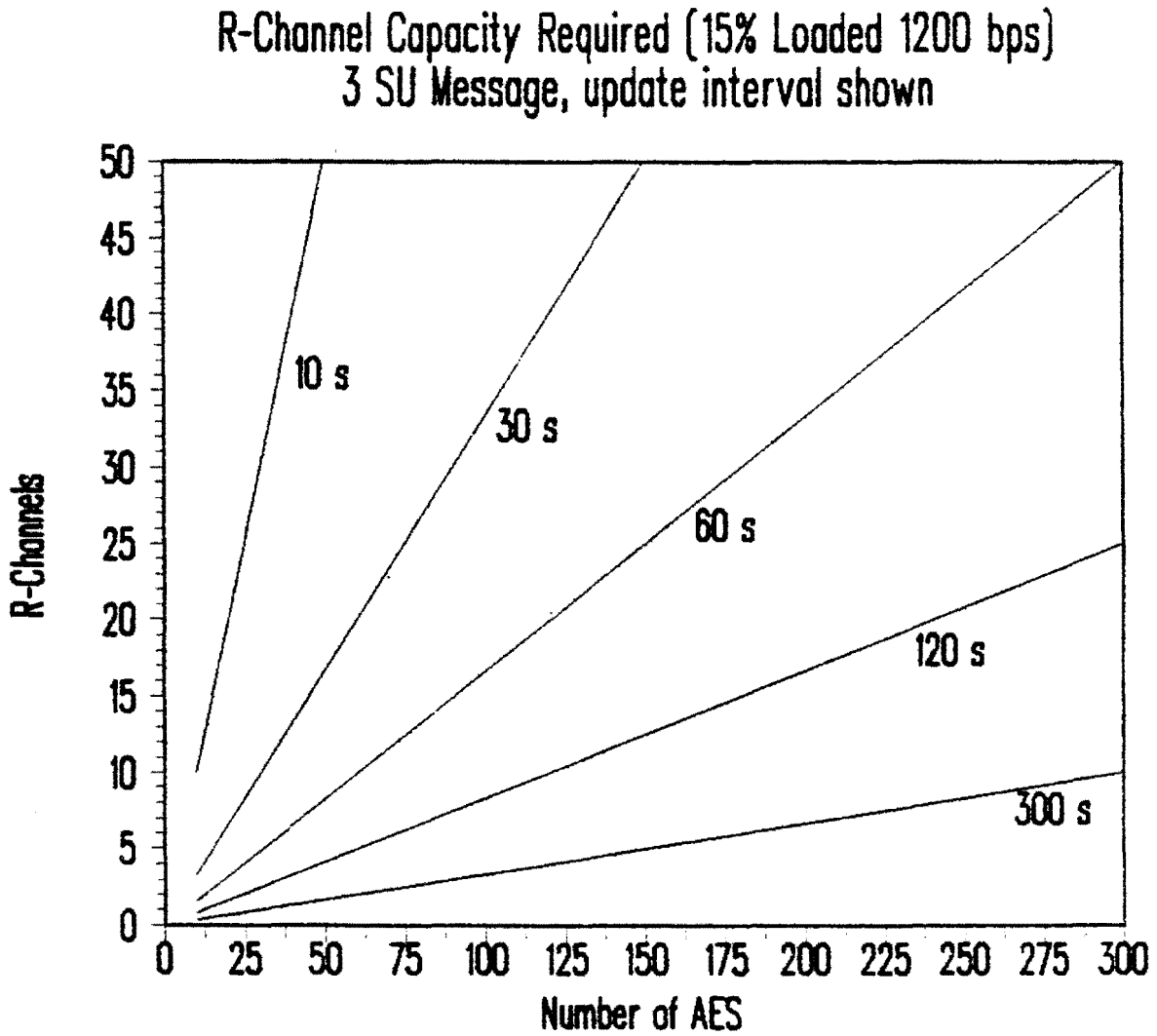

FIGURE 6. R-CHANNEL CAPACITY REQUIRED FOR 3 SU MESSAGE

(1200 BPS CHANNEL)

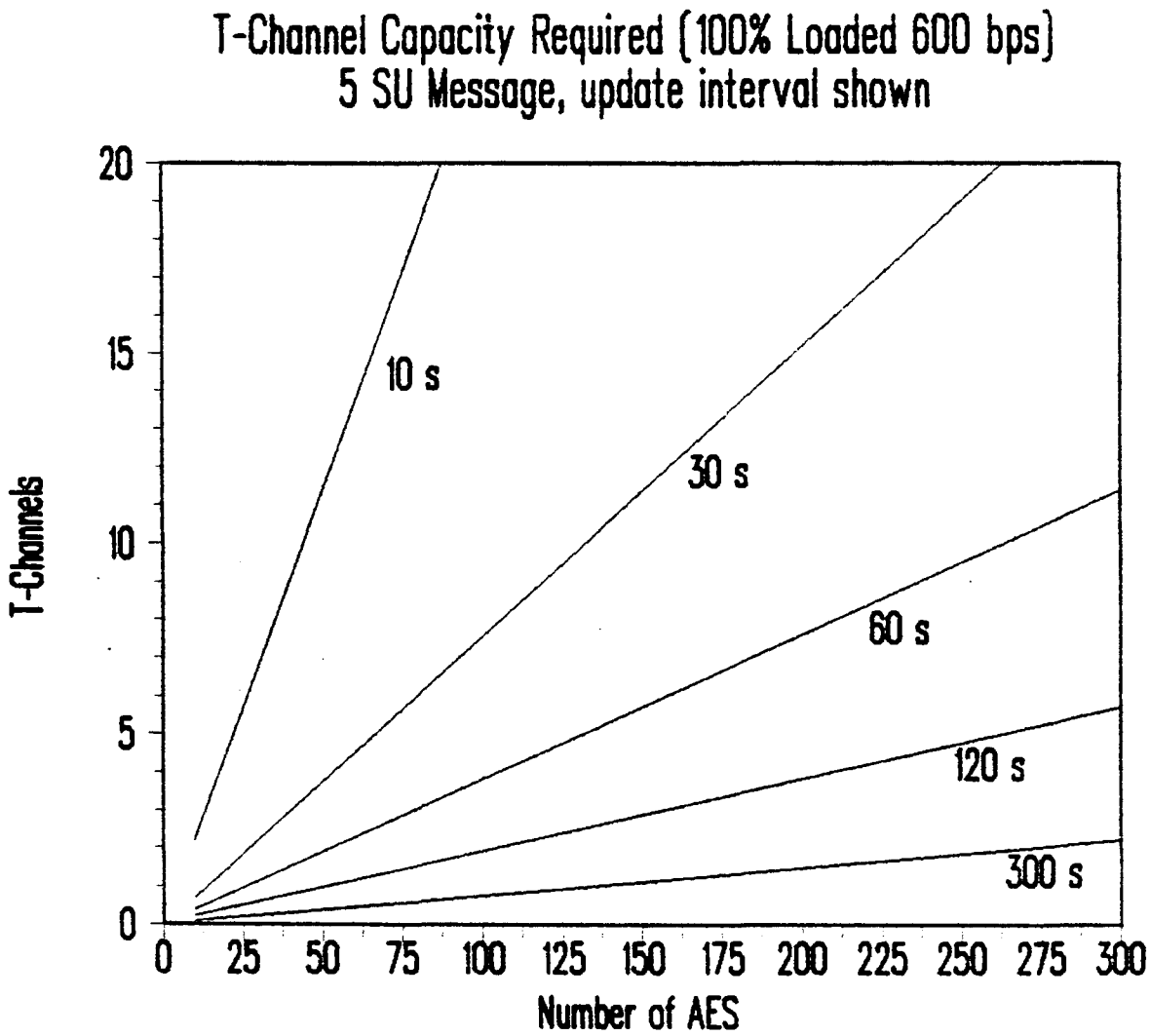

FIGURE 7. T-CHANNEL CAPACITY REQUIRED FOR 5 SU MESSAGE (600 BPS CHANNEL)

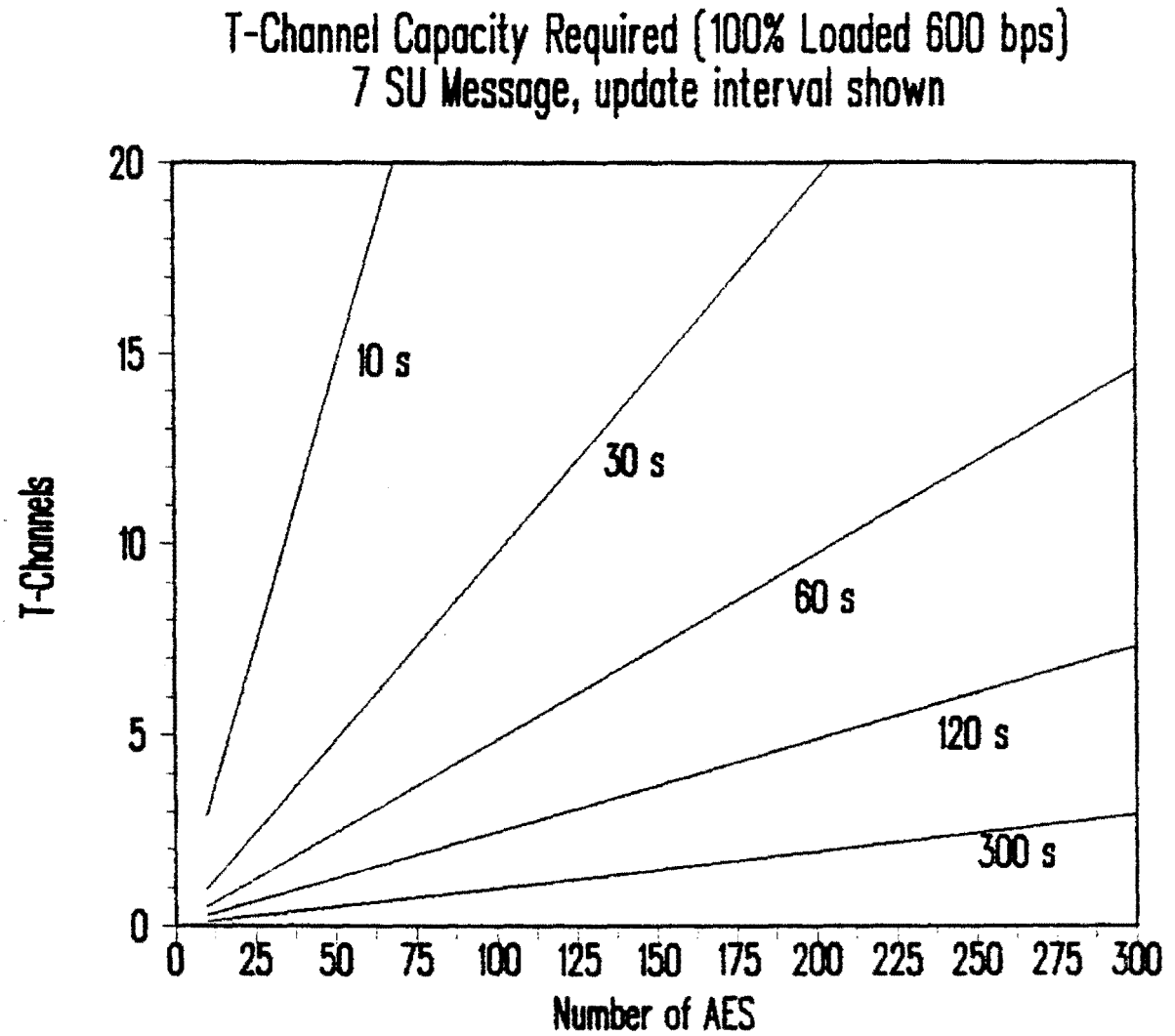

FIGURE 8. T-CHANNEL CAPACITY REQUIRED FOR 7 SU MESSAGE

(600 BPS CHANNEL)

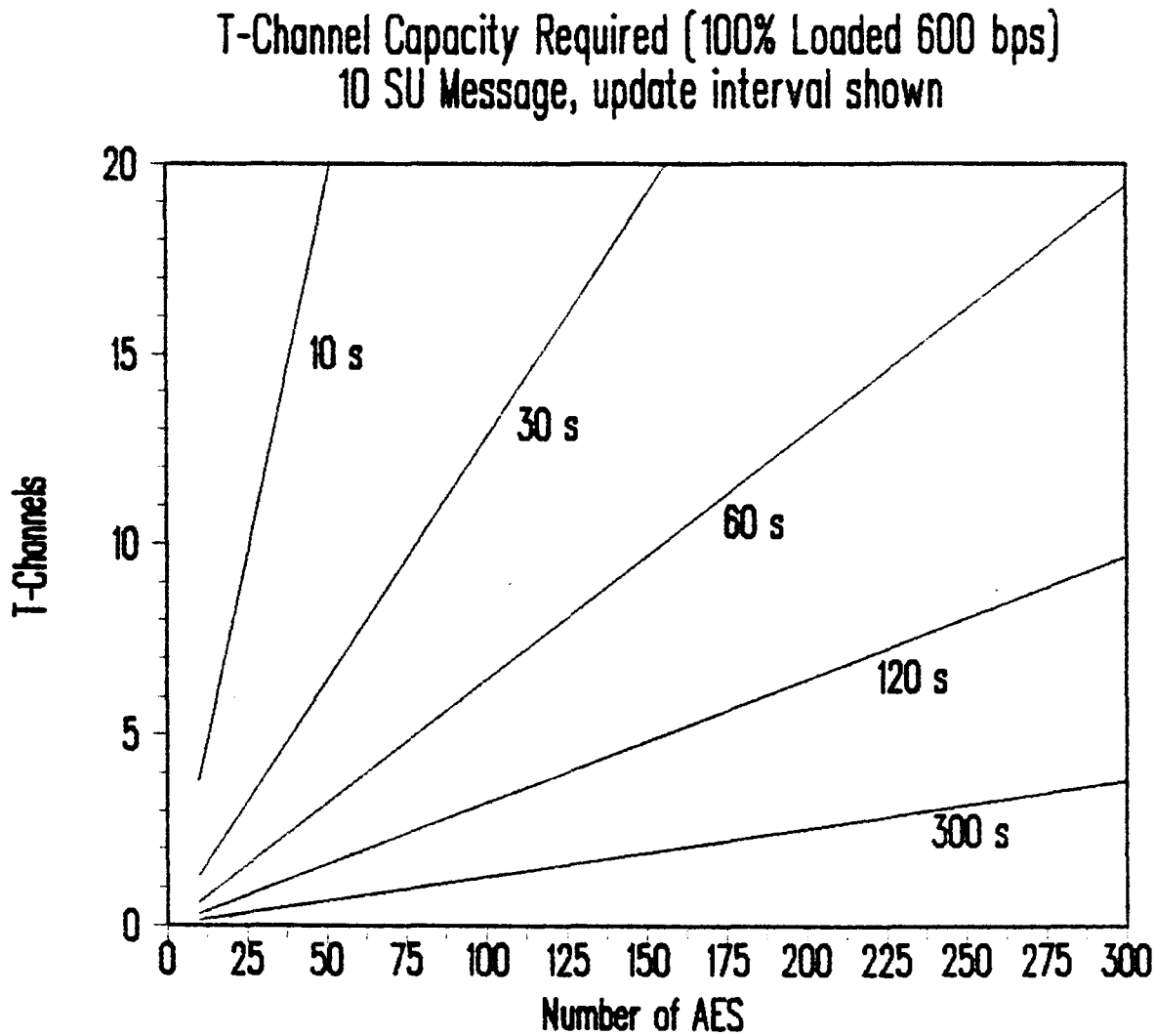

FIGURE 9. T-CHANNEL CAPACITY REQUIRED FOR 10 SU MESSAGE (600 BPS CHANNEL)

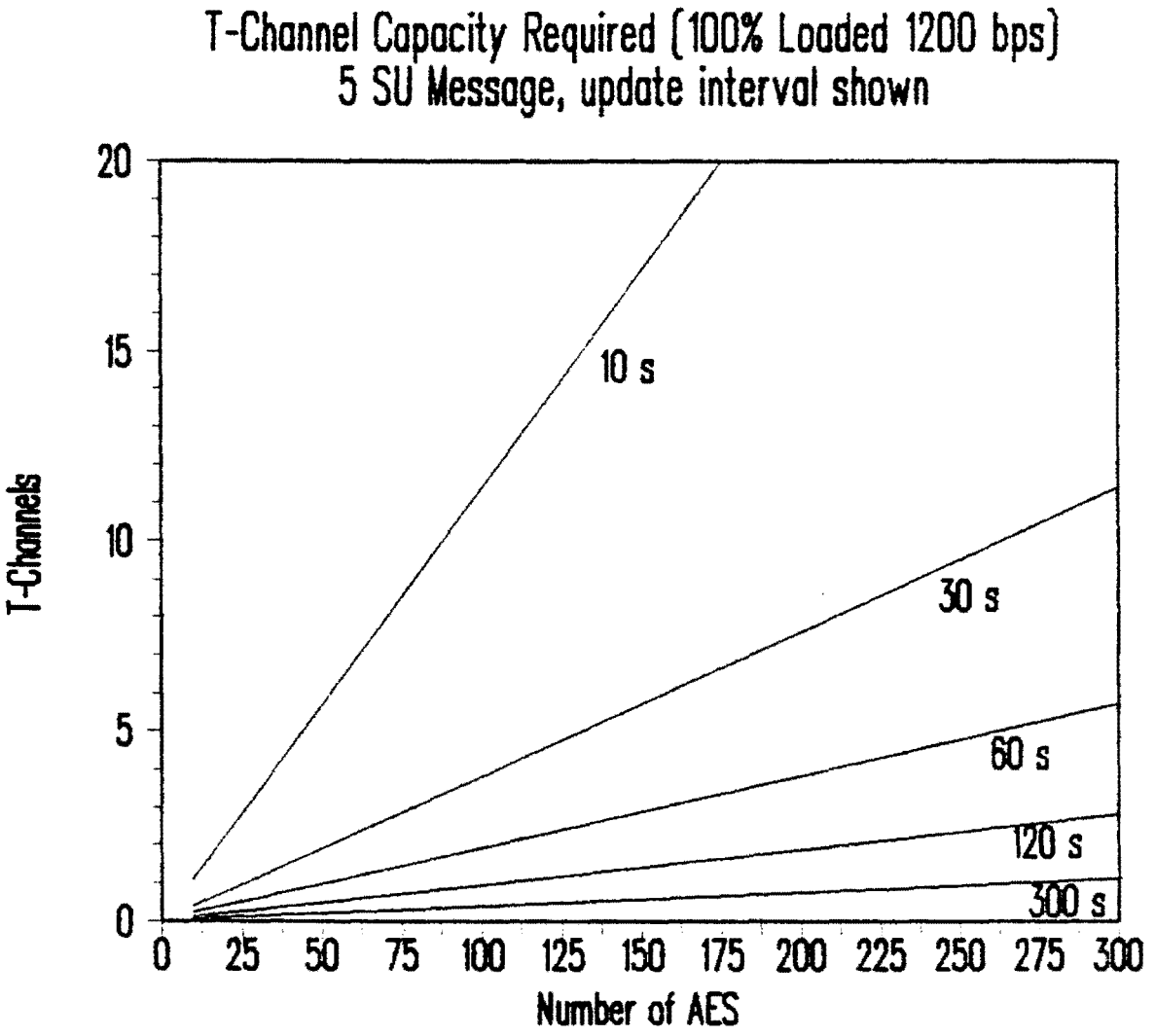

FIGURE 10. T-CHANNEL CAPACITY REQUIRED FOR 5 SU MESSAGE

(1200 BPS CHANNEL)

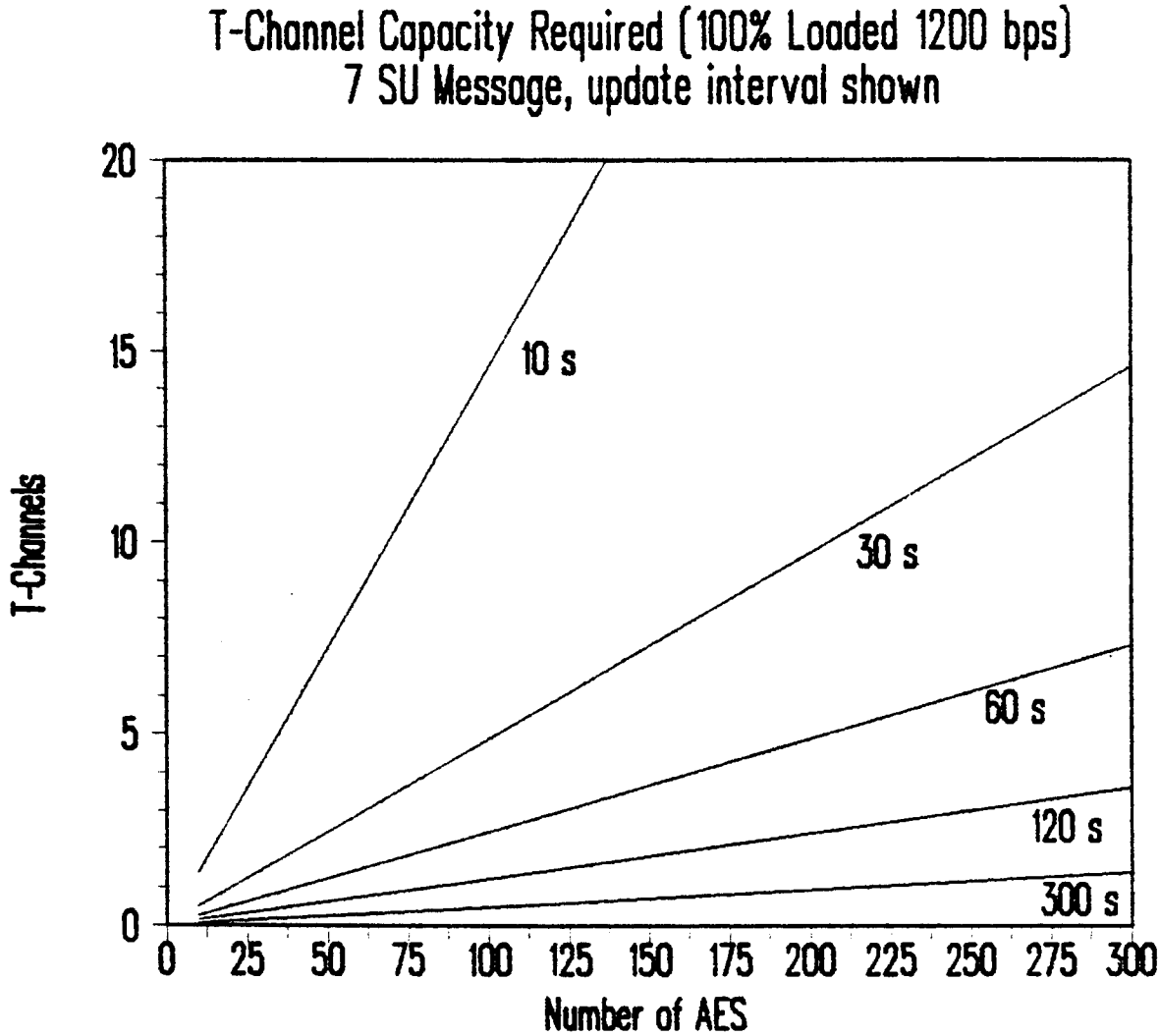

FIGURE 11. T-CHANNEL CAPACITY REQUIRED FOR 7 SU MESSAGE

(1200 BPS CHANNEL)

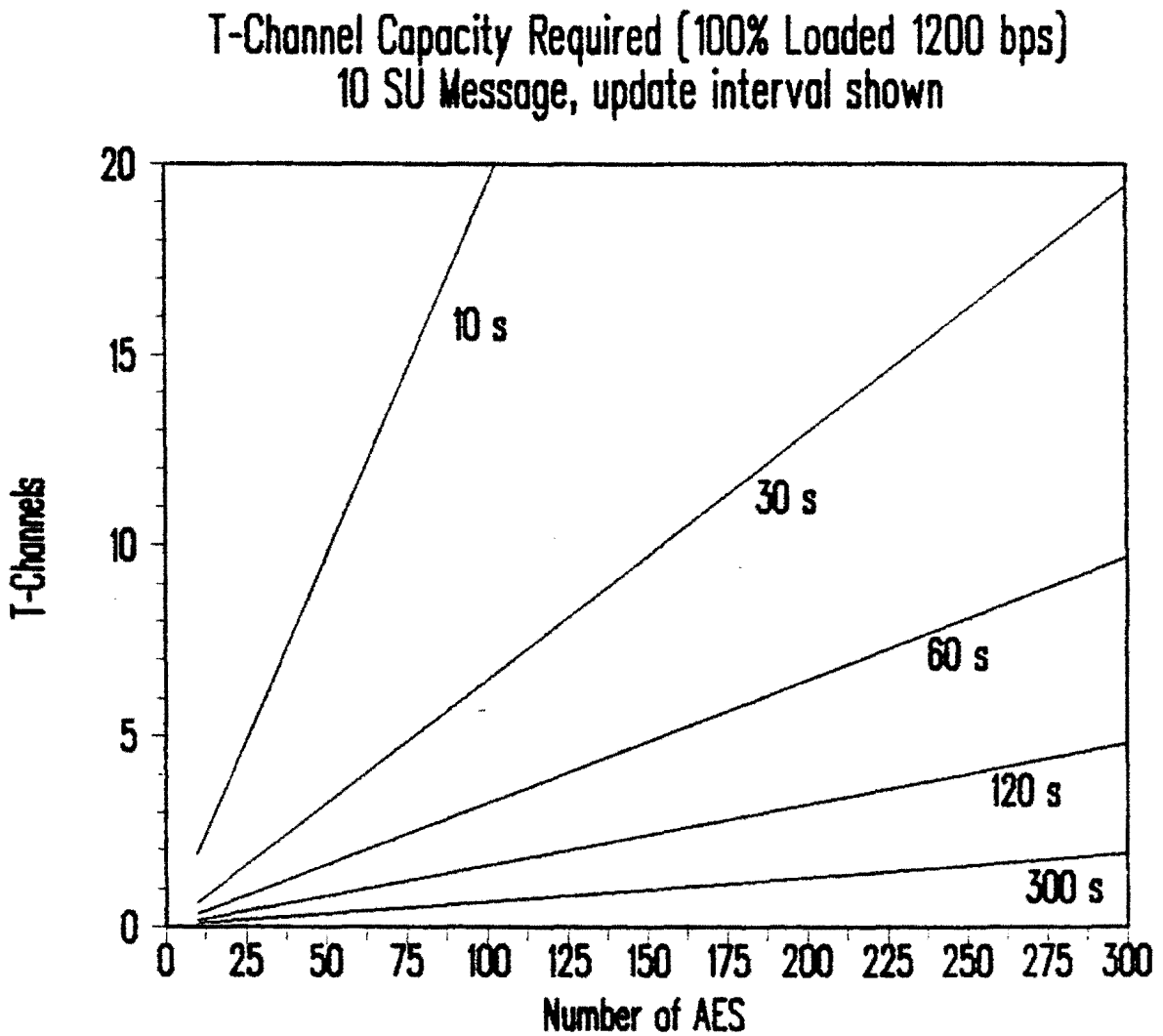

FIGURE 12. T-CHANNEL CAPACITY REQUIRED FOR 10 SU MESSAGE (1200 BPS CHANNEL)

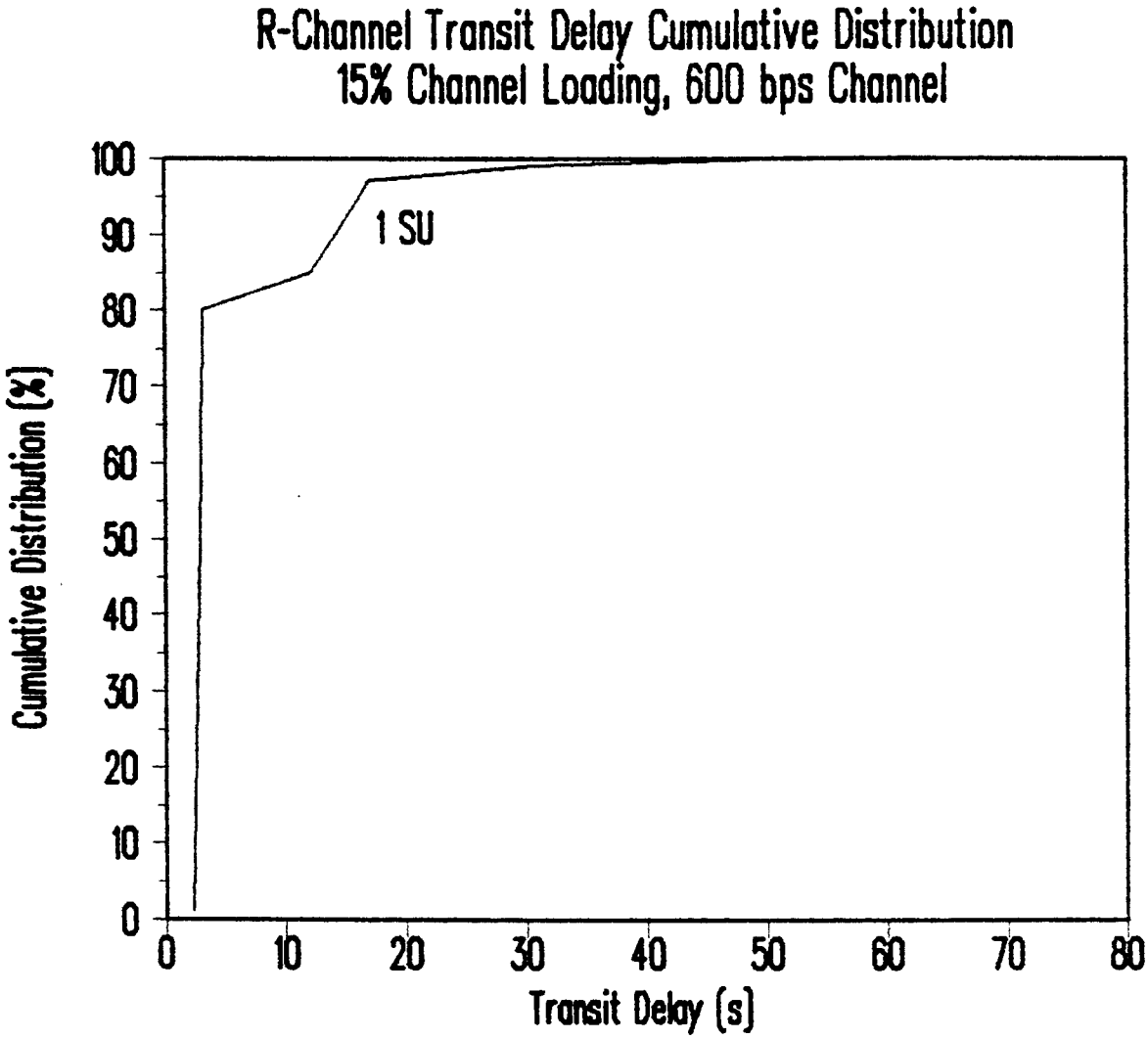

FIGURE 13. R-CHANNEL TRANSIT DELAY FOR 1 SU MESSAGE
(600 BPS CHANNEL)

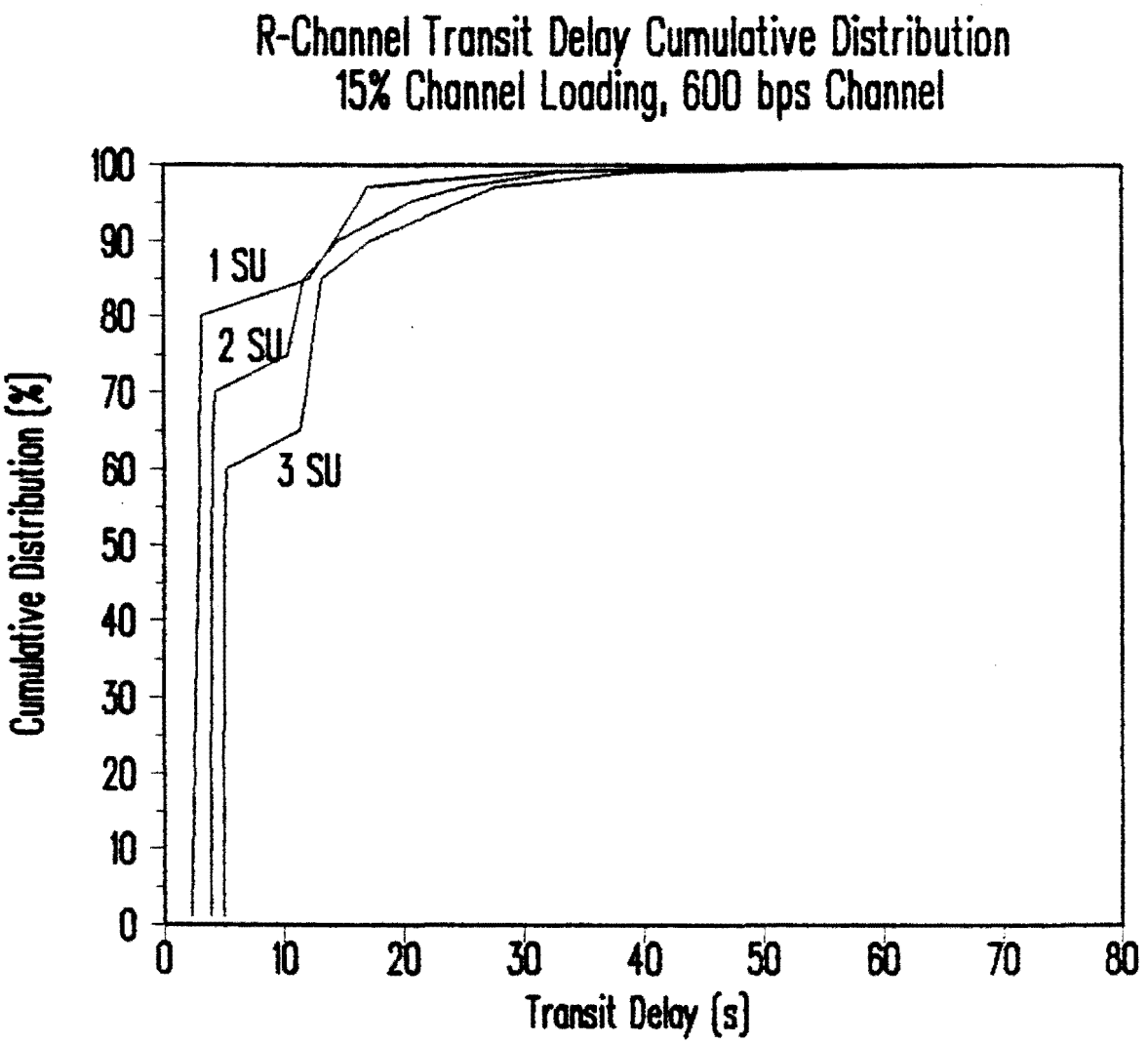

FIGURE 14. R-CHANNEL TRANSIT DELAY FOR 1-3 SU MESSAGE
(600 BPS CHANNEL)

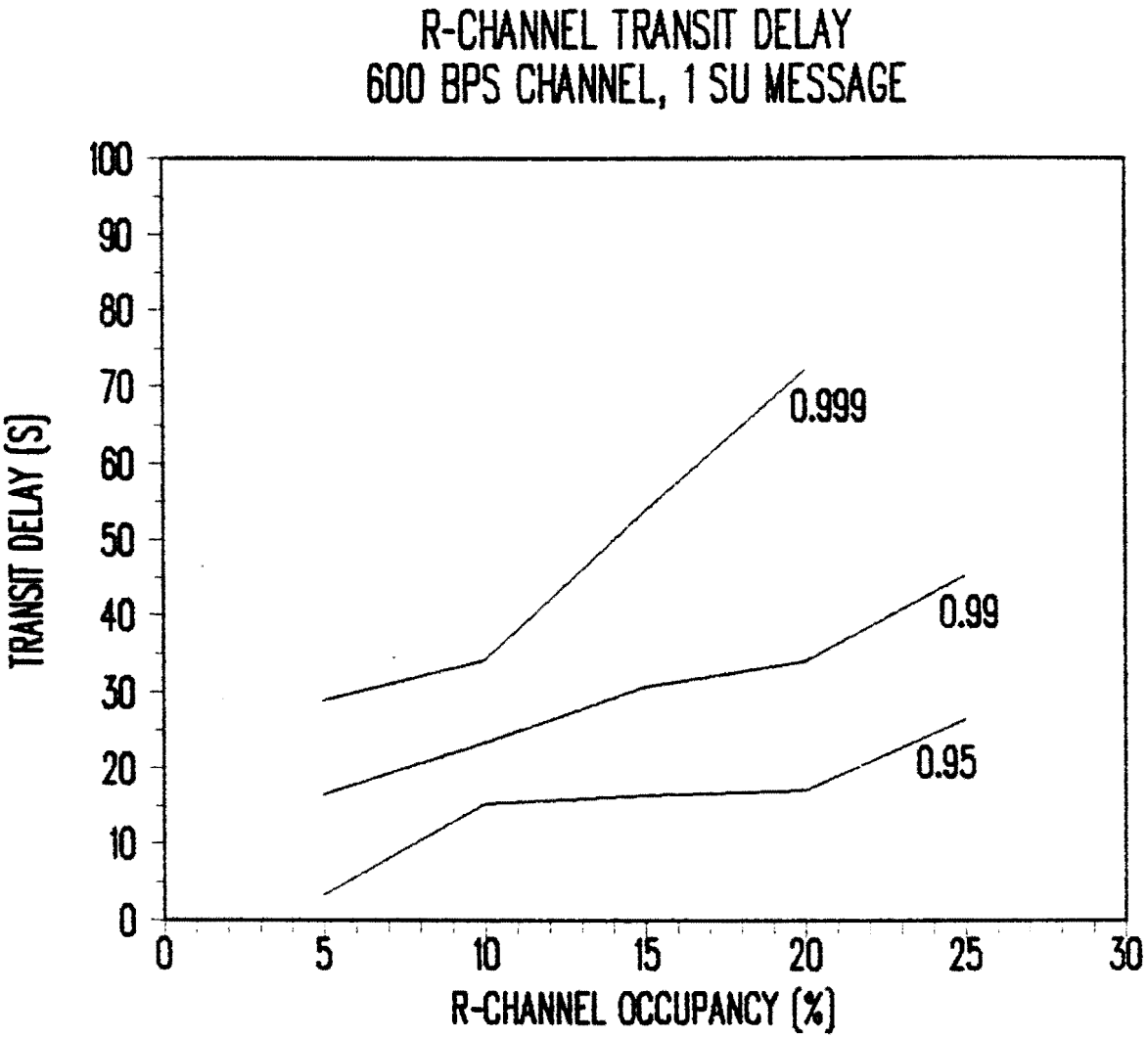

FIGURE 15. R-CHANNEL TRANSIT DELAY FOR 1 SU MESSAGE (CUMULATIVE, 600 BPS CHANNEL)

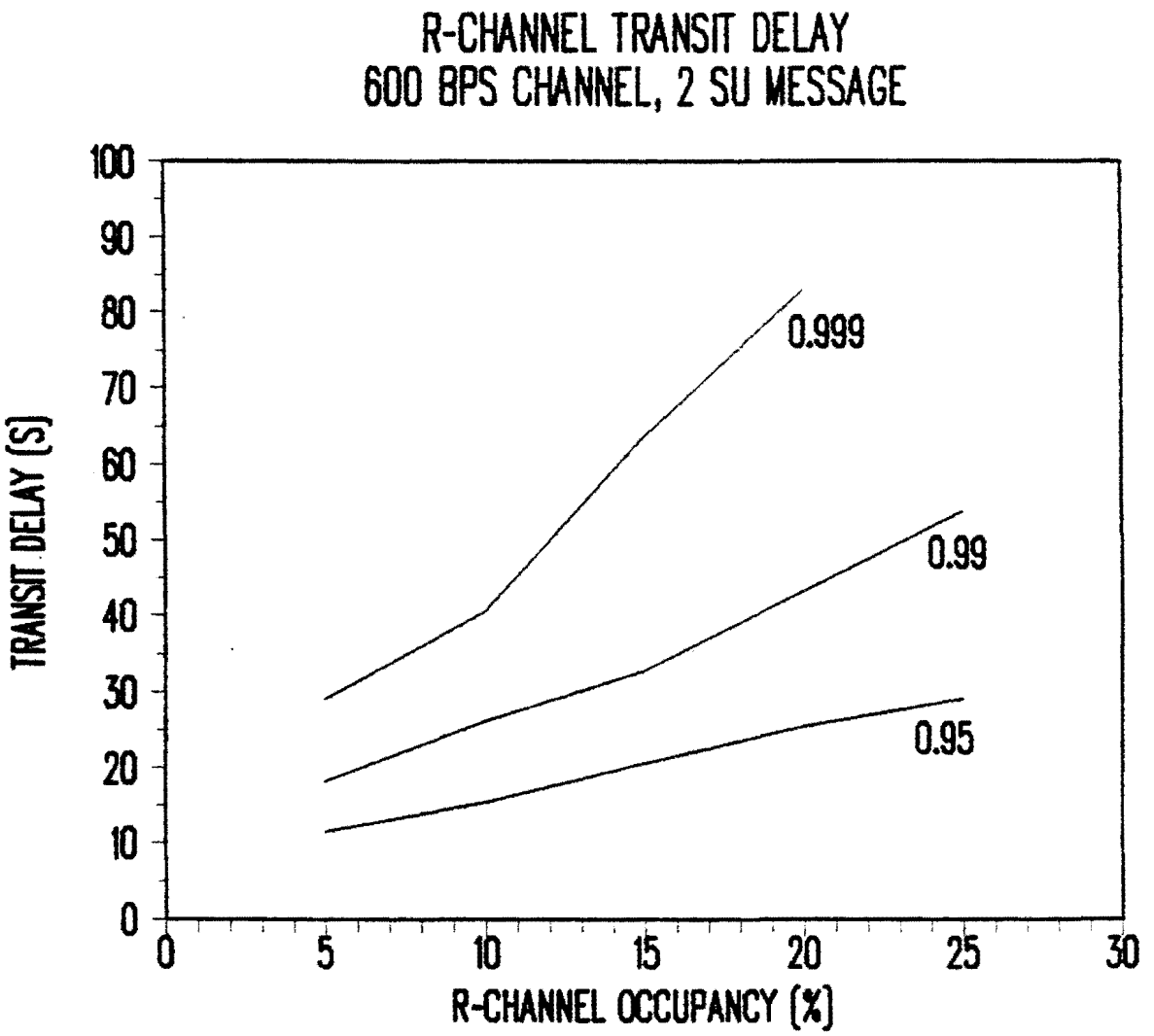

FIGURE 16. R-CHANNEL TRANSIT DELAY FOR 2 SU MESSAGE (CUMULATIVE, 600 BPS CHANNEL)

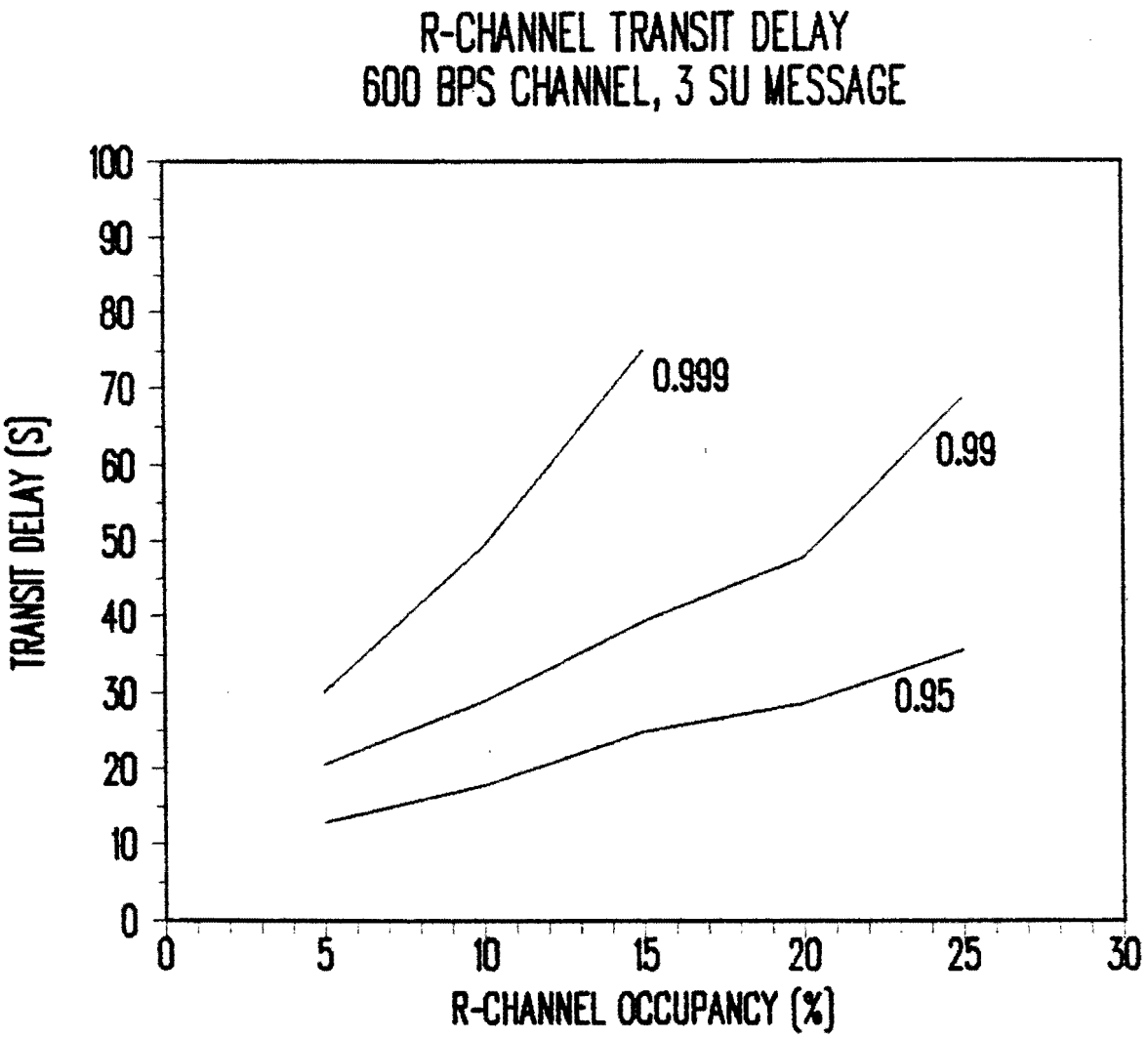

FIGURE 17. R-CHANNEL TRANSIT DELAY FOR 3 SU MESSAGE
(CUMULATIVE, 600 BPS CHANNEL)

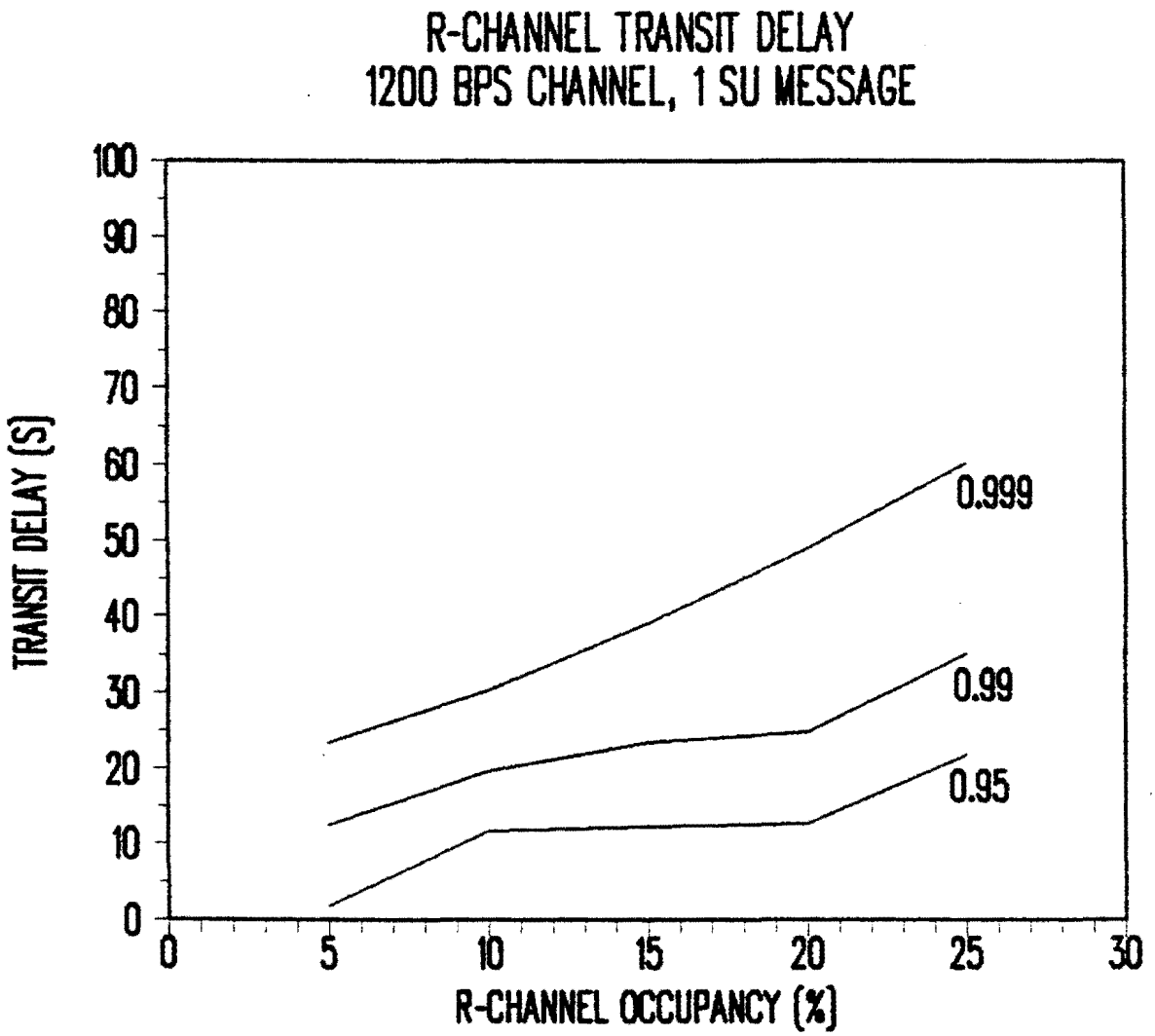

FIGURE 18. R-CHANNEL TRANSIT DELAY FOR 1 SU MESSAGE

(CUMULATIVE, 1200 BPS CHANNEL)

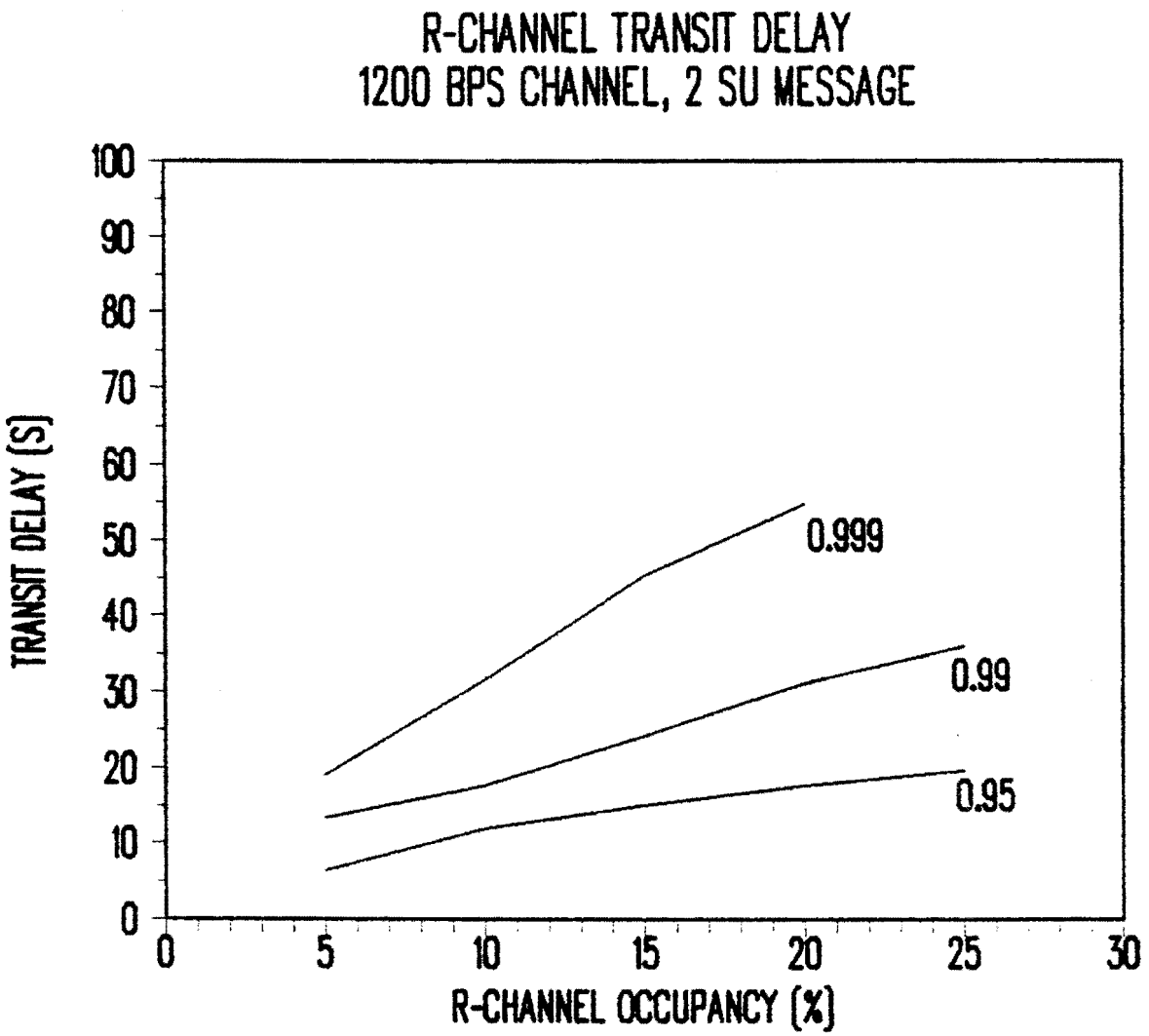

FIGURE 19. R-CHANNEL TRANSIT DELAY FOR 2 SU MESSAGE

(CUMULATIVE, 1200 BPS CHANNEL)

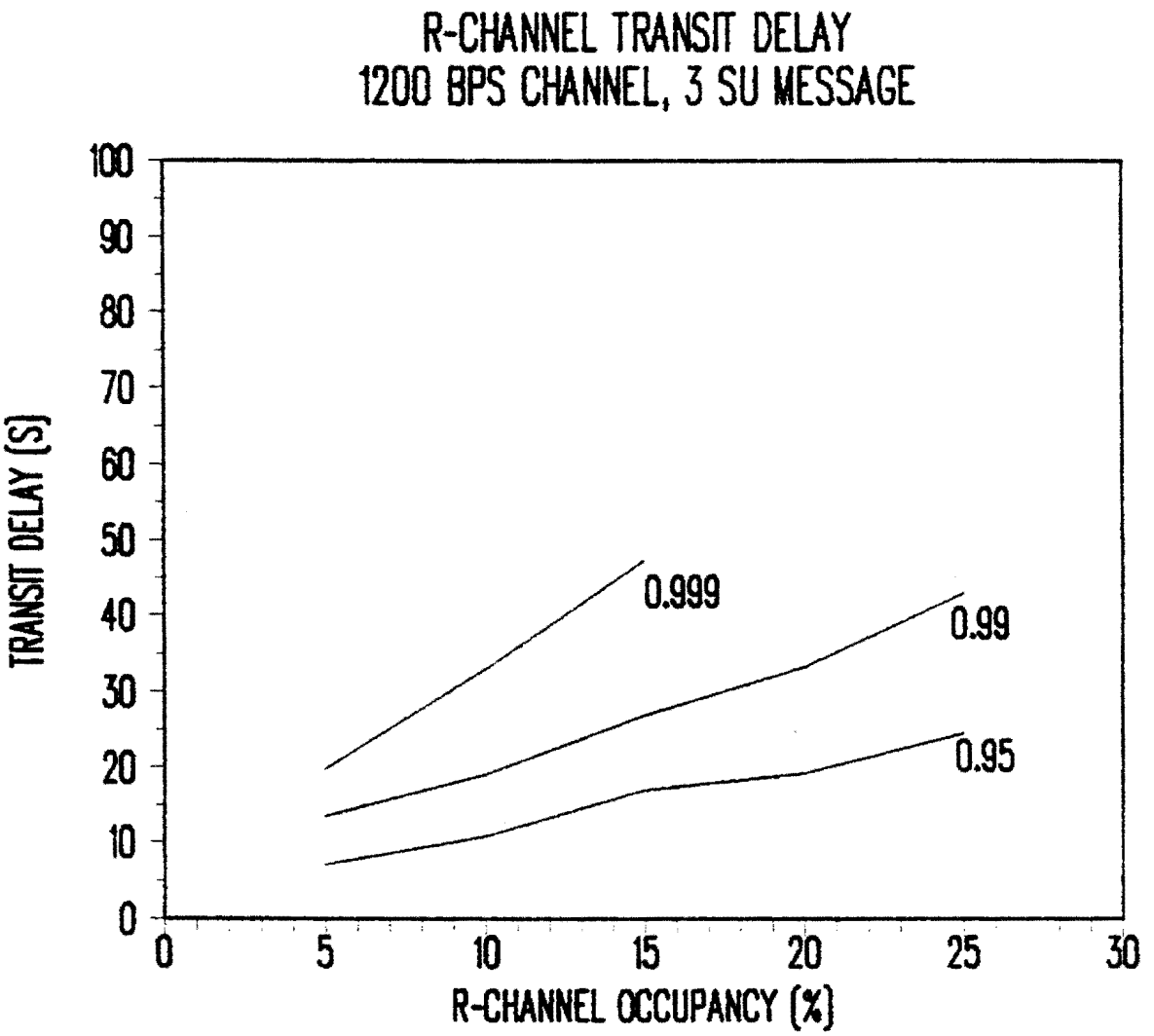

FIGURE 20. R-CHANNEL TRANSIT DELAY FOR 3 SU MESSAGE

(CUMULATIVE, 1200 BPS CHANNEL)

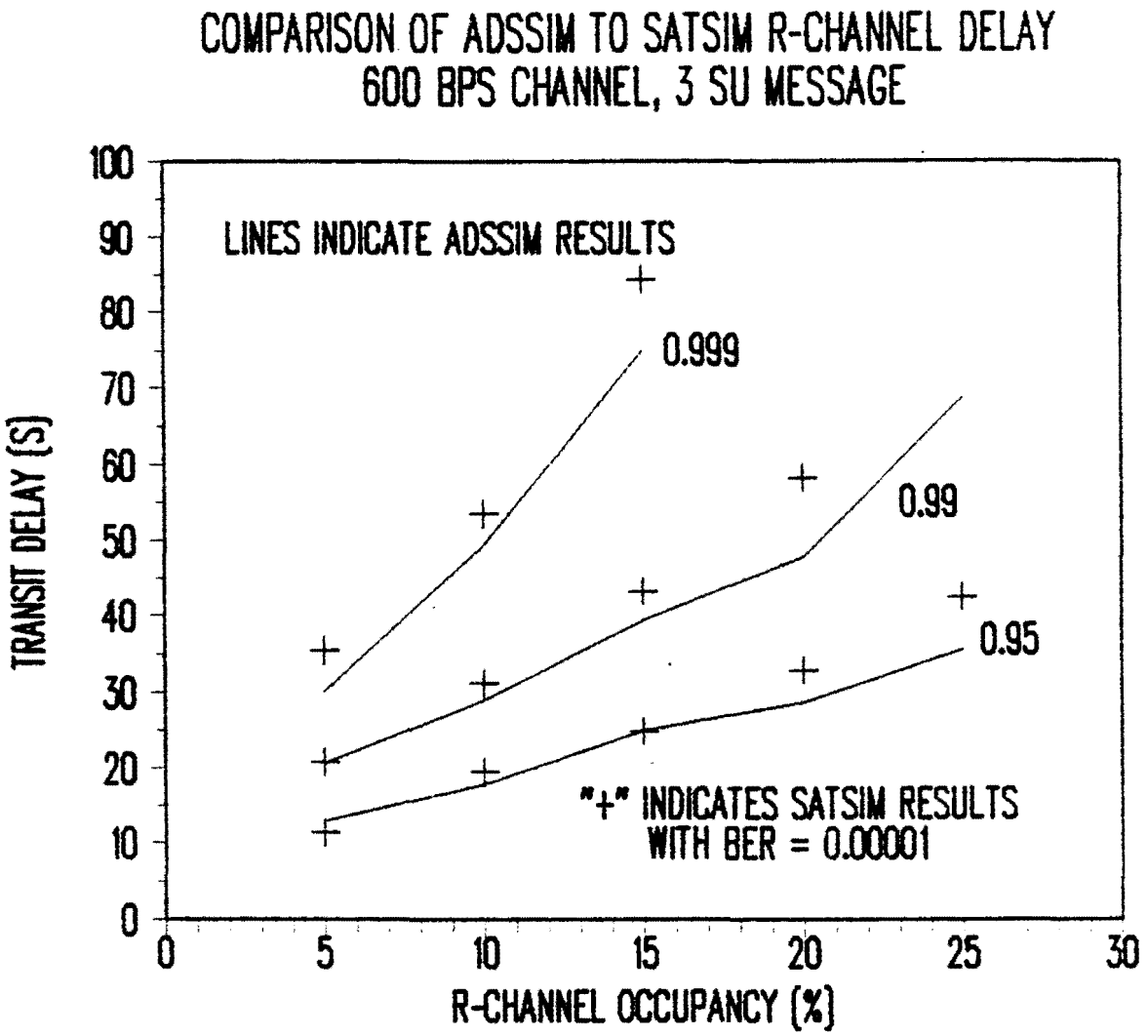

FIGURE 21. COMPARISON OF ADSSIM TO SATSIM RESULTS

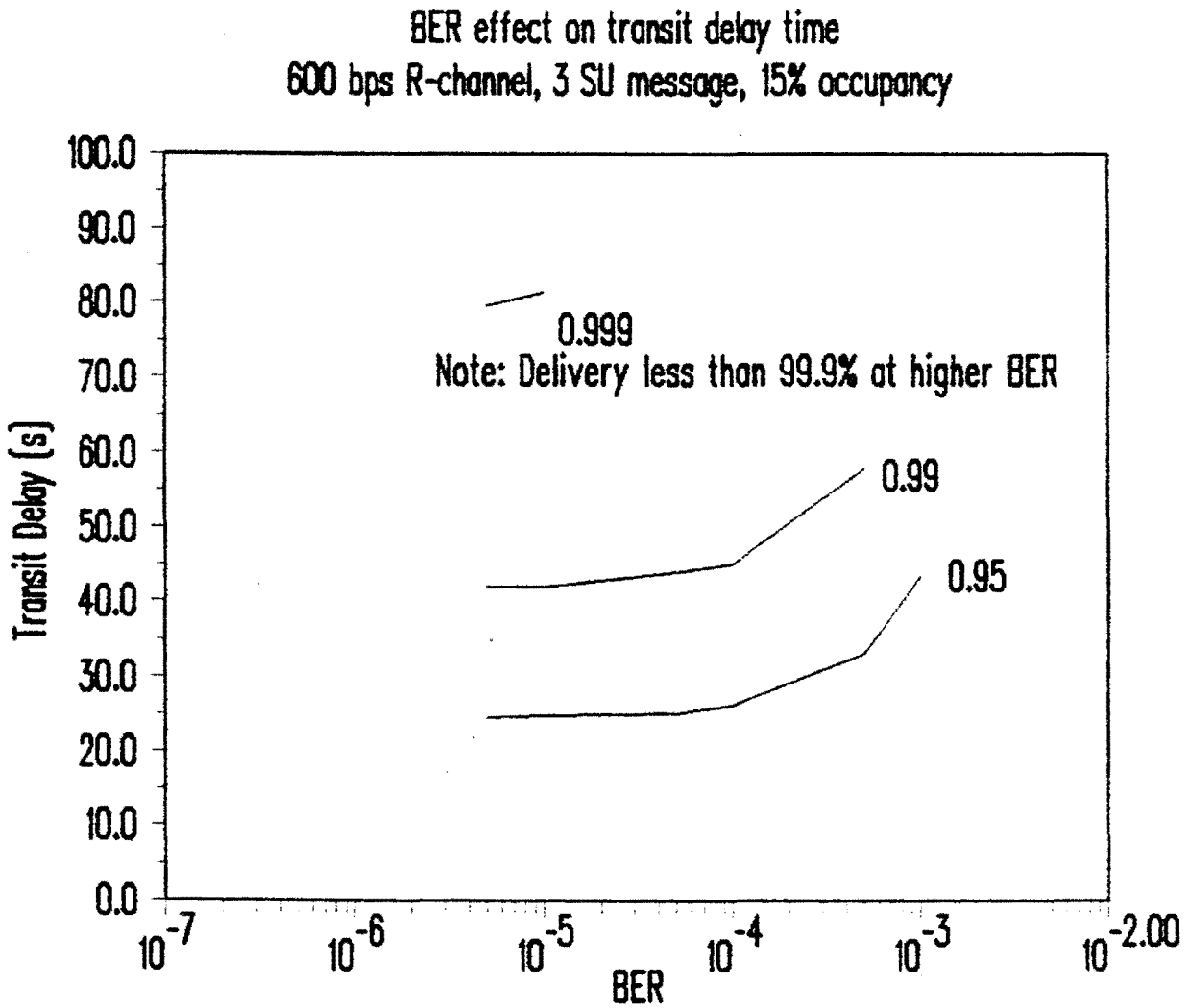

FIGURE 22. EFFECT OF BIT ERROR RATE ON TRANSIT DELAY

APPENDIX A

AMSS CAPACITY RESULTS

TABLE A-1

Conditions:

Channel (R or T): R, 15% Loaded
Message Length (SUs): 1
Channel Bit Rate: 600 bps

Number of Aircraft

Update Interval (sec)	10	25	50	100	200	300
5	13.3	33.3	66.6	133.3	266.6	400
10	6.6	16.6	33.3	66.6	133.3	200
30	2.2	5.5	11.1	22.2	44.4	66.6
60	1.1	2.7	5.5	11.1	22.2	33.3
120	0.5	1.3	2.7	5.5	11.1	16.6
300	0.2	0.5	1.1	2.2	4.4	6.6

Number of required channels

TABLE A-2

Conditions:

Channel (R or T): R, 15% Loaded
Message Length (SUs): 2
Channel Bit Rate: 600 bps

Number of Aircraft

Update Interval (sec)	10	25	50	100	200	300
5	26.6	66.6	133.6	266.6	533.3	800
10	13.3	33.3	66.6	133.3	266.6	400
30	4.4	11.1	22.2	44.4	88.8	133.3
60	2.2	5.5	11.1	22.2	44.4	66.6
120	1.1	2.7	5.5	11.1	22.2	33.3
300	0.4	1.1	2.2	4.4	8.8	13.3

Number of required channels

TABLE A-3

Conditions:

Channel (R or T): R, 15% Loaded
Message Length (SUs): 3
Channel Bit Rate: 600 bps

Update Interval (sec)	Number of Aircraft: 10	25	50	100	200	300
5	40	99.9	200	400	800	1200
10	20	50	99.9	200	400	600
30	6.7	16.6	33.3	66.6	133.3	200
60	3.3	8.3	16.6	33.3	66.6	99.9
120	1.6	4.1	8.3	16.6	33.3	50
300	0.6	1.6	3.3	6.6	13.3	20

Number of required channels

TABLE A-4

Conditions:

Channel (R or T): R, 15% Loaded
Message Length (SUs): 1
Channel Bit Rate: 1200 bps

Number of Aircraft

Update Interval (sec)	10	25	50	100	200	300
5	6.6	16.6	33.3	66.6	133.3	200
10	3.3	8.3	16.6	33.3	66.6	100
30	1.1	2.7	5.5	11.1	22.2	33.3
60	0.5	1.3	2.7	5.5	11.1	16.6
120	0.2	0.6	1.3	2.7	5.5	8.3
300	0.1	0.2	0.5	1.1	2.2	3.3

Number of required channels

TABLE A-5

Conditions:

Channel (R or T): R, 15% Loaded
Message Length (SUs): 2
Channel Bit Rate: 1200 bps

Number of Aircraft

Update Interval (sec)	10	25	50	100	200	300
5	13.3	33.3	66.6	133.3	266.6	400
10	6.6	16.6	33.3	66.6	133.3	200
30	2.2	5.5	11.1	22.2	44.4	66.6
60	1.1	2.7	5.5	11.1	22.2	33.3
120	0.5	1.3	2.7	5.5	11.1	16.6
300	0.2	0.5	1.1	2.2	4.4	6.6

Number of required channels

TABLE A-6

Conditions:

Channel (R or T): R, 15% Loaded
Message Length (SUs): 3
Channel Bit Rate: 1200 bps

Number of Aircraft

Update Interval (sec)	10	25	50	100	200	300
5	20	50	100	200	400	600
10	10	25	50	100	200	300
30	3.3	8.3	16.6	33.3	66.6	100
60	1.6	4.1	8.3	16.6	33.3	50
120	0.8	2.0	4.1	8.3	16.6	25
300	0.3	0.8	1.6	3.3	6.6	10

Number of required channels

TABLE A-7

Conditions:

Channel (R or T): R, 15% Loaded
Message Length (SUs): 1
Channel Bit Rate: 2400 bps

Number of Aircraft

Update Interval (sec)	10	25	50	100	200	300
5	3.3	8.3	16.6	33.3	66.6	100
10	1.6	4.1	8.3	16.6	33.3	50
30	0.5	1.3	2.7	5.5	11.1	16.6
60	0.2	0.7	1.3	2.7	5.5	8.3
120	0.1	0.3	0.7	1.3	2.7	4.1
300	0.05	0.1	0.2	0.5	1.1	1.6

Number of required channels

TABLE A-8

Conditions:

Channel (R or T): R, 15% Loaded
Message Length (SUs): 2
Channel Bit Rate: 2400 bps

Number of Aircraft

Update Interval (sec)	10	25	50	100	200	300
5	6.6	16.6	33.3	66.6	133.3	200
10	3.3	8.3	16.6	33.3	66.6	100
30	1.1	2.7	5.5	11.1	22.2	33.3
60	0.5	1.3	2.7	5.5	11.1	16.6
120	0.2	0.6	1.3	2.7	5.5	8.3
300	0.1	0.2	0.5	1.1	2.2	3.3

Number of required channels

TABLE A-9

Conditions:

Channel (R or T): R, 15% Loaded
Message Length (SUs): 3
Channel Bit Rate: 2400 bps

Number of Aircraft

Update Interval (sec)	10	25	50	100	200	300
5	10	25	50	100	200	300
10	5	12.5	25	50	100	150
30	1.6	4.1	8.3	16.6	33.3	50
60	0.8	2.0	4.1	8.3	16.6	25
120	0.4	1.0	2.0	4.1	8.3	12.5
300	0.1	0.4	0.8	1.6	3.3	5

Number of required channels

TABLE A-10

Conditions:

Channel (R or T): R, 15% Loaded
Message Length (SUs): 1
Channel Bit Rate: 10500 bps

Number of Aircraft

Update Interval (sec)	10	25	50	100	200	300
5	1.6	4.1	8.3	16.6	33.3	50
10	0.8	2.0	4.1	8.3	16.6	25
30	0.2	0.7	1.3	2.7	5.5	8.3
60	0.1	0.3	0.7	1.3	2.7	4.1
120	0.07	0.1	0.3	0.7	1.3	2.0
300	0.02	0.07	0.1	0.2	0.5	0.8

Number of required channels

TABLE A-11

Conditions:

Channel (R or T): R, 15% Loaded
Message Length (SUs): 2
Channel Bit Rate: 10500 bps

Number of Aircraft

Update Interval (sec)	10	25	50	100	200	300
5	3.3	8.3	16.6	33.3	66.6	100
10	1.6	4.1	8.3	16.6	33.3	50
30	0.5	1.3	2.7	5.5	11.1	16.6
60	0.2	0.7	1.3	2.7	5.5	8.3
120	0.1	0.3	0.7	1.3	2.7	4.1
300	0.05	0.1	0.2	0.5	1.1	1.6

Number of required channels

TABLE A-12

Conditions:

Channel (R or T): R, 15% Loaded
Message Length (SUs): 3
Channel Bit Rate: 10500 bps

Number of Aircraft

Update Interval (sec)	10	25	50	100	200	300
5	5	12.5	25	50	100	150
10	2.5	6.2	12.5	25	50	75
30	0.8	2.0	4.1	8.3	16.6	25
60	0.4	1.0	2.0	4.1	8.3	12.5
120	0.2	0.5	1.0	2.0	4.1	6.2
300	0.08	0.2	0.4	0.8	1.6	2.5

Number of required channels

TABLE A-13

Conditions:

Channel (R or T): T, 100% Loaded
Message Length (SUs): 5
Channel Bit Rate: 600 bps

Number of Aircraft

Update Interval (sec)	10	25	50	100	200	300
5	4.5	11.4	22.8	45.6	91.2	136.8
10	2.2	5.7	11.4	22.8	45.6	68.4
30	0.7	1.9	3.8	7.6	15.2	22.8
60	0.38	0.95	1.9	3.8	7.6	11.4
120	0.19	0.47	0.95	1.9	3.8	5.7
300	0.07	0.19	0.38	0.76	1.5	2.2

Number of required channels

TABLE A-14

Conditions:

Channel (R or T): T, 100% Loaded
Message Length (SUs): 7
Channel Bit Rate: 600 bps

Number of Aircraft

Update Interval (sec)	10	25	50	100	200	300
5	5.4	14.6	29.2	58.4	116.8	175.2
10	2.9	7.3	14.6	29.2	58.4	87.6
30	0.97	2.4	4.8	9.7	19.4	29.2
60	0.48	1.2	2.4	4.8	9.7	14.6
120	0.24	0.60	1.2	2.4	4.8	7.3
300	0.09	0.24	0.48	0.97	1.9	2.9

Number of required channels

TABLE A-15

Conditions:

Channel (R or T): T, 100% Loaded
Message Length (SUs): 10
Channel Bit Rate: 600 bps

Number of Aircraft

Update Interval (sec)	10	25	50	100	200	300
5	7.7	19.4	38.8	77.6	155.2	232.8
10	3.8	9.7	19.4	38.8	77.6	116.4
30	1.3	3.2	6.4	12.9	25.8	38.8
60	0.6	1.6	3.2	6.4	12.9	19.4
120	0.3	0.8	1.6	3.2	6.4	9.7
300	0.12	0.32	0.64	1.2	2.5	3.8

Number of required channels

TABLE A-16

Conditions:

Channel (R or T): T, 100% Loaded
Message Length (SUs): 5
Channel Bit Rate: 1200 bps

Number of Aircraft

Update Interval (sec)	10	25	50	100	200	300
5	2.2	5.7	11.4	22.8	45.6	68.4
10	1.1	2.8	5.7	11.4	22.8	34.2
30	0.38	0.95	1.9	3.8	7.6	11.4
60	0.19	0.47	0.95	1.9	3.8	5.7
120	0.09	0.23	0.47	0.95	1.9	2.8
300	0.03	0.09	0.19	0.38	0.76	1.1

Number of required channels

TABLE A-17

Conditions:

Channel (R or T): T, 100% Loaded
Message Length (SUs): 7
Channel Bit Rate: 1200 bps

Number of Aircraft

Update Interval (sec)	10	25	50	100	200	300
5	2.9	7.3	14.6	29.2	58.4	87.6
10	1.4	3.6	7.3	14.6	29.2	43.8
30	0.48	1.2	2.4	4.8	9.7	14.6
60	0.24	0.60	1.2	2.4	4.8	7.3
120	0.12	0.30	0.60	1.2	2.4	3.6
300	0.04	0.12	0.24	0.48	0.97	1.4

Number of required channels

TABLE A-18

Conditions:

Channel (R or T): T, 100% Loaded
Message Length (SUs): 10
Channel Bit Rate: 1200 bps

Number of Aircraft

Update Interval (sec)	10	25	50	100	200	300
5	3.8	9.7	19.4	38.8	77.6	116.4
10	1.9	4.8	9.7	19.4	38.8	58.2
30	0.64	1.6	3.2	6.4	12.9	19.4
60	0.32	0.80	1.6	3.2	6.4	9.7
120	0.16	0.40	0.80	1.6	3.2	4.8
300	0.06	0.16	0.32	0.64	1.2	1.9

Number of required channels

TABLE A-19

Conditions:

Channel (R or T): T, 100% Loaded
Message Length (SUs): 5
Channel Bit Rate: 2400 bps

Number of Aircraft

Update Interval (sec)	10	25	50	100	200	300
5	1.1	2.8	5.7	11.4	22.8	34.2
10	0.57	1.4	2.8	5.7	11.4	17.1
30	0.19	0.47	0.95	1.9	3.8	5.7
60	0.09	0.23	0.47	0.95	1.9	2.8
120	0.04	0.11	0.23	0.47	0.95	1.4
300	0.02	0.04	0.09	0.19	0.38	0.57

Number of required channels

TABLE A-20

Conditions:

Channel (R or T): T, 100% Loaded
Message Length (SUs): 7
Channel Bit Rate: 2400 bps

Number of Aircraft

Update Interval (sec)	10	25	50	100	200	300
5	1.4	3.6	7.3	14.6	29.2	43.8
10	0.73	1.8	3.6	7.3	14.6	21.9
30	0.24	0.60	1.2	2.4	4.8	7.3
60	0.12	0.30	0.60	1.2	2.4	3.6
120	0.06	0.15	0.30	0.60	1.2	1.8
300	0.02	0.06	0.12	0.24	0.48	0.73

Number of required channels

TABLE A-21

Conditions:

Channel (R or T): T, 100% Loaded
Message Length (SUs): 10
Channel Bit Rate: 2400 bps

Number of Aircraft

Update Interval (sec)	10	25	50	100	200	300
5	1.9	4.8	9.7	19.4	38.8	58.2
10	0.97	2.4	4.8	9.7	19.4	29.1
30	0.32	0.80	1.6	3.2	6.4	9.7
60	0.16	0.40	0.80	1.6	3.2	4.8
120	0.08	0.20	0.40	0.80	1.6	2.4
300	0.03	0.08	0.16	0.32	0.64	0.97

Number of required channels

TABLE A-22

Conditions:

Channel (R or T): T, 100% Loaded
Message Length (SUs): 5
Channel Bit Rate: 10500 bps

Number of Aircraft

Update Interval (sec)	10	25	50	100	200	300
5	0.39	0.98	1.9	3.9	7.9	11.8
10	0.19	0.49	0.98	1.9	3.9	5.9
30	0.06	0.16	0.32	0.65	1.3	1.9
60	0.03	0.08	0.16	0.32	0.65	0.98
120	0.016	0.04	0.08	0.16	0.32	0.49
300	0.006	0.016	0.03	0.06	0.13	0.19

Number of required channels

TABLE A-23

Conditions:

Channel (R or T): T, 100% Loaded
Message Length (SUs): 7
Channel Bit Rate: 10500 bps

Number of Aircraft

Update Interval (sec)	10	25	50	100	200	300
5	0.46	1.1	2.3	4.6	9.3	14.0
10	0.23	0.58	1.1	2.3	4.6	7.0
30	0.07	0.19	0.39	0.78	1.5	2.3
60	0.03	0.09	0.19	0.39	0.78	1.1
120	0.019	0.048	0.097	0.19	0.39	0.58
300	0.007	0.019	0.039	0.078	0.15	0.23

Number of required channels

TABLE A-24

Conditions:

Channel (R or T): T, 100% Loaded
Message Length (SUs): 10
Channel Bit Rate: 10500 bps

Number of Aircraft

Update Interval (sec)	10	25	50	100	200	300
5	0.57	1.4	2.8	5.7	11.5	17.3
10	0.28	0.72	1.4	2.8	5.7	8.6
30	0.09	0.24	0.48	0.96	1.9	2.8
60	0.048	0.12	0.24	0.48	0.96	1.4
120	0.024	0.060	0.12	0.24	0.48	0.72
300	0.009	0.024	0.048	0.096	0.19	0.28

Number of required channels

APPENDIX B

AMSS TRANSIT DELAY RESULTS

TABLE B-1

ADSSIM Conditions:

Channel (R or T): R
Message Length (SUs): 1
Channel Bit Rate: 600 bps

Cumulative Distribution	Channel Occupancy (%) 5	10	15	20	25
99.9%	28.8	34.1	53.6	72.1	u
99%	16.5	23.3	30.6	34.0	45.3
97%	14.3	16.3	17.1	27.0	30.4
95%	3.3	15.2	16.3	17.0	26.3
90%	3.2	12.2	14.3	15.3	16.3
85%	3.2	3.2	12.2	13.8	14.9
80%	3.1	3.2	3.2	3.3	13.5
75%	3.1	3.1	3.2	3.2	3.3
70%	3.0	3.1	3.1	3.2	3.2
65%	3.0	3.0	3.0	3.1	3.1
60%	2.9	2.9	3.0	3.0	3.1
55%	2.9	2.9	2.9	3.0	3.0
50%	2.8	2.8	2.9	2.9	2.9

Transit Delay Time (sec)

(u = undeliverable)

TABLE B-2

ADSSIM Conditions:

Channel (R or T): R
Message Length (SUs): 2
Channel Bit Rate: 600 bps

Cumulative Distribution	Channel Occupancy (%) 5	10	15	20	25
99.9%	28.9	40.5	63.6	82.8	u
99%	18.1	26.1	32.8	43.2	53.6
97%	12.1	18.3	25.1	28.4	38.9
95%	11.4	15.3	20.6	25.3	29.0
90%	4.3	11.5	14.6	18.4	24.1
85%	4.2	10.8	11.7	14.0	18.4
80%	4.2	4.3	11.1	11.7	15.1
75%	4.1	4.2	10.4	11.2	11.9
70%	4.1	4.2	4.3	10.7	11.3
65%	4.0	4.1	4.2	9.9	10.9
60%	4.0	4.0	4.1	4.2	10.4
55%	3.9	4.0	4.1	4.1	4.3
50%	3.8	3.9	4.0	4.1	4.2

Transit Delay Time (sec)

(u = undeliverable)

TABLE B-3

ADSSIM Conditions:

Channel (R or T): R
Message Length (SUs): 3
Channel Bit Rate: 600 bps

	Channel Occupancy (%)				
	5	10	15	20	25
99.9%	30.1	49.3	75.0	u	u
99%	20.5	28.8	39.4	47.8	68.7
97%	13.5	21.6	27.8	33.6	44.7
95%	12.9	17.8	24.8	28.6	35.5
90%	12.0	13.1	17.2	22.9	27.2
85%	5.3	12.5	13.3	18.8	22.6
80%	5.2	12.0	12.8	13.5	19.7
75%	5.2	11.3	12.4	13.0	13.9
70%	5.1	5.3	12.0	12.6	13.2
65%	5.1	5.2	11.5	12.2	12.8
60%	5.0	5.1	5.3	11.9	12.5
55%	4.9	5.1	5.2	11.4	12.2
50%	4.9	5.0	5.1	5.3	11.8

Cumulative Distribution

Transit Delay Time (sec)

(u = undeliverable)

TABLE B-4

ADSSIM Conditions:

Channel (R or T): R
Message Length (SUs): 1
Channel Bit Rate: 1200 bps

Cumulative Distribution	Channel Occupancy (%) 5	10	15	20	25
99.9%	23.3	30.2	39.0	48.9	60.1
99%	12.4	19.5	23.3	24.7	35.0
97%	11.3	12.3	12.6	21.4	23.4
95%	1.7	11.6	12.2	12.6	21.6
90%	1.7	1.7	11.2	11.8	12.3
85%	1.7	1.7	1.7	11.0	11.6
80%	1.7	1.7	1.7	1.7	11.0
75%	1.6	1.7	1.7	1.7	10.2
70%	1.6	1.6	1.7	1.7	1.7
65%	1.6	1.6	1.6	1.7	1.7
60%	1.6	1.6	1.6	1.6	1.7
55%	1.5	1.6	1.6	1.6	1.6
50%	1.5	1.5	1.5	1.6	1.6

Transit Delay Time (sec)

TABLE B-5

ADSSIM Conditions:

Channel (R or T): R
Message Length (SUs): 2
Channel Bit Rate: 1200 bps

	Channel Occupancy (%)				
	5	10	15	20	25
99.9%	19.0	31.5	45.3	54.7	u
99%	13.2	17.6	24.1	31.0	35.9
97%	6.7	13.2	17.1	19.3	27.9
95%	6.4	11.9	14.9	17.6	19.6
90%	2.3	6.42	11.3	13.5	16.7
85%	2.2	6.1	6.5	11.5	13.3
80%	2.2	2.3	6.2	6.5	11.8
75%	2.2	2.2	5.8	6.3	6.6
70%	2.1	2.2	2.2	6.0	6.4
65%	2.1	2.2	2.2	5.6	6.1
60%	2.1	2.1	2.2	2.2	5.9
55%	2.1	2.1	2.1	2.2	2.3
50%	2.0	2.1	2.1	2.1	2.2

Cumulative Distribution

Transit Delay Time (sec)

(u = undeliverable)

TABLE B-6

ADSSIM Conditions:

Channel (R or T): R
Message Length (SUs): 3
Channel Bit Rate: 1200 bps

	Channel Occupancy (%)				
	5	10	15	20	25
99.9%	19.7	32.9	47.2	u	u
99%	13.4	19.0	26.8	33.2	42.9
97%	7.4	14.3	18.6	22.4	30.3
95%	7.1	10.8	16.9	19.1	24.4
90%	6.7	7.2	8.1	16.3	18.5
85%	2.8	6.9	7.3	11.5	16.2
80%	2.7	6.7	7.1	7.5	11.9
75%	2.7	6.3	6.9	7.2	7.6
70%	2.7	2.7	6.6	7.0	7.3
65%	2.6	2.7	6.4	6.8	7.1
60%	2.6	2.7	2.8	6.7	6.9
55%	2.6	2.6	2.7	6.4	6.8
50%	2.6	2.6	2.7	2.8	6.6

Cumulative Distribution

Transit Delay Time (sec)

(u = undeliverable)

TABLE B-7

SATSIM Conditions:

Channel (R or T): R
Message Length (SUs): 2
Channel Bit Rate: 1200 bps
Bit Error Rate (after FEC): 0.00001

	Channel Occupancy (%)				
	5	10	15	20	25
99.9%	24.3	35.3	43.3	u	u
99%	13.1	21.1	25.3	33.6	43.6
97%	11.8	13.3	16.0	24.3	28.5
95%	5.0	12.6	14.0	17.2	24.7
90%	2.0	10.8	12.2	13.3	15.6
85%	2.0	4.5	10.9	12.2	13.3
80%	2.0	2.0	4.7	11.2	12.3
75%	1.9	2.0	4.2	4.8	11.4
70%	1.9	2.0	2.0	4.4	4.9
65%	1.9	1.9	2.0	3.9	4.6
60%	1.8	1.9	1.9	2.0	4.2
55%	1.8	1.9	1.9	1.9	2.0
50%	1.8	1.8	1.9	1.9	2.0

Cumulative Distribution

Transit Delay Time (sec)

TABLE B-8

SATSIM Conditions:

Channel (R or T): R
Message Length (SUs): 3
Channel Bit Rate: 1200 bps
Bit Error Rate (after FEC): 0.00001

Cumulative Distribution	Channel Occupancy (%) 5	10	15	20	25
99.9%	25.5	41.1	u	u	u
99%	15.0	23.8	30.5	40.8	u
97%	13.0	15.9	22.1	28.5	36.1
95%	6.3	13.9	16.8	24.3	29.7
90%	5.2	12.0	13.9	16.5	21.1
85%	4.4	5.6	12.3	14.3	16.7
80%	2.5	5.2	5.8	12.9	15.2
75%	2.5	4.8	5.4	8.2	13.6
70%	2.4	2.5	5.2	5.7	12.2
65%	2.4	2.5	4.9	5.4	6.2
60%	2.4	2.4	2.5	5.1	5.6
55%	2.3	2.4	2.5	4.9	5.3
50%	2.3	2.4	2.4	2.5	5.1

Transit Delay Time (sec)

TABLE B-9

SATSIM Conditions:

Channel (R or T): R
Message Length (SUs): 2
Channel Bit Rate: 600 bps
Bit Error Rate (after FEC): 0.00001

Cumulative Distribution	Channel Occupancy (%) 5	10	15	20	25
99.9%	32.3	45.0	57.5	u	u
99%	17.9	24.9	33.7	46.3	58.4
97%	15.3	17.7	23.2	31.7	39.1
95%	12.8	16.5	19.2	24.9	32.6
90%	3.5	9.6	15.9	18.1	22.2
85%	3.5	7.9	13.4	16.0	18.0
80%	3.5	3.5	8.3	14.0	16.1
75%	3.4	3.4	7.5	8.6	14.3
70%	3.3	3.4	3.5	7.9	8.9
65%	3.2	3.3	3.4	7.1	8.1
60%	3.2	3.3	3.4	3.5	7.5
55%	3.1	3.2	3.3	3.4	3.5
50%	3.1	3.1	3.2	3.3	3.4

Transit Delay Time (sec)

TABLE B-10

SATSIM Conditions:

Channel (R or T): R
Message Length (SUs): 3
Channel Bit Rate: 600 bps
Bit Error Rate (after FEC): 0.00001

		Channel Occupancy (%)				
		5	10	15	20	25
Cumulative Distribution	99.9%	35.4	53.4	84.3	u	u
	99%	20.7	31.1	43.2	58.2	u
	97%	17.2	23.0	30.2	39.3	51.2
	95%	11.3	19.4	24.7	32.8	42.5
	90%	9.4	15.6	19.2	23.8	30.1
	85%	4.5	10.2	16.3	19.8	24.4
	80%	4.5	9.4	10.7	17.3	21.3
	75%	4.4	8.5	9.9	14.9	18.4
	70%	4.3	4.5	9.3	10.4	16.0
	65%	4.3	4.4	8.7	9.8	11.2
	60%	4.2	4.3	4.5	9.2	10.1
	55%	4.2	4.3	4.4	8.6	9.6
	50%	4.1	4.2	4.3	4.5	9.1

Transit Delay Time (sec)

TABLE B-11

SATSIM Conditions:

Channel (R or T): R
Message Length (SUs): 3
Channel Bit Rate: 600 bps
Bit Error Rate (after FEC): From 0.000005 to 0.001
Channel Occupancy: 15%

Bit Error Rate

	5x10-6	1x10-5	5x10-5	1x10-4	5x10-4	1x10-3
99.9%	79.5	81.3	u	u	u	u
99%	41.9	41.9	43.8	44.9	57.7	u
97%	29.2	29.4	31.2	33.4	39.5	55.3
95%	24.4	24.6	24.9	26.1	33.0	43.3
90%	19.1	19.0	19.6	20.1	24.3	31.4
85%	16.2	16.1	16.6	17.2	20.2	25.1
80%	10.6	10.7	11.0	13.9	17.4	22.0
75%	9.9	9.9	10.0	10.2	15.1	18.8
70%	9.3	9.3	9.5	9.6	10.5	16.4
65%	8.7	8.6	8.9	9.0	9.8	14.4
60%	4.5	4.5	4.5	8.2	9.3	10.5
55%	4.4	4.4	4.4	4.5	8.8	9.9
50%	4.3	4.3	4.4	4.4	7.7	9.4

u = undeliverable

Transit Delay Time (sec)