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City University of New York, 1991

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PERFORMANCE ANALYSIS OF A METEOR BURST PACKET NETWORK

by

MUHAMMAD S. MIAN

A dissertation submitted to the Graduate Faculty
in Engineering in partial fulfillment of the
degree of Doctor of Philosophy, The City
University of New York.

1991

This manuscript has been read and accepted for the Graduate Faculty in Engineering in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

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ABSTRACT**PERFORMANCE OF A METEOR BURST COMMUNICATION PACKET
NETWORK**

by

MUHAMMAD S. MIAN

Advisor: Professor Tarek N. Saadawi

The delay-throughput characteristics of a meteor burst communication network has been analyzed. The intermittent nature of a meteor burst (MB) channel is modelled by random service interruptions on a waiting line process. In the first part of this work a protocol for a point to point link has been devised to utilize the channel efficiently. First and second moments of message "completion time" have been computed in order to determine the average packet delay. A continuous time Markov chain method has been used for the analysis and the results have been compared with the completion time analysis. Due to the short durations of existence of the MB channel, shorter packets are appropriate. Optimum packet size has been obtained. The meteor arrival rate changes diurnally. It is maximum in the early morning hours and minimum in the late evening hours. A comparison has been made in the throughput values for these peak hours.

In the second part of the problem, the work has been extended to a multi-node network. A star topology is considered in which all nodes access a centralized station. The network protocol proposed uses the ALOHA-type multiple access scheme with probe and busy tone (BT). The performance has been measured in terms of average packet delay, throughput and probability of blocking. It has been concluded that the multiple access scheme significantly improves the network performance when compared with the polling scheme used in the earlier MBC systems, when the number of nodes is high. In the case that the remote nodes (especially mobile) are located at different distances from the central node, a near/far capture effect can be exploited to minimize the probability of packet collision. Finally, a simulation has been performed using Simscript II.5 simulating language and the results have been compared with those obtained through the numerical analysis.

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I dedicate this dissertation to my late parents, my wife and young kids. I want to thank all the friends at the Computer Network Laboratory and at the the Electrical Engineering Department. Finally, I want to thank my colleague Dr. Ibrahim Habib for the time to time discussions we had in connection to this research work.

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1 INTRODUCTION

1.1 OVERVIEW OF METEOR BURST COMMUNICATION

In Meteor Burst Communication a radio signal in the VHF band is reflected from ionized trails made by meteors. Everyday billions of meteoroids bombard earth's atmosphere. These small particles weighing 10^{-7} to 10^3 gram travel with a high velocity of thousands miles per hour. Due to this high speed friction causes them to heat up, burn and vaporize. The vaporized atoms escaping from the surface of the meteor collide with those of the atmosphere, ionizing them and leaving columns of free electrons. These are called meteor burst trails and are responsible for the communication. A geographical picture of a point to point link is shown in figure (1.1) and a typical block diagram circuitry of a MB communication system is shown in figure (1.2).

There are some geographical limitation on MBC. The minimum and the maximum range for the distance over which the communication can occur is 400 km and 2000 km respectively with a signal operating frequency of 40-100 MHz. There are two kinds of meteor trails named underdense and overdense. The overdense trails have more duration of existence and also can reflect more signal power as compared to the underdense trails but occur very less frequently. On the other hand, the underdense trails are of comparatively short duration but occur many more in numbers. Underdense meteor trails are considered to be mostly responsible for supporting a data communication link between two stations. A MB trail which comes with proper directivity in between sending and the receiving station and reflects sufficient transmitted power with a value above the

threshold of the receiving station, establishes a link between them. This kind of trail is termed as a useful trail. The duration of a meteor burst trail is very short and ranges from 0.1 to 1.0 seconds but with a proper data rate, a short message can be transmitted successfully. The rate of arrival of useful meteors depends on global position, time of day and on some seasonal and diurnal variations.

The average delay for a message is usually equal to the average interarrival time of the useful meteor trails. A typical delay time of one minute for a 50 baud, 150 characters long message has been noticed. The behavior of the channel made by the MB trail is of ON/OFF character. When a MB trail becomes into existence it may disappear after any fraction of a second. The attempt is to use the channel as soon as it is made up. We will describe a protocol governing the transmission procedure. When the transmission is interrupted due to the disappearance of the existing trail, a search for another useful trail starts. The time period elapsed since the instance of the interruption to the instance of restoration of the transmission is termed as the duration of interruption. The system is consisted of transmission periods and the interruption periods. We will treat the fading of the channel due to the disappearance of the useful meteor burst trail as an interruption to the service caused by the channel. We will first analyze the behavior of MB channel with the application of the results of Gaver[1] for evaluating the mean and variance of message service time. Gaver used the notion of completion time which he defined as the duration of the period that elapses between the instance at which the service of the n th message begins and that at which service of the $(n+1)$ th may begin. This completion time in this work is consisted of the actual packet transmission time and the sum of the

duration of interruptions happened during the course of the packet. Secondly, we will use the Continuous Markov Chain to analyze the MB communication system. In addition to the numerical schemes, a simulation has been performed. Our first analysis deals with a point to point link and has been presented in chapter 4. The analysis has been extended to a multi-nosde case described in chapter 5.

The main advantages of MB communication are less susceptibility to jamming, less spectral congestion and nuclear survivability. Less susceptibility to jamming is due to the intermittent channel behavior which makes the signal somewhat like a time-hopped signal. Many researchers have developed various techniques for the analysis of the connectivity of the MB communication channel and hence have made the performance evaluation in terms of information throughput and waiting time.

There was a growing interest in meteor burst communication (MBC) in 1040's. Then a lot of definitive studies were performed in 1950's and 1960's to devise the methods how to use meteors practically. A lots of information were collected in this period. Actual MBC systems were built and were in operation in 1960's and 1970's based on previous studies. The first experimental system named JANET was built by Canada and was in operation in 1950's. It was used for Teletype communications between Toronto and Port Arthur, a distance of approximately 1000 km. The bit rate of the channel was 650 bits per second in a double sideband AM duplex mode at VHF frequency of 50 MHz. The transmitting and receiving signals were separated by 1 MHz with 500 watts of power. Although the JANET system proved a good possibility of meteor burst communication

feasibility, its low throughput and error performance prevented its further development.

Then a system called COMET (COmmunication by MEteor Trails) was designed with improved efficiency by NATO's Supreme Headquarters Allied Powers Europe (SHAPE) Technical Center. It was tested in 1965 and 1966 on a 1000-km path between The Netherlands and Southern France. The frequencies were 36 and 39 MHz and the transmitter power was 200 watts. Although the results were encouraging, the MB communication was put aside following that period. The reason was hardware complexity but most importantly the appearance of satellite which was a exciting emergence in the field of communications. Nevertheless, in late seventies and early eighties, it was realized that satellite might be vulnerable for certain circumstances and could not be relied totally. In 1970's, a modern netted system was established for U.S. Department of Agriculture called SNOTEL("snow telemetry") linking remote mountain snow survey sites to Soil Conservation Service offices in the west. This system is still in operation collecting data from hundreds of unmanned remote sites spread over several western states. Then Alaska Meteor Burst Communication System (AMBCS) was established jointly by several government agencies in Alaska wilderness areas collecting aeronautical and environmental data. It was also providing a message communication among remote manned camps.

In the past decade, many commercial meteor burst systems implemented at low data rate applications have been marketed in addition to their military applications. In previous years, with the help of automated equipments computer models of links and

systems has been built which can predict the performance of potential applications with considerable accuracy. The channel efficiency can be increased through the design changes indicated by model predictions. Western Union installed a netted MB system in 1980 for Department of Agriculture [2]. It is consisted of several remote unmanned stations that communicate with one or two master stations.

Recently, with the advent of sophisticated solid-state microelectronics and low cost very large scale integrated (VLSI) microprocessors and memories, the interest in MB communication has been renewed. Modern equipments with affordable signal processing capabilities are being produced to utilize the MB channel more efficiently.

Meteor burst network shown in figure (1.3) provides a full-duplex communication link for the North American Aerospace Defence Command (NORAD). The first phase of the system became operational in 1983. In May of 1990, Meteor burst Communication Corporation (MCC) temporarily installed a station in Ketehikan to link together Alaska and the lower 48 states. For the first time in history, the US military has a meteor burst Network extending from Mac Dill, Florida to Alaska. A point to point Communication can be provided between a number of stations throughout the CONUS and Alaska for both mobile and fixed locations. MCC's full networking software is used in this system.

1.2 MILITARY APPLICATIONS

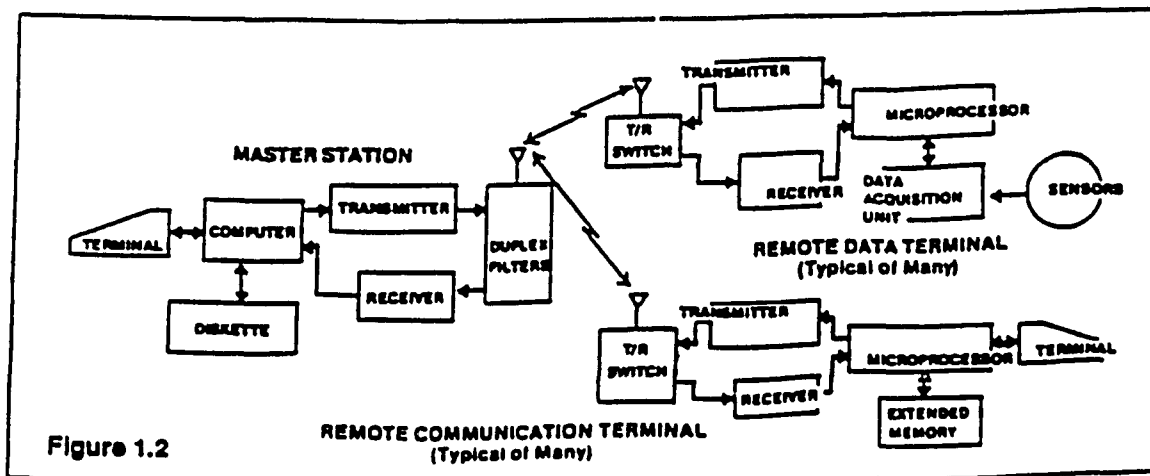
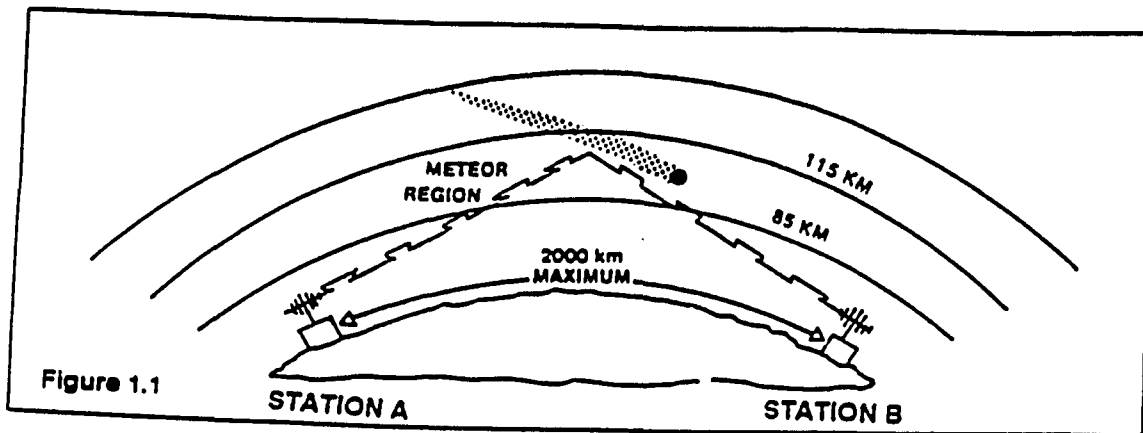
The meteor burst communication channel has inherent reliability, less susceptibility to jamming, less spectral congestion and nuclear survivability. The inherent property of

restricted foot-print of reflections attracts many military applications. There have been numerous proposals to provide Low probability of intercept (LPI) and Antijam (AJ) meteor burst systems for Department of Defense. The MB communication channel can be used for Beyond Line-of Sight(BLOS) record/teletype system. This involves the communication of digital data between fixed or mobile platforms at average throughput of 75 to 2400 bps. The mobile platforms include military ground vehicles, ships or aircrafts. The mode of operation can be point-to-point, netted or broadcast over a range from 400 to 2000 km. As compared to HF signal which suffers from a number of medium problems, the MB channel is not appreciably affected by natural and man-made ionospheric disturbances including associated with nuclear explosions. The MB communication also has advantage over HF for a smaller sized hardware requirements including antennas.

1.3 COMMERCIAL APPLICATIONS

There is great potential in the medium for the commercial applications as well where time delays of possibly a few minutes can be tolerated. However, it is needed to improve throughput and delay characteristics in order to make the MB media useful for many other communication systems. The MB channel offers wide bandwidth which has tempted experimentations with facsimile transmission [3]. A low resolution (67 elements/inch) black and white pictures were successfully transmitted over 910 miles at a frequency of 40 MHz. The transmitted power was 20 kw. Raytheon conducted experiments for commercial TV receivers to receive the video signal from television stations at ranges from 600 to 1300 miles [4]. It was estimated [5] that a 4 MHz TV

signal could be transmitted at frequency of 40 MHz using a transmitted power of 1 MW. These experiments suggest a simple but effective means of transmitting facsimile over BLOS ranges via MB channel. This simple scheme would be capable of transmitting one picture per burst, even for bursts of short duration. The system could be used in mobile-to-mobile or mobile-to-fixed applications.



NORAD MBC NETWORK

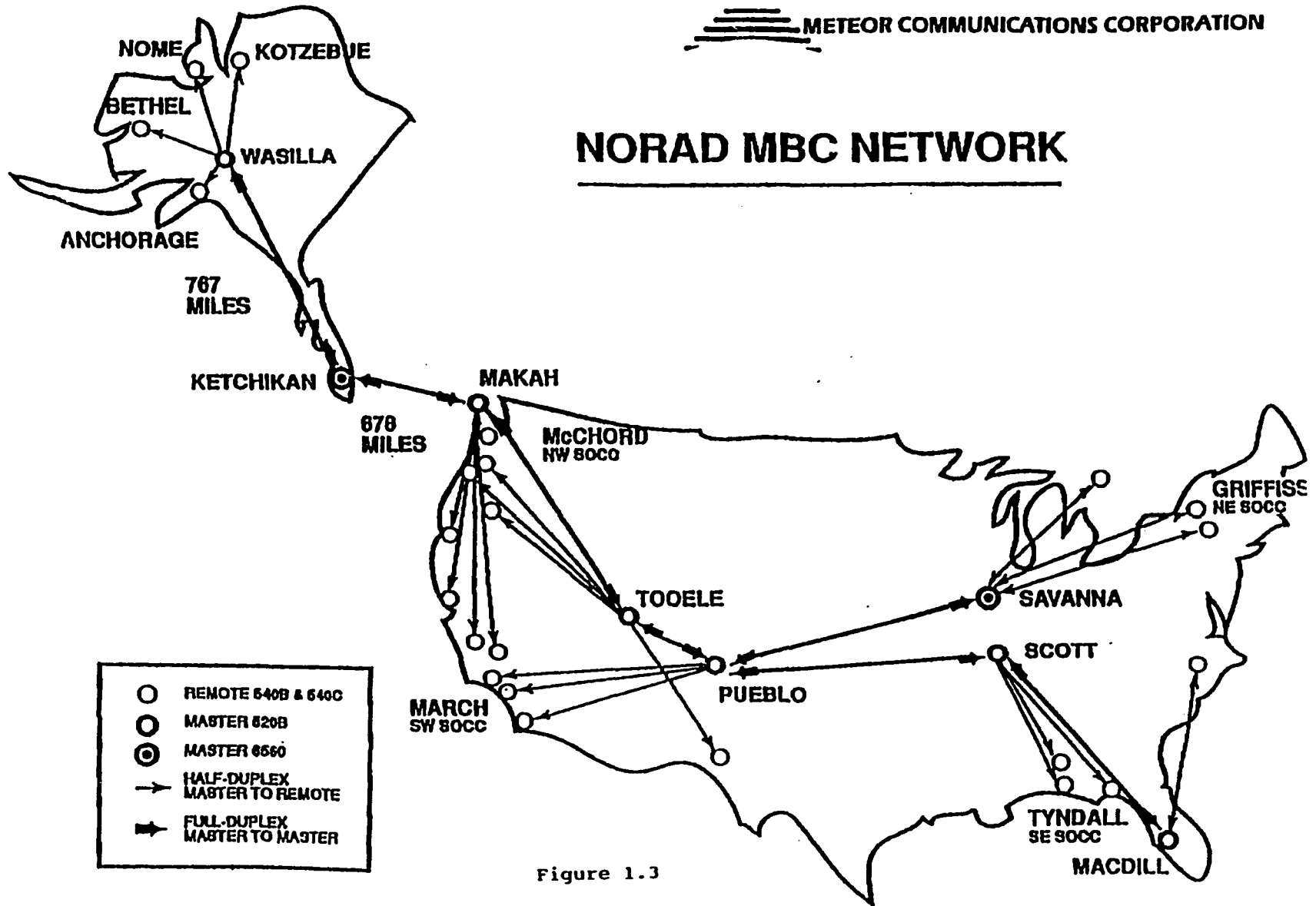


Figure 1.3

2 SYSTEM OPERATION

2.1 MB NETWORK CONFIGURATIONS

Meteor burst systems are employed in various configurations with respect to various applications. The simplest configuration is a single master station collecting data from a number of remote stations. The example is SNOTEL system shown in figure (2.2). If the network is consisted of more than one master stations and each master station has communication with at least one other master station in addition to its own remote stations, the level of complexity increases. The example of this level of networking is the Chinese MB communication network shown in figure (2.2). This network incorporates full-duplex master-to-master and half-duplex master-to-transceiver(remote) communication. However, this kind of networking does not require all the features necessary to support medium to large networks. When a fourth master station is added, the software gains a final level of complexity, primarily in network routing algorithms.

2.2 MB SYSTEM PROTOCOLS

Before the sending station can transmit a packet, it should recognize the existence of the meteor burst channel. Also the transmitter should be capable of determining the disappearance of the channel. To utilize the meteor burst channel efficiently different protocols has been devised by many researchers, see for example, Oetting[5], Milstein[6], Davidovic[7] and Miller & Milstein [8]. In summary, they fall in three major categories described in the following.

(I) The transmitter repeats the copies of the same packet continuously, without knowing that the MB burst is there or not, until the packet is received correctly by the receiver with a pre-specified reliability. This protocol is not efficient for point to point communication because even if the packet is received, the sender wastes time in repeating the same packet. Other packets could be transmitted in the same time. This protocol may be good for a broadcast case.

(II) The transmitter when ready to send some packets, sends a continuous probe (tone) to the receiver. When a MB channel comes across, the probe arrives at the receiver which in turn sends a message to the transmitter to send the data. In this protocol, the channel is used more efficiently when compared to the protocol (I). Here, a time duration equal to two propagation delays is elapsed before the actual data transmission can take place.

(III) In a third case the receiver is the one which transmits a continuous probe to the transmitter. When a proper MB trail comes across, this probe finds its way to the sending station indicating that the channel is available. On the receipt of the probe, the sending station immediately starts sending the packets of data to the receiving station. Therefore, only a time duration equal to approximately one propagation delay is elapsed before the start of the packet transmission. On successful reception of a packet, the receiving station sends an acknowledgment back to the transmitter. No acknowledgement is sent back for a disrupted partially received packet by the receiver. If the transmitter does not receive an acknowledgement after a certain time out period, it is assumed that either the packet

is disrupted or is lost and another copy of the same message must be re-transmitted. When an acknowledgment is received, the next packet at HOL is transmitted on the present trail or on the arrival of the next MB trail.

2.3 MODES OF OPERATION

A meteor burst communication system can be operated in three configurations: point-to-point, netted and broadcast. All the systems described above have been implemented for point to point operation but a MB system can be operated in any of these modes. Also, the operation can be half-duplex or full-duplex. In the later case, the more traffic can be handled due to the maximum use of each useable meteor trail and the communication can take place in both directions simultaneously. In half duplex case, both the transmitters have same frequency but in the full-duplex case they use different frequencies. The frequency of operation used in early systems was around 40 MHz. A sophisticated experiment [9] was performed over 1000 km path at frequencies in the 36 to 39 MHz band and with 200 watts transmitter power. It gave a minimum transmission rate of 50 bauds in the presence of errors (ARQ) and diversity reception. Tests in Canada showed that even at frequencies as high as 104 MHz meteor-burst circuits were not, as had been hoped, entirely free from black-outs in Arctic regions [10]. However, at lower latitudes in Norway no such difficulties were encountered.

2.4 DESIGN FACTORS

Meteor burst communication system like other communication systems are composed of two elements: Equipments (hardware) and procedures (software/firmware). A typical

hardware for a central, a remote station and a remote data collection terminal was shown in figure (1.2). The capacity for on-line encryption of traffic on an MBC circuit has been developed. Work is underway to develop embedded cryptographic chips that can be integrated onto the MBC computer/microoperations controller. RF components include the usual noise filters, modulation/demodulation units, power amplifiers and antennas. The selection of power amplifiers and antennas depend upon a particular application. It has been worked to standardize military MBC systems. In case of packet transmission, the packet includes some type of error detection or forward-error-correction scheme.

2.5 CHOICE OF FREQUENCY

The choice of frequency in a meteor burst communications system is constrained by several factors. Firstly equation $I_c \sim \lambda^{2.7}$ [10] shows that the information duty cycle is increased by reducing the frequency. Secondly, the high path loss associated with MBC signals requires that the level of interfering signals to be kept to a minimum. As a consequence, the operating frequency should be above that at which normal ionospheric modes propagate. Thirdly, absorption should be minimized, which also requires the use of as high a frequency as possible. This is particularly of concern for systems operated at high latitudes, where auroral and polar cap absorption can attenuate and even totally absorb the signal if the operating frequency is too low [11]. It has been shown that at certain times, Faraday rotation of linearly polarized meteor burst communication signals will severely reduce the communication link capacity for frequencies below about 40 Mhz. Evidently, the first constraint is in conflict with the latter three, and when making his frequency choice the system designer must judge the appropriate weighting to be

assigned to each.

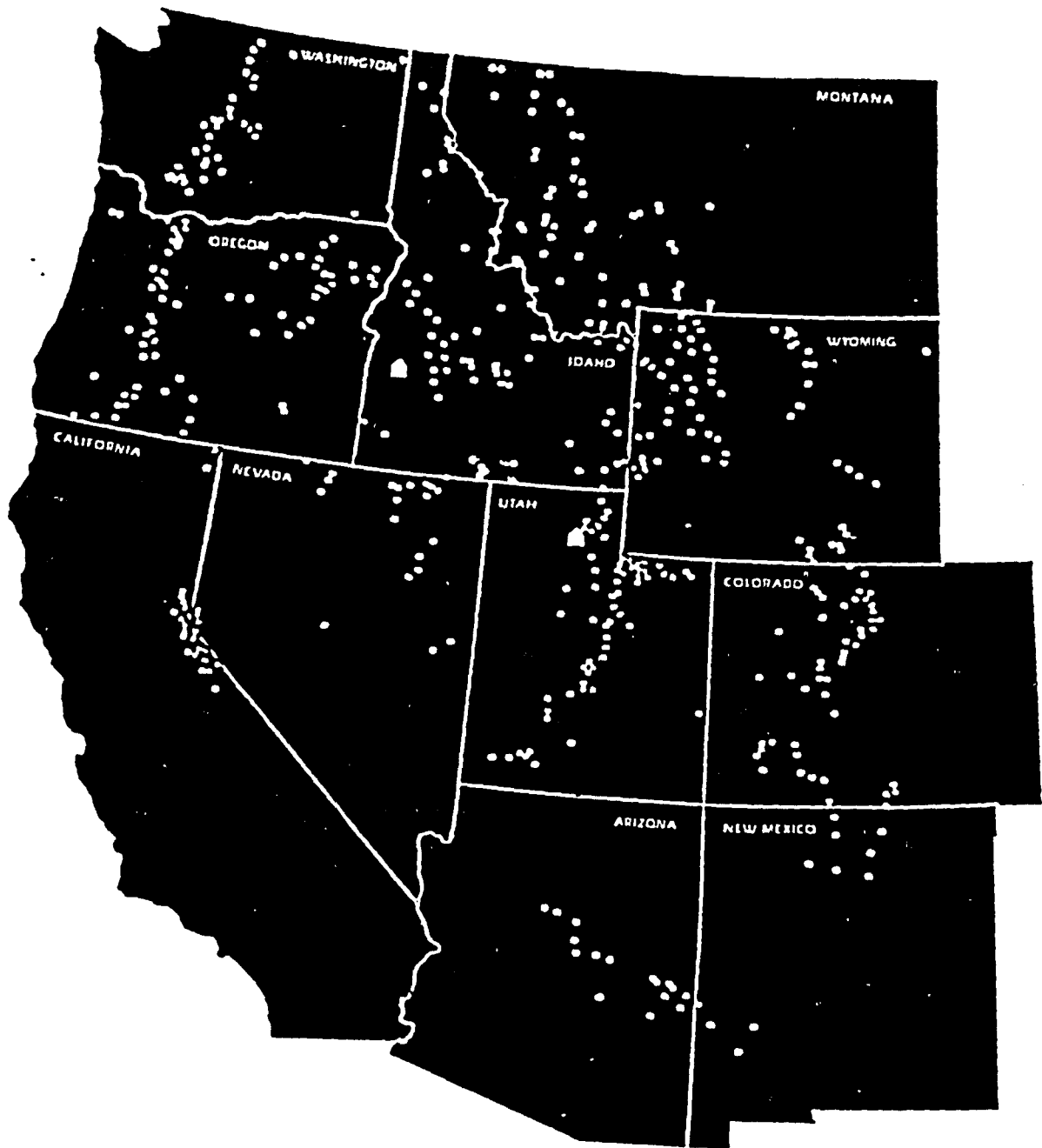


Figure 2.1 SNOTEL (Snow Telemetry) system linking remote mountain snow survey sites to head offices in the west

CHINESE METEOR BURST COMMUNICATION NETWORK



PRIMARY PURPOSE:

POINT TO POINT COMMUNICATION BETWEEN MILITARY CAMPS

Figure 2.2

[Smith, Fulthop. 13]

3 PERFORMANCE PARAMETERS AND PREVIOUS WORK

Most of the early stage studies upto 1960's, in the field of meteor burst communication were of phenomenal nature. Spezio[11] did a complete analysis concerning signal propagation, statistical characteristics and geographical setup. Since about two decades MB communication has been revived and several studies have been conducted in terms of system performance analysis. The characteristics like message delay, throughput and probability of correct message transmission are usually measured for performance evaluation of a meteor burst communication channel. The attempts have been made to decrease the waiting time and to increase the throughput. In the following, some details are presented about the performance analysis work done by many researchers.

Oetting[5] produced comprehensive informations in his paper in 1980. He showed the diurnal and the seasonal variations in terms of density of meteors as given in Figures (3.1 & 3.2). Duty cycle versus frequency curve is given in figure (3.3). The duty cycle of a MB communication system is defined as the percent of the time for which the channel is available. Table.I gives the required transmission time of a broadcast message by all L remote stations with a 99% probability of reception. He also derived an expression for waiting time and for the probability $P_c(t_D)$ of completing a message within a time t_D when more than one burst may be required.

Because the signal to noise ratio (SNR) varies from burst to burst and within a burst, it is difficult to characterize the bit error rate that occurs on meteor burst channels. Using

ARQ scheme it is important to calculate two parameters: Probability of a detected error and the probability of an undetected error. The former influences the throughput of the system because the packet re-transmissions are required in case of detected errors. The later is a good measure of the system reliability. There is a tradeoff between reliability and throughput for the system employing ARQ scheme. To study this tradeoff, a theoretical throughput was calculated for a hypothetical MB system as a function of instantaneous data rate, average interval between bursts, ARQ block size and channel bit rate. The average burst duration was assumed to be 0.58 seconds.

In addition to many other factors, the throughput of a MB system also depends on transmitted power, operating frequency, communication range and data rate. Some calculations show that for a fixed packet the throughput is roughly proportional to the instantaneous data rate, assuming that the transmitted power is increased linearly with a data rate to maintain a constant bit error rate. The experimental results [12] show that if the transmitted power is kept constant, the throughput varies as $R^{0.4}$. Where R is the instantaneous data rate. Now if data rate is fixed, the throughput is proportional to $p^{0.6}$, where P is the transmitted power. The dependence of throughput on communication range has been estimated [13] by developing the empirical relations based on a linear approximation to some experimental data. Experimental evidence shows that the throughput varies with frequency reasonably close to $f^{-2.4}$, where f is the radio frequency when it is close to 40 MHz. This dependence varies markedly if the frequency is increased.

As explained earlier, the throughput also depends on environmental variables as time

of day and season of the year. The throughput varies by a factor of 5 diurnally and by a factor of 3 seasonally. Table II shows the variation in the average interarrival of the burst time diurnally and seasonally. To see how these factors change the throughput, it is interesting to note that in order to get a yearly average throughput of 2400 bps during early morning hours, the transmitted power should be 3kw whereas for the same value of the throughput the transmitted power of 47 kw is required if the transmission is performed in the late evening hours.

The delay to a message (packet) in a MBC system can be measured as the total time required to transmit a packet successfully or alternatively, the probability that the total waiting time is less than a specified value called the observation time. Oetting [4] has derived an expression for the probability that the waiting time is less than a specified value as a function of the message duration, average trail duration, average trail interarrival time and the time required to achieve synchronization at the beginning of each burst.

Oetting, Booz, Allen and Hamilton [14] have estimated intercept efficiency as varied with data rate, sidelobe level (db) and waiting time. The curve for efficiency versus data rate is shown in figure (3.4). We see a slight increase in efficiency as data rate increases after 2 kbps.

Smith and Fulthop [15] has used ISO (International Standard Organization) model of layered communication system to examine the software design requirements and implementation considerations to support multi-node meteor burst network. Three of the standard

communication layers, transport, link and network has been explored and their impact on meteor burst communication has been discussed in detail. It has been concluded that there are a number of unique features necessary in the implementation of medium to large MB communication networks. The function of the three layers in the context of MB communication is explained below:

(1) TRANSPORT LAYER: It involves node definitions and connectivity management, message input flow control, message accountability, multiple destinations and duplicate message filtering. The transport layer is responsible for message level input/output over the I/O ports of the meteor burst terminal. It is also responsible for providing a virtual connection for reliable message delivery with all the other nodes in a network. Because of the intermittent nature of the meteor burst channel, it is necessary to provide adequate message buffering and flow control. Messages must be buffered so that they are ready to transmit within a few milliseconds of the detection of a meteor path to a neighbor station.

(2) NETWORK LAYER: Items considered include message precedence, packet accountability, congestion control, connectivity management, routing functions and retries. The network layer is responsible for routing messages through the network from source to destination. It must also maintain network connectivity information, subdivide long messages into packets, handle packet accountability functions and provide network congestion control. In meteor burst networks, because of the long range operation of each link, there can easily exist several alternate routes for each source/destination node to send different packets of a message over different routes simultaneously. This may reduce the overall

message delay and increase throughput as well as provide network load balancing.

(3) LINK LAYER: The considerations include short channel acquisition, contention algorithms, receive flow control, and segment forwarding. The link layer is responsible for detecting the presence of a MB channel link, acquiring the channel, acknowledging segments successfully received, detecting contention, handling flow control and at the same time providing for segment forwarding and priority preemption. This is not referred to as the physical layer, although the link layer software does work with an actual meteor burst link.

Figure (3.5) shows the flow of messages through a Master Station, with a functional breakdown of the main tasks into the appropriate software layers. In general, the transport layer processes data as messages, the network layer processes data as packets, and the link layer processes data as segments.

Milstein et.al;[6] calculated the probability of completing a given message under two different protocols. In the first case the transmitter knows of the entire duration of the meteor burst. The receiver continuously transmits a sounder to the transmitter. Whenever the transmitter receives the sounder signal, it gets an indication that the channel is present and hence starts sending the message. As soon as the reception of the sounder ceases, the transmitter stops transmitting. The message is considered to be consisted of only one packet. The transmission of a given packet might span several meteor burst trails.

In the second protocol given in this paper, the transmitter probes for a channel. When

the channel comes across, it gets the response from the receiver and starts the transmission. In this case the channel is utilized less efficiently. It has been suggested that using this protocol only one packet is transmitted per meteor burst. A two way propagation delay is encountered here (about 14ms), which is negligible however in most of times. A typical meteor trail duration is in the range of 0.2 to 1 seconds.

The SNR of a given MB decay about exponentially in time, the probability of error due to thermal noise at the receiver will vary from symbol to symbol. Therefore, the probability of error results has been computed using the SNR that is present at the end of an MB trail which is the smallest value of SNR of the burst involved. This is because the final results must be really upper bounds. In this work Reed-Solomon(RS) code is used to take care of the burst errors. Assuming a packet consisting of I information bits which are broken into J groups of mK bits per group. An (N,K,E) RS code is used to encode each group where $N = 2^2 - 1$. This code has a block length of N , has K information symbols and corrects upto E errors. To receive the packet correctly, all J codewords must be correctly received. It has been concluded through this paper that for a constant bandwidth constraint, an uncoded scheme, with its corresponding shorter packet length has yielded comparable performance to that of the coded systems.

A study of a MB communication system with the assumptions of worst case bit error rate (BER) conditions has been performed by Hampton[15]. Taking into account the actual time-varying nature of the BER, he computed the time required to broadcast a message

consisting of a set of packets to several number of receivers. The broadcast time was computed as a function of different modulation schemes and the system parameters using an ARQ or hybrid ARQ/FEC error control method.

Abel[17] and Weitzen[18] has investigated the MB communication system with constant SNR and time-varying bit rate conditions. Abel found the maximum number of bits which can be transmitted during a single burst using either an optimum constant bit rate or a continuously varying bit rate. Weitzen used time-varying bit rate approach to compute the capacity of the channel.

Davidovici and Kanterakis[9] has investigated the MB channel with the assumption that a message to be transmitted is completely contained in one packet. They have used a variable data rate which is function of the channel state. In their scheme the transmission data rate is changed in such a way that the probability of bit error remains nearly constant. The performance evaluation in their work is done in terms of probability of successful message completion (PCM) in a given time period T_D . A new expression for PCM has been derived. If the data rate is kept constant, the SNR changes. On the other hand SNR can be kept constant if the data rate is varied accordingly. There is however some lower bound limits on data rate, which depends upon the electron line density of the meteor trail. Figures (3.6 & 3.7) shows two curves for PCM for upper and lower limit on data rate. In this work optimum signal-to-noise ratio used for the two protocols as a function of packet size is shown in figure (3.8). A threshold can be seen at a packet length of about 2 Kbits. It is found that the SNR required for the operation decreases as the packet length decrease. Therefore, with

a decrease in packet size, it is possible to decrease SNR and increase the bit error rate and still get an acceptable probability of successful reception. It has been suggested that it is appropriate to assume a minimum data rate of 1Kbps.

For a MB channel the throughput is defined as the average number of bits transmitted per unit time over the channel. Davidovici [8] has calculated this parameter in terms of a specified bit rate, SNR and system setup. In Stop-and-wait strategy, the throughput is defined as the ratio of the number of information bits per packet to the total average number of bits that had to be transmitted before a particular packet is received without an error [22]. A useful meteor trail is the one which can reflect a sufficient signal power above some threshold. The electron density of the trail decrease after its emergence. A useful trail can be defined as its ability to support a communication link at or above the minimum data rate R_{min} after synchronization. As the trail electron density decreases its ability to support a higher data rate also decreases. Therefore there is certain duration of trail which is useful as shown in figure 3.9.

Miller and Milstein [8] have examined the performance of a MB communication system using three different protocols. By a comparison, it has been proved that the stop-and-wait ARQ scheme with "ability to sense the presence of a channel" has significant advantage over the other protocols. For the packet size of the order of the average burst duration, this protocol has shown a 20 percent reduction in the time necessary to complete a message. Their model is based on variable SNR and it is suggested that this model has significant better performance over a constant SNR model. Protocol A given in this paper

assumes that the transmitter does not know when the meteor burst trails are occurring. Whenever the transmitter has a message to be sent, it continuously repeats it for enough number of times until it is received by the receiver correctly with a pre-specified reliability. No ARQ scheme is used. This protocol is only good for a broadcast system and is not appropriate for a point to point link because much of the time is wasted transmitting the packet which has already been sent and has been received successfully. However, this protocol is of significant importance when the transmitter is a master station broadcasting to a large number of remote stations. The automatic repeat request (ARQ) scheme becomes inappropriate in this case since it is not practical for every receiver to respond to each packet in this case.

In protocol B, whenever the transmitter is ready to send a packet, it probes for channel by sending a continuous tone. With the channel availability, the receiver gets this tone and directs the transmitter to send the packet. The transmitter then sends a packet and waits for an ACK from the receiver and sends another packet when the ACK is received for the previous one. In the case of no acknowledgement from the receiver, the transmitter repeats the copy of the previous packet until it receives an ACK for the packet. Protocol C uses the same scheme of ARQ as used in protocol B but does not use a probe to detect the channel. On the other hand, the transmitter sends a packet whenever a packet is ready to be sent. It repeats the first packet until an ACK is received back and then sends the next packet.

The authors of this work have designed the protocol C to find whether the difference in performance between protocol A and B is due to the probing included in protocol B to

detect the availability of the channel or due to the use of an ARQ scheme. The three protocols described have been analyzed in this work and several curves have been generated for probability of message completion, throughput and average waiting time with the variations of the parameters like packet length, SNR and threshold (db). It has been concluded that the ability to sense the channel (probing) reduces 20 percent of the message waiting time. The ARQ scheme was found to offer an improvement when the packets are of larger size than a few times of the meteor burst duration. This scheme was rather found counter-productive for very short packets.

The analysis by Djuknic [20] has been performed at a constant data rate of an ARQ communication system under two protocols: stop-and wait and selective-repeat. It has been found that in both coded and uncoded stop-and-wait strategy, there exists a optimum packet length for every data rate in terms of minimizing the waiting and maximizing the throughput. The conclusion has been made that the packet duration should be slightly larger than the average burst length. A coded and uncoded transmission for throughput and waiting time has been compared. The result shows that small amount of forward error correction improves ARQ performance and the use of codes is only appropriate for high data. In case of low data rate although more errors can be corrected, the additional parity is a over burden for the channel of short availability.

Djuknic has evaluated the MB channel in terms of ARQ and Hybrid FEC-ARQ transmission. This analysis has been done for 1 kbps and 2 kbps data rates, for uncoded transmission. It has been pointed out that more steep rise in waiting time is observed at lower

bit rate. It has been concluded for this sample system that for packets of upto 1000 bits it is better to send data at 1kbps and for longer packet sizes the transmission rate should be increased. Both of these results have been achieved for uncoded transmission. It has been seen that for relatively short packet sizes (from 100 to 1000 bits), the throughput decreases monotonically with increase in data rate and no optimum data rate is concluded. The decrease is attributed mainly to the increase in the interarrival time of the meteor trails. The mean interarrival time of the underdense trails which are considered to be dominantly responsible for the MB support, is 2.25 seconds at 1Kbps and goes to 8.62 seconds at 10 kbps. Mean interarrival time of overdense trail is about 150 seconds which remains same upto 100 kbps. For this sample system we see the throughput more for the larger packet sizes decreasing at lower data rate. This is because at lower data rate the packet length increases with the trails duration and therefore probability of correct reception of a packet lowers.

His throughput versus packet size curve shows that the optimum packet length is slightly more than the average trail duration. Maximum throughput is achieved for packet length of about 1400 bits at 2 kbps. Further increase in packet length does not increase any value in throughput.

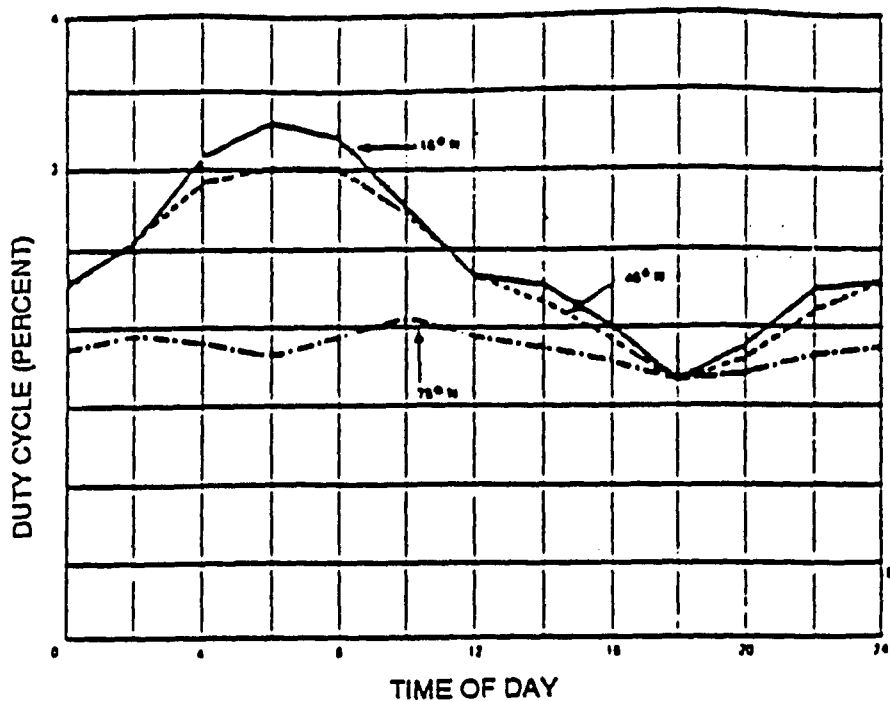


Figure 3.1 DUTY CYCLE VS. TIME OF DAY AND LATITUDE (DEGREE NORTH LATITUDE)

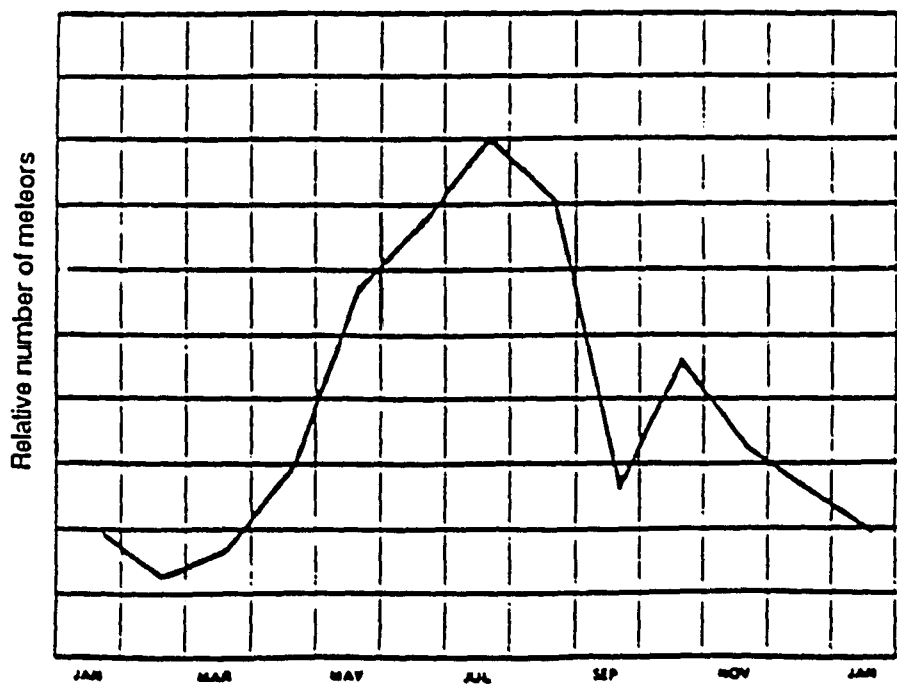


Figure 3.2 Yearly variation of the relative numbers of meteors [BROWN, 28]

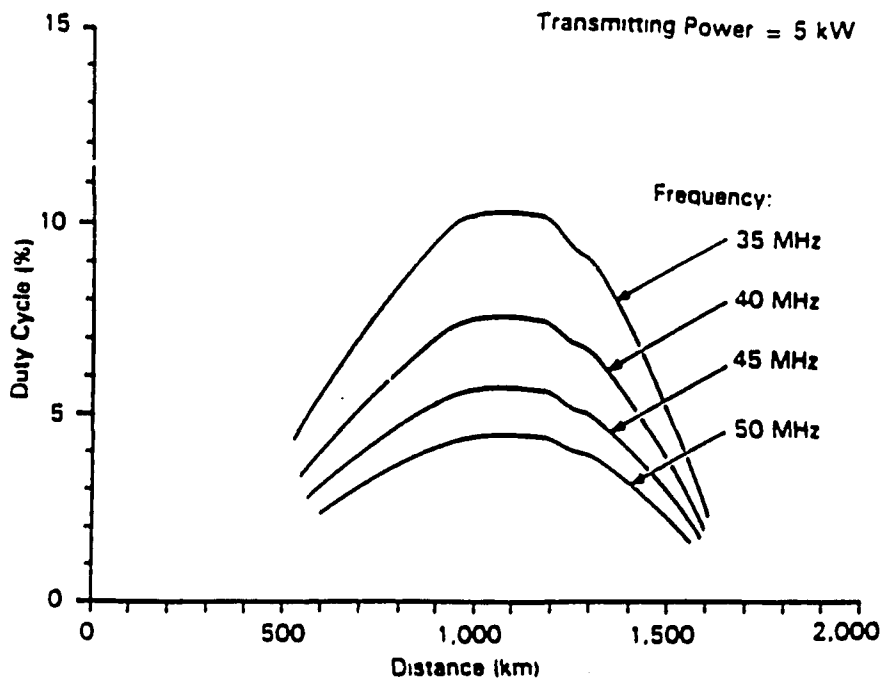


Figure 3.3 Illustrative duty cycle versus distance at different frequencies

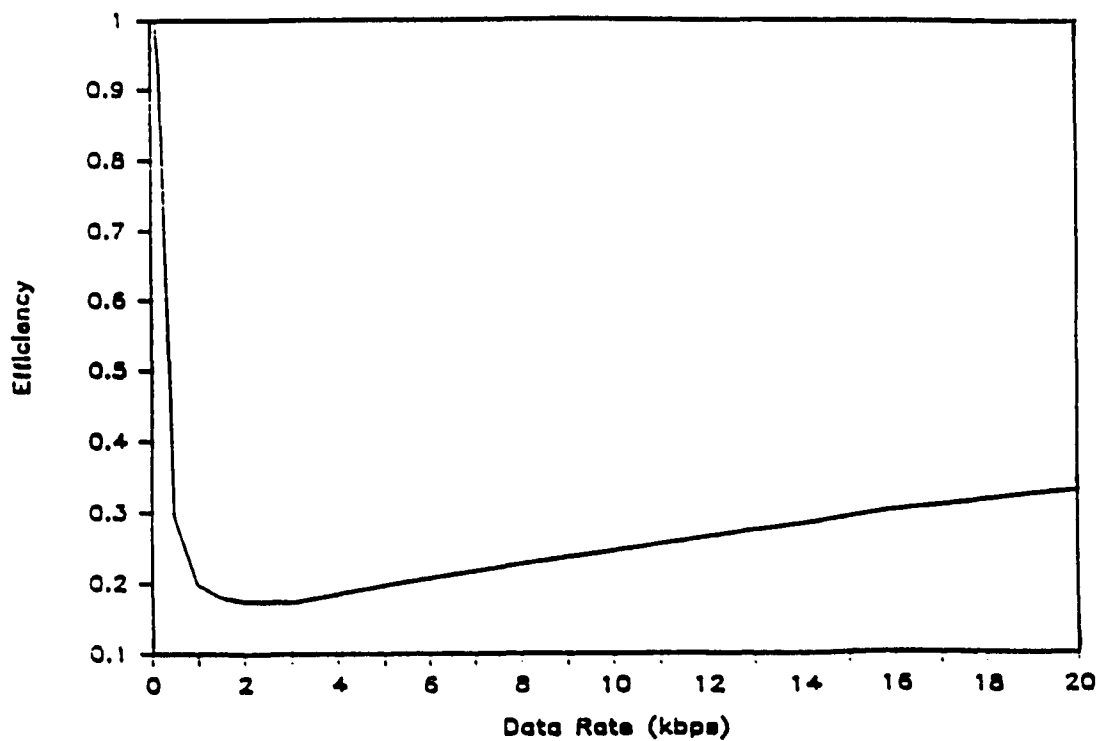
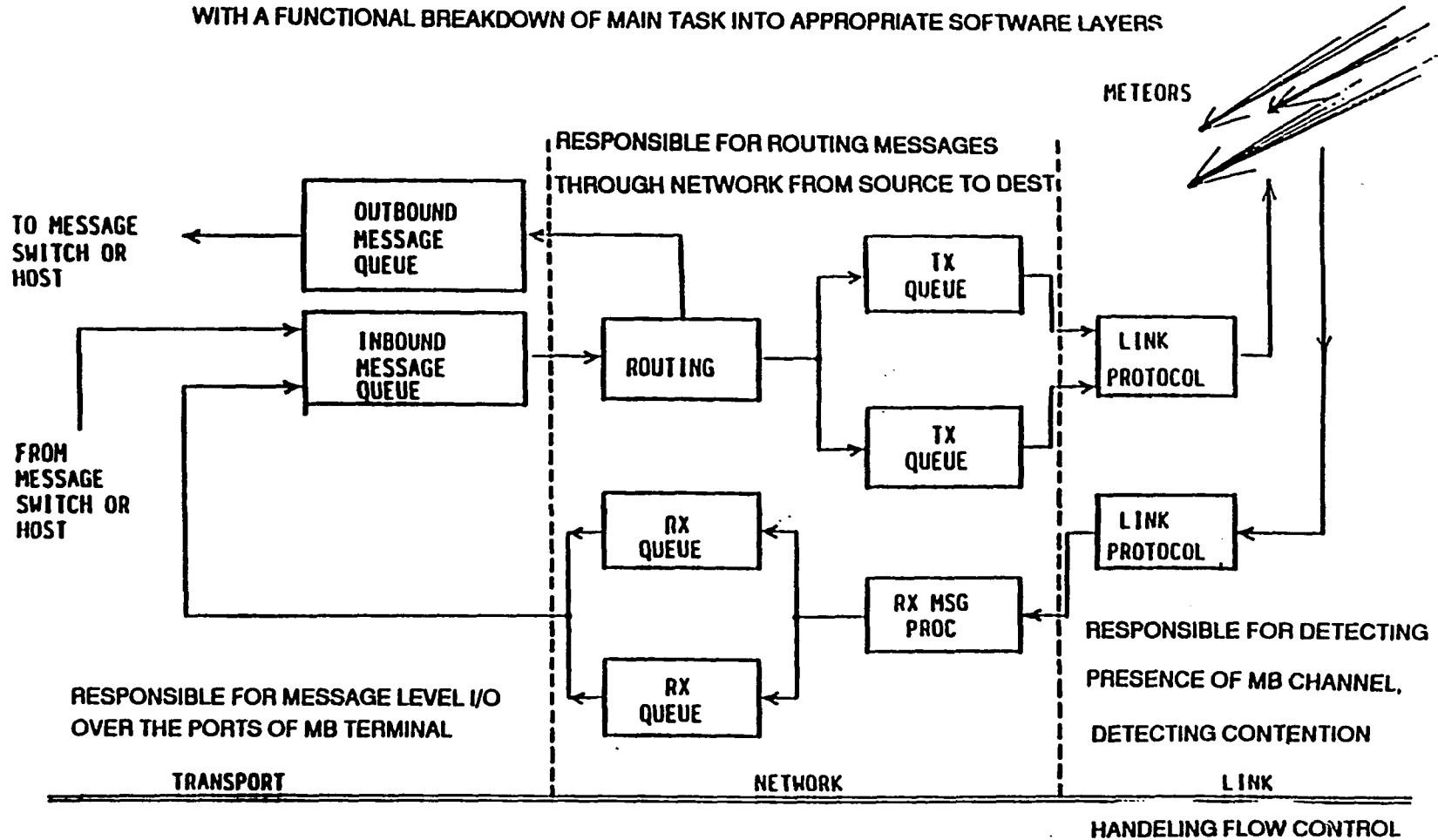


Figure 3.4

[Oetting, Allen, Booz and Hamilton, 13]

MESSAGE FLOW IN AN ADVANCED MASTER STATION NETWORK
WITH A FUNCTIONAL BREAKDOWN OF MAIN TASK INTO APPROPRIATE SOFTWARE LAYERS



ISO MODEL TO EXAMINE SOFTWARE DESIGN
REQUIREMENTS AND IMPLEMENTATION
IMPACT OF 3 LAYERS ON MBC DESCRIBED

Figure 3.5

[Smith and Fulthop]

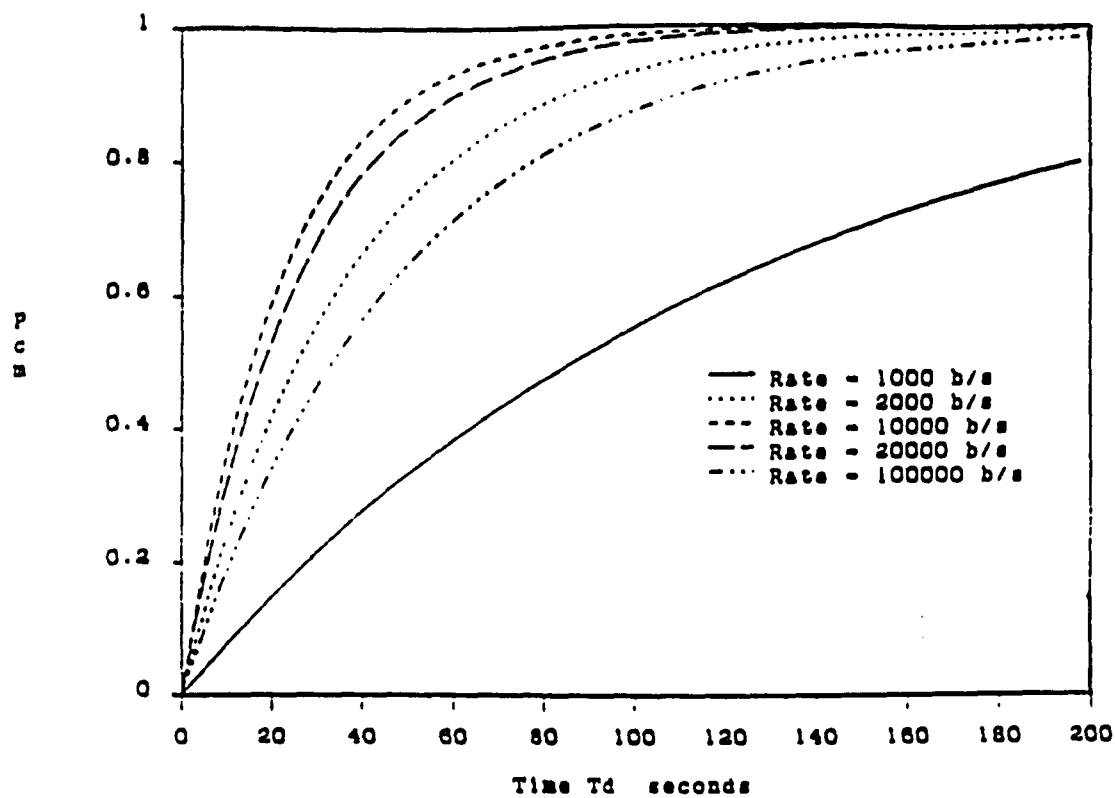


Figure 3.6 Probability of successful message completion versus T_D using the first protocol and constant rate.

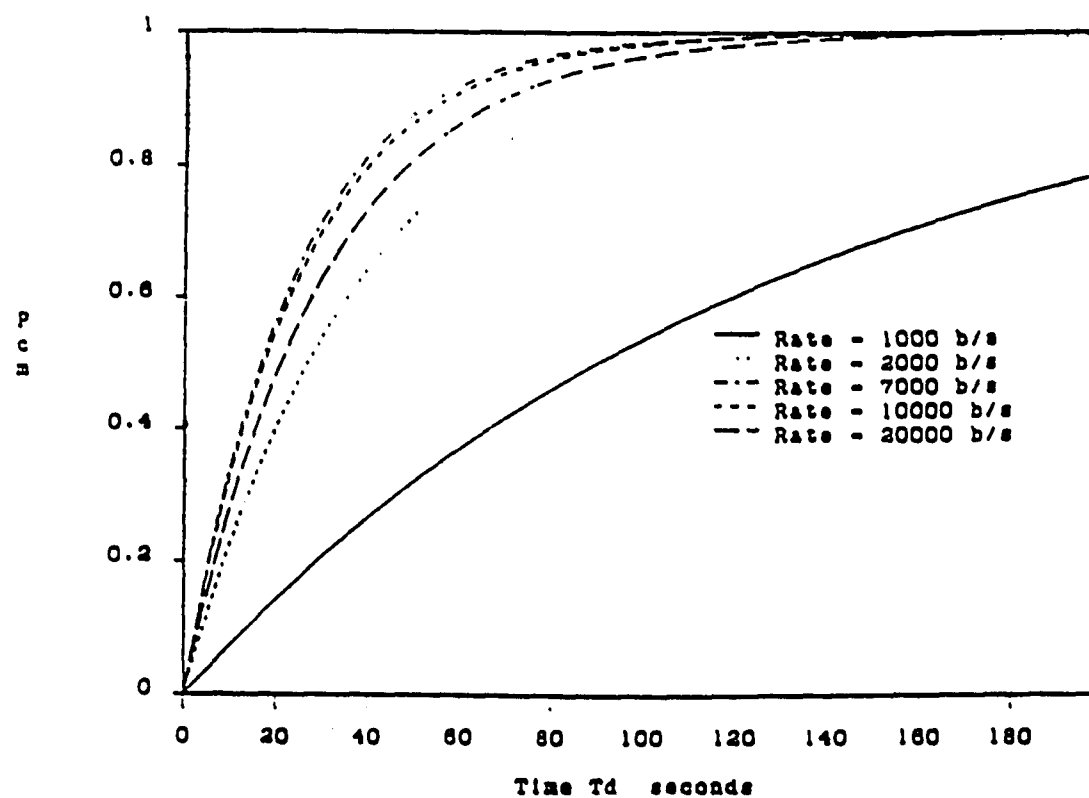


Figure 3.7 Probability of successful message completion versus T_D using the second protocol and constant rate.

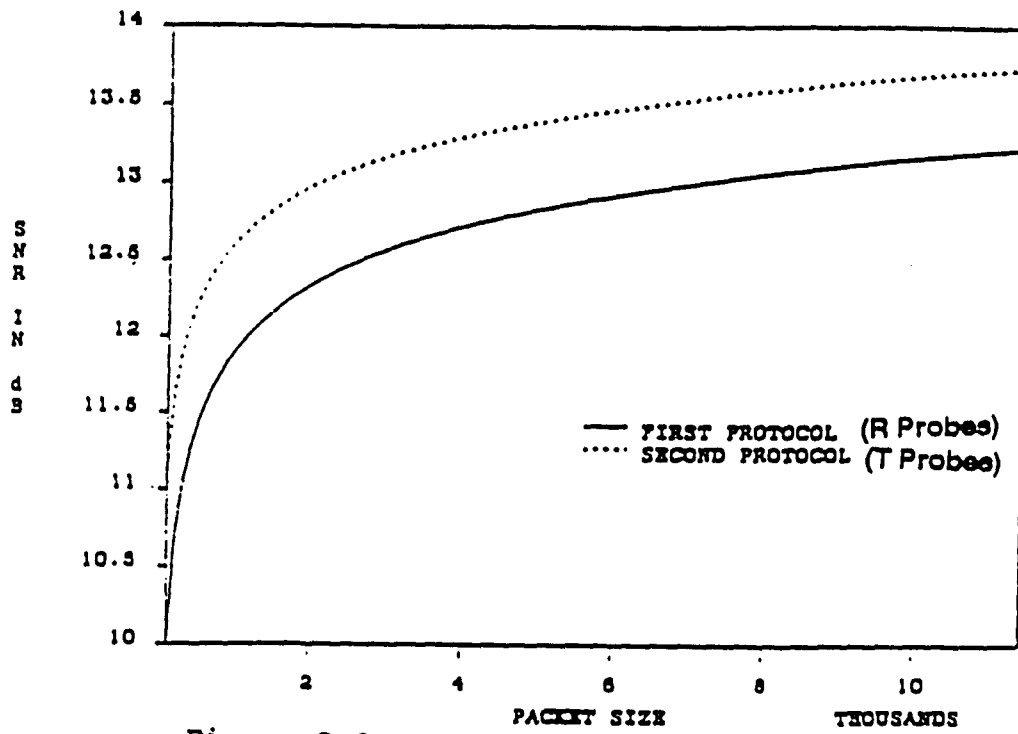


Figure 3.8 Optimal signal-to-noise ratios

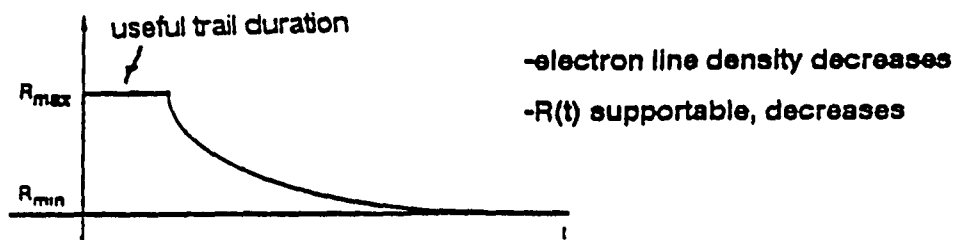


Figure 3.9 Rate $R(t)$ as a function of time

4 POINT TO POINT COMMUNICATION ANALYSIS

4.1 COMPLETION TIME METHOD APPLIED TO MBC

We treat the disappearances of the channel in MB communication as the service interruptions appearing at random to a waiting line process. Packets of data are supposed to arrive with Poisson process with an average rate of λ . If the channel is not available immediately, the packets stay in the buffer. A queue of infinite length is assumed at the sending station. As soon as the channel becomes available, the packet at the head on line (HOL) is transmitted on a first come first served (FCFS) basis.

This paper analyzes protocol (III) and provides a delay-throughput results. The MB link is modeled as a single server system with stationary compound Poisson input and general independent service time. The service time is subjected to random interruptions of independent but otherwise arbitrary distributed durations. For a service interrupted environment, Gaver [1] has described four postulates for computing the message completion time. The message completion time denoted by $E(C)$ is the packet transmission time with interruptions accounted for. The postulate applied to the meteor burst channel environment is named preemptive-repeat identical interruptions (abbreviated p.rept.i), which is stated as follows: When a p.rept.i. Interruption appears during an arrival's service period, it immediately halts that service until the interruption is cleared, at which time a service period of the same duration as the one interrupted begins again from scratch. Service is completed (completion time terminates) when for the first time, a (repeated) service period elapses without any interruption.

In a packet radio environment, the packet which is transmitted over a MB channel, has its destiny in the hands of the duration of the MB trail. If the duration of the trail is long enough, the packet may reach the receiving station without any disruption. However, if the trail duration is less, the packet may be interrupted during the transmission once or more times. In this case the total time for a packet to be successfully transmitted to the receiver, which is defined as the completion time will be given as follows:

$$C = S + \sum_{i=0}^N I_i + \sum_{i=0}^N \bar{S}_i \quad (1)$$

Where S is the actual service (transmission) time for the packet if there would have been no interruptions; $I_1, I_2, I_3, \dots, I_N$ are durations of interruptions and \bar{S} is the time wasted to transmit the portion of the packet until the disappearance of the MB trail. Here, N is the number of failed transmissions (due to interruptions) for a packet. After the successful reception of a packet, the receiver sends an ACK back to the transmitter. The channel must be available for the return of the ACK right after the transmission of a packet. To simplify the analysis, we assume that the ACK has always a MB channel available. If the transmitting station does not receive an ACK within a time out period t_o , it transmits another copy of the packet assuming that the packet has been disrupted. The time out period is relatively negligible and is ignored for simplicity. The moments calculated for the completion time are given as follows:

$$E(C) = [E\{e^{vS}\} - 1][E(I) + 1/v] \quad (2)$$

$$E(C^2) = 2\{E(I) + 1/v\}^2 E\{e^{vS} - 1\}^2 \\ + \{E(I^2) + 2E(I)/v + 2/v^2\} \{E\{e^{vS} - 1\} - 2\{E(I) + 1/v\}E\{Se^{vS}\}\} \quad (3)$$

Where v is the rate of interruptions and $E(I)$ is the average duration of interruptions.

We assume Poisson arrival of packets with an average rate of λ at the sending station. The arriving packets are served through the channel created by the MB trails. When the transmission is supported by one trail and suddenly the trail disappears, the packet under transmission has to be sent over the next trail. The trail duration is variable. The service performed by the channel therefore is of variable nature and the distribution of the service time is considered to be arbitrary or general. At any time either there is one server (trail) or no server at all. So the system under consideration follows a M/G/1 criteria. The pollczek-Khintchine formula for the average value of the waiting time W_q experienced by an arbitrary customer in the equilibrium M/G/1 queue is given below:

$$E(W_q) = \rho/(1 - \rho) \{E(S)/2 + \sigma^2/2E(S)\} \quad (4)$$

Here S is the packet service(transmission) time in a non-interruption environment.

However in the case of meteor burst communication, S has to be replaced by C which is the service time with the interruption durations included, termed as completion time. Hence equation (4) changes to :

$$E(Wq) = \rho/(1-\rho) \{E(C)/2 + \sigma^2/2E(C)\} \quad (5)$$

Where σ^2 is the variance of the message completion time and C is related to S by equation (1). Now the total message delay will be as follows:

$$E(D) = E(Wq) + E(C) + W_{met} + W_p \quad (6)$$

Where W_{met} is the waiting time for the arrival of the first meteor, the value of which is taken as $0.693/v$, [20], with v being the meteor arrival rate. The meteor arrival rate changes with time in the day. There are two peak arrival rate times, early morning hours and late evening hours. The value of v in the early morning hours is much different from the evening hours. The average value of this rate is 0.25 and 0.05 meteors per second respectively. As it can be viewed in Figure (4.2), the channel interruption rate values comes to be the same as the arrival rate values.

After substitution of equations (2), (3) and (5) into equation 6. We get the total average packet delay $E(D)$ for using a MB channel for a point to point communication as shown below:

$$\begin{aligned}
 E(D) = & \rho/2(1-\rho)[E\{e^{(\nu S)}-1\}\{E(I)+1/\nu\} \\
 & + \frac{\{E(I^2)+2E(I)/\nu+2/\nu^2\}}{\{E(I)+1/\nu\}} - \frac{E\{S.e^{(\nu S)}\}}{E\{e^{(\nu S)}-1\}}] \\
 & + E\{e^{(\nu S)}-1\}\{E(I)+1/\nu\} + 0.693/\nu + W_p
 \end{aligned} \tag{7}$$

Some of the terms can be simplified to the closed forms as follows:

$$E(e^{\nu S} - 1) = \frac{\nu}{\mu - \nu}, \quad \mu > \nu$$

$$E(S e^{\nu S}) = \frac{\mu}{(\mu - \nu)^2}, \quad \mu > \nu$$

Substituting the above values into equation (7) we get,

$$\begin{aligned}
 E(D) = & \frac{\rho}{2(1-\rho)} \left[\frac{\nu\{E(I)+1/\nu\}}{(\mu-\nu)} + \frac{\{E(I^2)+2E(I)+2/\nu^2\}}{\{E(I)+1/\nu\}} - \frac{\mu}{\nu(\mu-\nu)} \right] \\
 & + \frac{\nu\{E(I)+1/\nu\}}{(\mu-\nu)} + 0.693/\nu + W_p, \quad \mu > \nu
 \end{aligned} \tag{8}$$

Where μ is the service time in packets per second and v is the average meteor arrival rate. The value of μ remains always greater than the value of v . Even if the packet size is very large, say 48 kbits, the value of μ becomes 1. Notice that the value of v ranges from 0.05 to 0.25. W_p is the one way propagation delay. The transmitter starts sending the packets as soon as it receives the probe from the receiver. Therefore, only one way propagation delay is included. Its value is 7 milliseconds approximately. The arrival of meteors is a Poisson process with v parameter and therefore the first and the second moments of interruption duration become as shown below:

$$E(I) = \frac{1}{v} \quad ; \quad E(I^2) = \frac{2}{v^2}$$

Now because the interarrival time of the meteors is 4 seconds in the early morning hours and 20 seconds in the late evening hours as referred to figure (4.2) we have,

Early Morning Hours: $E(I) = 3.42 \text{ sec.} \quad ; \quad E(I^2) = 23.62 \text{ sec.}$

Late Evening Hours: $E(I) = 19.42 \text{ sec.} \quad ; \quad E(I^2) = 768.9 \text{ sec.}$

4.2 CONTINUOUS TIME MARKOV CHAIN SOLUTION TO THE MB CHANNEL

The delay analysis previously performed for the meteor burst channel follows the

Gaver's procedure of computing the first and second moments of so called completion time for the meteor burst channel. In the following section we use a two dimensional continuous time Markov chain (CTMC), as pictured in figure (4.5) to analyze the channel. It is assumed that the packets of exponentially distributed length arrive at the sending station with a Poisson process. Also, meteor arrival is assumed to follow a Poisson process and meteor trail duration is exponentially distributed. The packets are queued in infinite buffer where first come first served (FIFO) strategy is followed for the transmission.

The state of the Markov chain (i,j) is defined as follows. The first letter i denotes one of the two states of the meteor burst channel whether it is available or not. The second letter j is the number of packets in the queue at the transmitting station. $p_{1,j}$ is the probability that the MB channel is available or active and there are j packets in the queue. $p_{0,j}$ is the probability that the channel is not active (not available) while the input queue has j packets at this time. The input packet arrives with Poisson process with parameter λ and if the channel is available and the input queue is empty, it is transmitted immediately. However, if the channel is not available, the packet has to wait in the queue until the next useful MB trail availability. If the queue is not empty, the incoming packets are stored in the queue and the one at the head of the line (HOL) is transmitted when a channel is established by a meteor burst. The useful MB channel becomes active with a transmission rate α and it goes from an active state to the non-active state with a transmission rate β . As referred to figure (4.4), the values of α and β are as follows:

$$\alpha = \frac{1}{E(td)} \quad ; \quad \beta = \frac{1}{E(I)}$$

In the following we build the state balance equations for the two cases. Firstly when the channel is available,

$i = 1$, channel available, (see figure 4.5)

$$(\alpha + \lambda)p_{1,0} = \beta p_{0,0} + \mu p_{1,1} \quad \dots \dots \dots j = 0 \quad (9)$$

$$(\alpha + \lambda + \mu)p_{1,j} = \lambda p_{1,j-1} + \beta p_{0,j} + \mu p_{1,j+1} \dots \dots j \geq 1 \quad (10)$$

and for the second case when there is no useful MB trail in between the transmitting and the receiving station,

$i = 0$, channel not available

$$(\beta + \lambda)p_{0,0} = \alpha p_{1,0} \dots \dots \dots j = 0 \quad (11)$$

$$(\beta + \lambda)p_{0,j} = \alpha p_{1,j} + \lambda p_{0,j-1} \dots \dots \dots j \geq 1 \quad (12)$$

Equations (9) through (12) should be solved to find all the state probabilities. However, it is easy first, to find $p_{1,0}$ and $p_{1,1}$ in terms of $p_{0,0}$ from equations (9) and (11), which are for $j=0$, so we get:

$$p_{1,0} = \left(\frac{\alpha}{\beta + \lambda} \right) p_{0,0} \quad (13)$$

$$p_{1,1} = \left(\frac{\tau + \rho\sigma}{\sigma} - \frac{\tau}{\rho(1 + \sigma\rho)} \right) p_{0,0} \quad (14)$$

Where $\tau = \frac{\alpha}{\beta}$ and $\sigma = \frac{\mu}{\beta}$

In order to solve equations (10) and (12) which are for $j \geq 1$, we define two generating functions as follows:

$$G_i(z) = \sum_{j=0}^{\infty} p_{i,j} z^j \quad i = 0, 1 \quad (15)$$

which should satisfy the condition

$$G_0(1) + G_1(1) = \sum_{j=0}^{\infty} p_{0,j} + \sum_{j=0}^{\infty} p_{1,j} = 1 \quad (16)$$

Now multiplying equation (10) by z^j and summing over all values of j for $j \geq 1$, we get:

$$(\alpha + \lambda + \mu) \sum_{j=1}^{\infty} p_{0,j} z^j = \lambda \sum_{j=1}^{\infty} p_{0,j-1} z^j + \beta \sum_{j=1}^{\infty} p_{1,j} z^j + \mu \sum_{j=1}^{\infty} p_{0,j+1} z^j$$

and using some identities we get,

$$\begin{aligned}
(\alpha + \lambda + \mu) \{G_0(z) - p_{0,0}\} &= \lambda z G_0(z) + \beta \{G_1(z) - p_{1,0}\} \\
&+ \frac{\mu}{z} \{G_0(z) - p_{0,0} - z p_{0,1}\}
\end{aligned} \tag{17}$$

A similar operation turns equation (12) to the following expression:

$$(\beta + \lambda) \{G_1(z) - p_{1,0}\} = \alpha \{G_0(z) - p_{0,0}\} + \lambda z G_1(z) \tag{18}$$

Solving equation (17) and (18) with the substitution of values of $p_{1,0}$ and $p_{1,1}$ from equations (13) and (14), we get the following moment generating functions in terms of $p_{0,0}$:

$$G_0(z) = \frac{\{1 + (1 - z)\sigma\rho\}p_{0,0}}{\sigma z^2 \rho^2 - z(\rho + \tau\rho + \sigma\rho^2 + \sigma\rho) + 1 + \sigma\rho} \tag{19}$$

$$G_1(z) = \frac{\tau p_{0,0}}{\sigma z^2 \rho^2 - z(\rho + \tau\rho + \sigma\rho^2 + \sigma\rho) + 1 + \sigma\rho} \tag{20}$$

To find $p_{0,0}$, we use the probability sum equality of equation (16) and get:

$$p_{0,0} = \left(\frac{1 - \rho - \tau\rho}{1 + \tau} \right) \quad (21)$$

The average number of packets in the system (in queue and any in service) denoted by \bar{N} is given by,

$$\bar{N} = \frac{dG_0(z)}{dz} \Big|_{z=1} + \frac{dG_1(z)}{dz} \Big|_{z=1}$$

Substituting from equations (11) and (12)

$$\bar{N} = \frac{\sigma\tau\rho^2 - 2\sigma\rho^2\sigma\rho - \tau\rho - \rho}{(1 - \rho - \tau\rho)(1 + \tau)} + \frac{-\tau(3\sigma\rho^2 + \sigma\rho - \tau\rho - \rho)}{(1 - \rho - \tau\rho)(1 + \tau)}$$

or,

$$\bar{N} = \frac{2\sigma\tau\rho^2 + 2\sigma\rho^2 + 2\sigma\rho + 2\rho\tau + \sigma\rho\tau + \rho\tau^2 + \rho}{(1 + \tau)(\rho\tau + \rho - 1)} \quad (22)$$

and using little's theorem we find the expression for average packet delay in the system $E(T)$,

$$E(T) = \frac{\bar{N}}{\lambda} = \frac{2\sigma\tau\rho^2 + 2\sigma\rho^2 + 2\sigma\rho + 2\rho\tau + \sigma\rho\tau + \rho\tau^2 + \rho}{\beta\rho\sigma(1+\tau)(\rho\tau + \rho - 1)} \quad (23)$$

Here ρ is the incoming load intensity at the transmitting station.

The probability that the channel is active is given as follows:

$$\text{Prob.}\{channel \text{ is active}\} = G_1(1)$$

$$= \frac{p_{0,0}}{\frac{\mu}{\beta}\rho^2 - \left(\rho + \rho_1\rho + \frac{\mu}{\beta}\rho^2 + \frac{\mu}{\beta}\rho\right) + 1 + \frac{\mu}{\beta}\rho} \quad (24)$$

The factor $p_{0,0}$ in turn has been evaluated in equation (21), and $\rho_1 = \frac{\alpha}{\beta}$

PROTOCOL
(ONE WAY P.D)

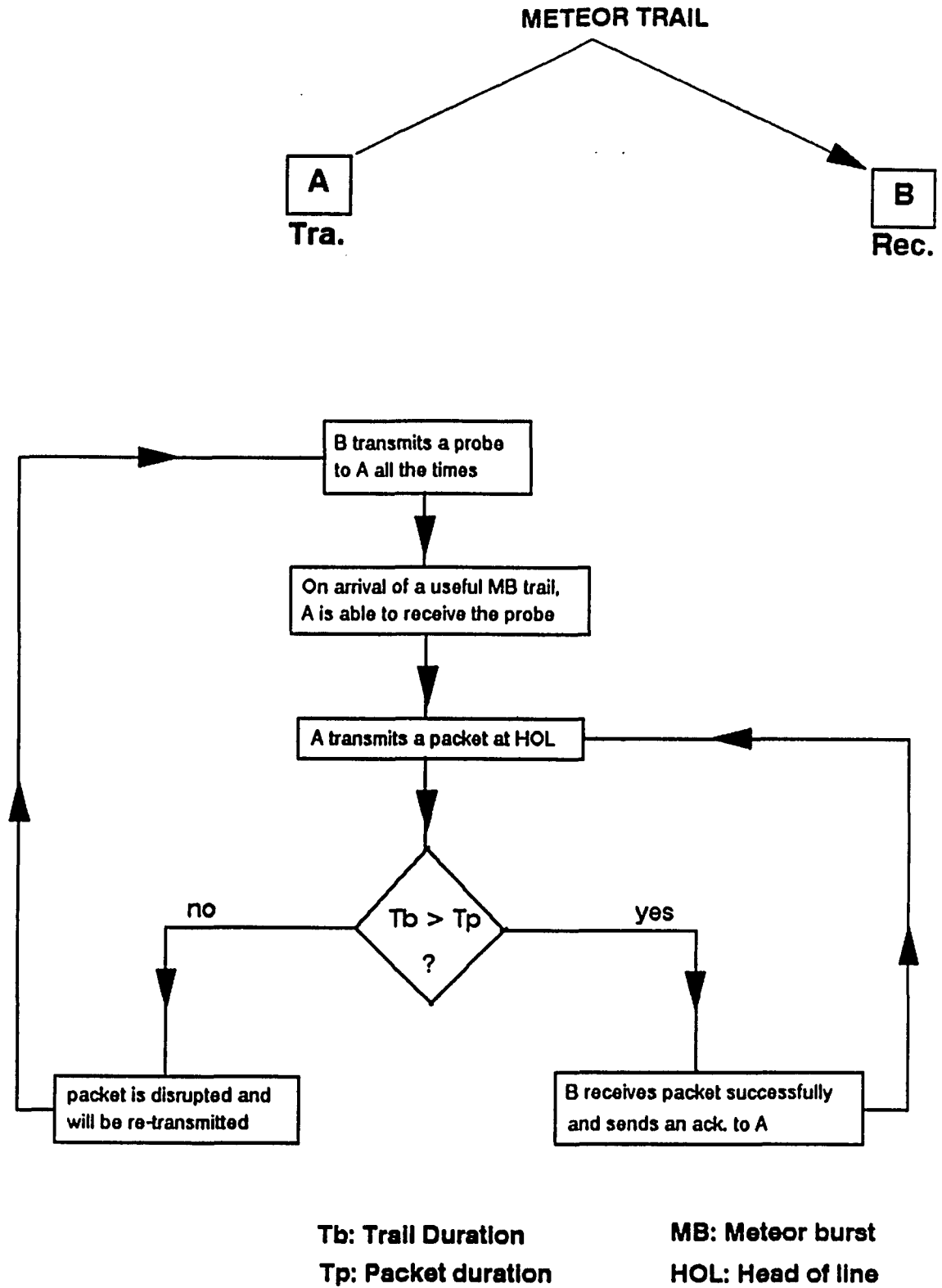
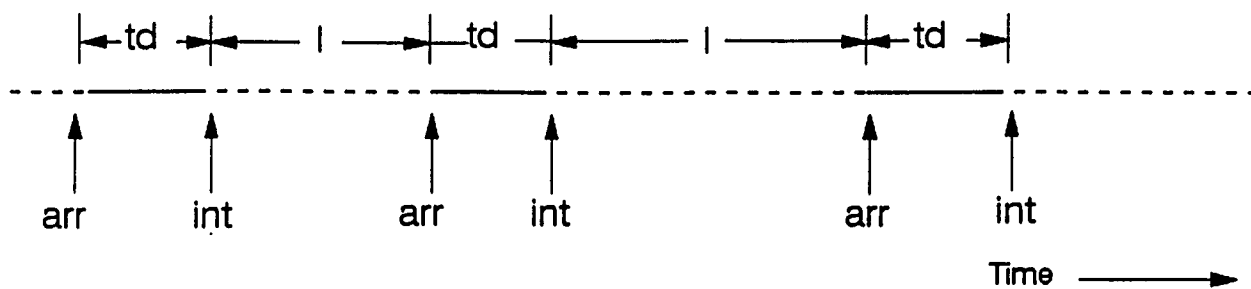


FIG.(4.1) STATION A SENDS DATA TO STATION B VIA MB TRAIL



td=Meteor trail duration ; I= Interruption duration

	Early Morning	Late Evening
Average Interarrival Time	4 sec.	20 sec.
Average Meteor Duration, $E(td)$	0.58 sec.	0.58 sec.
Average Interruption Duration, $E(I)$	3.42 sec.	19.42 sec.
Average Interruption Rate, $E(v)$	0.25 int/sec.	0.05 int/sec.

Fig.(4.2) Meteor Trail Arrival and Interruptions, (typical values)

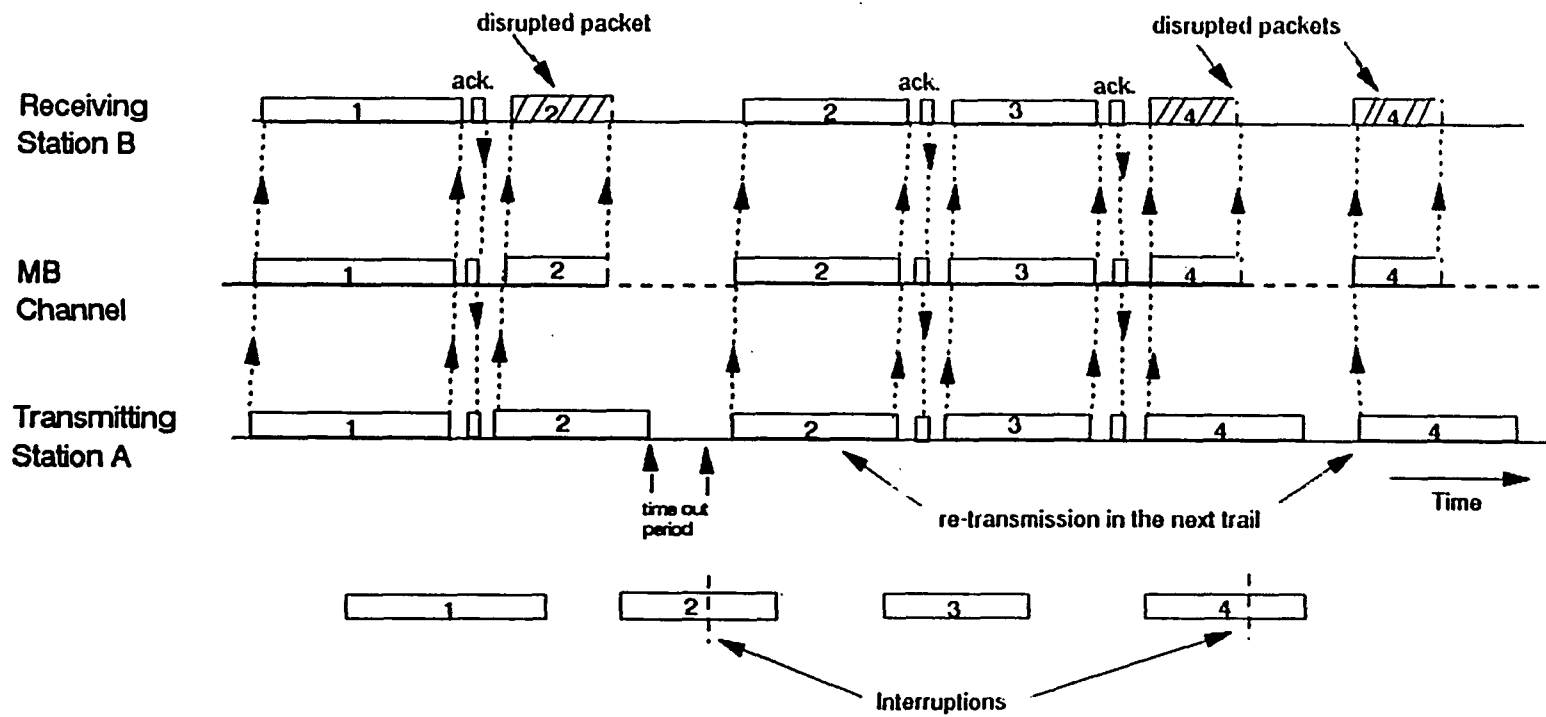
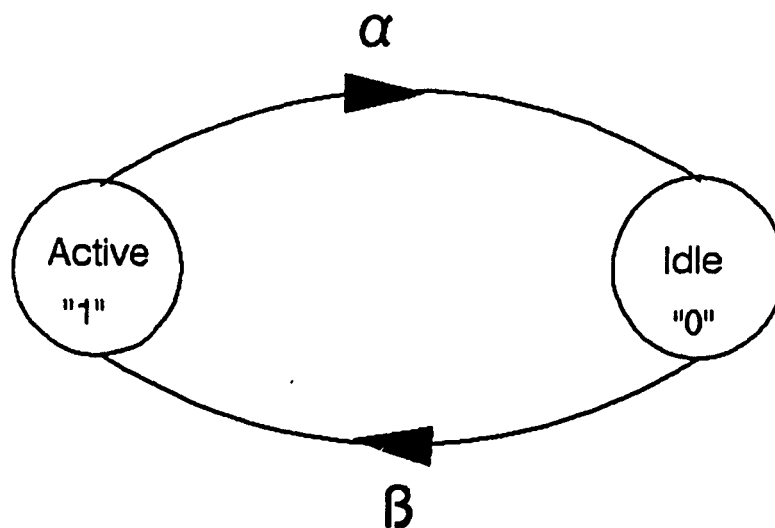
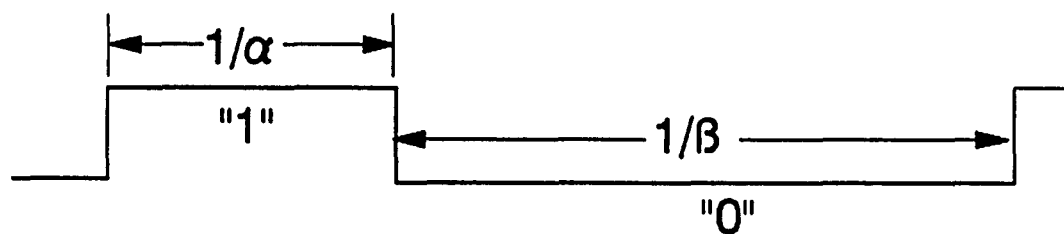


Fig.(4.3) Packet disruption during transmission through MB channel



α : Transition rate of channel availability

β : Transition rate of channel un-availability



$1/\alpha$: Mean active period of channel

$1/\beta$: Mean un-active period of channel

FIG. (4.4) Transitions of MB Channel

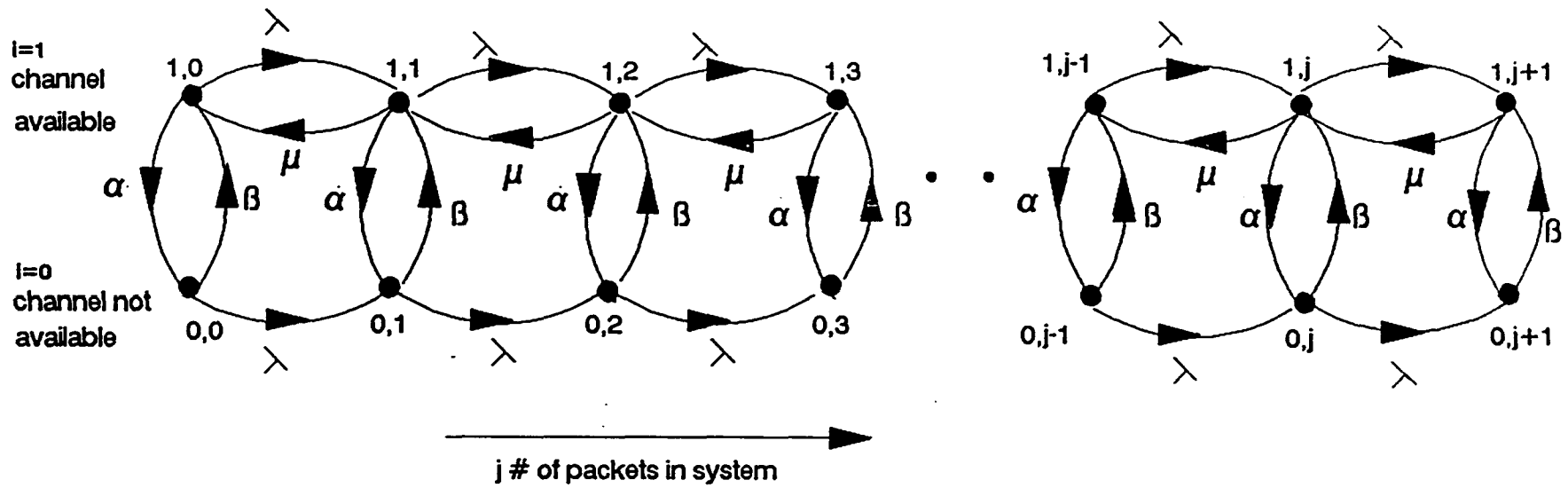


Fig.(4.5) Continuous Time Markov Chain

5 MBC MULTI-NODE NETWORK ANALYSIS

5.1 COMPLETION TIME METHOD

For the network case a packet generated from one of the remote nodes is further delayed to be received by the central node as the later is also busy in communication with other nodes. Therefore, the completion time in this case is as follows:

$$C = S + \sum_{i=0}^N I_i + \sum_{i=0}^N \bar{S}_i + \sum_{j=1}^{n-1} B_j \quad (25)$$

The first and the second moments for the network case are derived as given below:

$$E(C) = \{E(e^{vS}) - 1\} \{E(I) + E(B) + 1/v\} \quad (26)$$

$$\begin{aligned} E(C^2) = & 2\{E(I) + E(B) + 1/v\}^2 \{E(e^{vS} - 1)^2\} \\ & + \left\{ E(I+B)^2 + 2 \frac{E(I) + E(B)}{v} + 2/v^2 \right\} \{E(e^{vS} - 1)\} \\ & - 2\{E(I) + E(B) + 1/v\} \cdot E\{S \cdot e^{vS}\} \end{aligned} \quad (26)$$

Where v is the rate of interruptions, S is the transmission time for a packet, $E(I)$ is the average interruption duration and $E(B)$ is the average busy tone duration. This is the

average period for which the central node sends a BT to a remote station. The central sends a busy tone to all the remotes except the one which it is communicating with. The value of E(B) has been computed as follows:

When a remote is ready to transmit the probability that it will find the central busy $P_B(t)$, is equal to the probability that at least one out of the rest of the remotes (n-1) is transmitting to the central so that:

$$\text{prob.}[i \text{ nodes are busy with central}] = \sum_{i=1}^{n-1} \binom{n-1}{i} p^i (1-p)^{n-1-i} \quad (28)$$

$$p_{nb} = \text{prob.}[none of the nodes are busy with the central] = \binom{n-1}{0} p^0 (1-p)^{n-1}$$

$$p_{nb} = (1-p)^{n-1} \quad (29)$$

$$\text{prob.}[some, one or more nodes are busy] = 1 - (1-p)^{n-1} \quad (30)$$

Now, the pdf that channel is available at one link which is equivalent to the probability density function that one node is busy is $\alpha e^{-\omega}$ and therefore,

$$PDF[\text{one node busy}] = p = 1 - \alpha e^{-\alpha}$$

Substituting value of p in equation 29

$$\text{prob. of blocking (central is busy)} = 1 - [1 - (1 - \alpha e^{-\alpha})]^{n-1}$$

$$pdf(B.T.) = \alpha^n (n-1) e^{-\alpha(n-1)t} \quad (31)$$

The first and second moment are found as below:

$$E(t_B) = \int_0^{\infty} t \cdot pdf dt = \frac{\alpha^{n-2}}{n-1} \quad (32)$$

$$E(t_B^2) = 2 \frac{\alpha^{2(n-2)}}{(n-1)^2} \quad (33)$$

With the substitution of $E(t_B)$ and $E(t_B^2)$ into two moments of the completion time given in equations (26&27) and then using the later in polaczek-Khinchin (P-K)'s mean value formula, we get in the following, the total average packet delay for the meteor communication network:

$$\begin{aligned}
E(D) = & \rho/2(1 - \rho) \{E(e^{\nu S} - 1) \{E(I) + E(t_B) + 1/\nu\} \\
& + \frac{E(I^2) + E(t_B^2) + 2E(I)E(t_B) + 2\{E(I) + E(t_B)\}/\nu + 2/\nu^2}{E(I) + E(t_B) + 1/\nu} \\
& - \frac{E(S \cdot e^{\nu S})}{E(e^{\nu S} - 1)} \} + E\{e^{\nu S} - 1\} \{E(I) + E(t_B) + 1/\nu\} \\
& + W_p \tag{34}
\end{aligned}$$

Where W_p is the one way propagation delay and its value is around 7 millisecond, ν is the average interruption rate. The terms containing S , an exponentially distributed random variable with an probability density function of $\mu e^{-\mu S}$, can be brought into closed form:

$$E(e^{\nu S} - 1) = \frac{\nu}{\mu - \nu} \quad ; \quad E(S e^{\nu S}) = \frac{\mu}{(\mu - \nu)^2} \dots \dots \nu < \mu$$

The condition $\nu < \mu$ suggests that for all packet sizes the packet service rate should be greater than the interruption rate, which is actually true for the range of the packet sizes considered.

The interruptions occur with poisson process with parameter ν and with exponential distributed interarrival time. Therefore the first and second moment of the interruption duration I , have been calculated to be in the followings:

$$E(I) = \frac{1}{v} \quad ; \quad E(I^2) = \frac{2}{v^2}$$

5.2 MARKOV CHAIN ANALYSIS

The results for the MB channel obtained through the two dimensional Markov chain of figure (4.5) are extended for the multi-node case. We consider M remote nodes communicating with a central node. It is assumed that the packets of exponentially distributed length arrive at all the nodes with a Poisson process. The packets are queued in an infinite buffers (later we will consider a finite buffer) where first come first served (FIFO) strategy is followed for the transmission.

The network consisting of finite population of terminals would be under the operation of ALOHA scheme in the sense that whenever a probe (which is transmitted to all the nodes) is received by any of the nodes from the central station, the node transmits its packets. The transition state at n^{th} terminal, where n is 0, 1, 2,..... $n-1$, depends on following conditions:

- (1) The packet is ready to be sent; (the arrival rate at node n , is R_n in packets per second.
- (2) The terminal can transmit; which depends on the channel availability with probability p_{ca} and that the central is idle which occurs with probability p_{nb} .
- (3) The transmission is successful; it occurs with probability, $S(n)$ conditioned with (1)

and (2).

We assume that the terminal input flow rate is constant over the time. The success probability depend on p_{ca} and on p_{nb} . We derive $P_k(n), k = 0, 1, 2, \dots, \infty$, the steady state probability that terminal m has k packets in its buffer. The number of packets at any transition can decrease by one, increase by one or remain the same. If a new packet arrives and no packet is successfully transmitted then k is increased by one with a rate:

$$\lambda = R_n \{1 - p_{ca} p_{nb}\} \quad (35)$$

The arrival rate R_{sunbn} at the input buffer at a node follows a poisson process. The effective arrival rate λ given above is independant of p_{ca} but depends on p_{nb} . Although, λ does not strictly follows a poisson process, with making a negligible change in the analysis, we assume that the effective arrival also follows a poisson process. A packet at HOL is transmitted with probability $(p_{ca} p_{nb})$ and so the buffer size decreases with a rate:

$$\mu = \left(\frac{l}{C} \right) p_{ca} p_{nb} \quad (36)$$

Where C is the channel capacity in bits/sec and l is the packet size in bits. The Continuous Markov Chain concerned is drawn in figure (5.5), which is based on M/M/1 queue with birth rate λ and service rate μ as given above. Here, p_{ca} and p_{nb} are given by equations

(24) and (29). The state probabilities [22] are

$$P_k(n) = (1 - \rho)\rho^k, \quad k = 0, 1, 2, \dots, \infty \quad (37)$$

Where $\rho = \lambda/\mu$. The average number of packets in the buffer,

$$\bar{N} = \sum_{k=0}^{\infty} kP_k = \frac{\rho}{(1 - \rho)}, \quad \rho < 1 \quad (38)$$

Where ,

$$\rho = \frac{R_n C \{1 - p_{ca} p_{nb}\}}{l_{ca} p_{nb}}$$

The average delay then is given by the little's formula as follows:

$$E(D) = \frac{\bar{N}}{\lambda}$$

5.3 FINITE BUFFER CONSIDERATION

So far our analysis was based on infinite packet buffer assumption. However, the buffer can be considered of finite size. In this case when the buffer is full and a new packet arrives, the packet will be blocked. We find the blockage probability. Let the buffer size

is K . In this case the Markov chain as shown in figure (5.6) will end at $k=K$. Now it is a $M/M/1/K$ queueing system with arrival rate λ and μ given by equations (35) and (36) respectively. The state probabilities of this system are [45],

$$P_k = \frac{1-\rho}{1-\rho^{K+1}}\rho^k, \quad k = 0, 1, 2, \dots, K; \quad \rho = \lambda/\mu \quad (39)$$

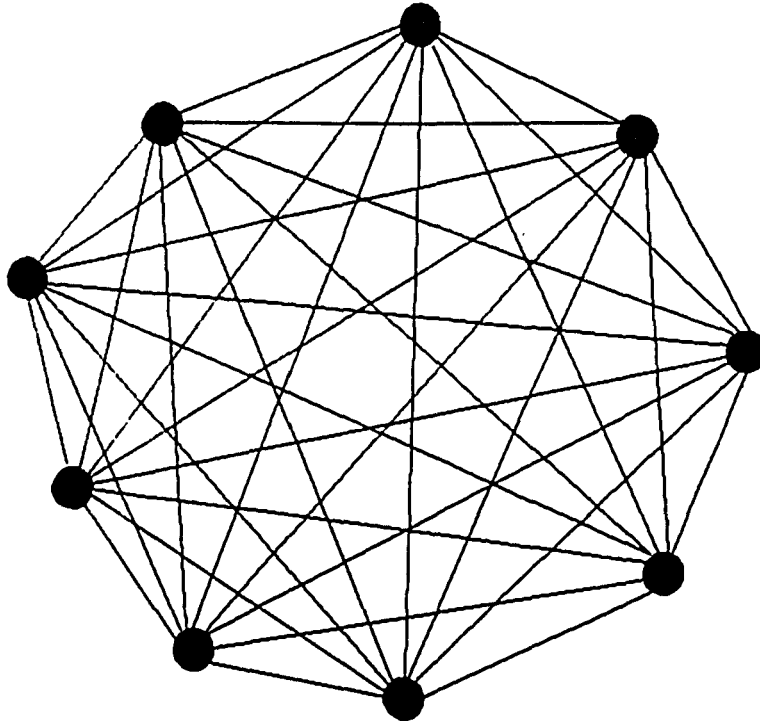
The throughput at a remote node is the average number of packets leaving the buffer, or equivalently to the number of packets accepted by the buffer at the node. The arriving packets are accepted unless the buffer is full with probability P_K and no packet is cleared immediately with probability $(1 - p_{ca}p_{nb})$. Therefore, the node under consideration having packet arrival rate R_n has throughput:

$$s = R_n - R_n(1 - p_{ca}p_{nb})P_K \quad (40)$$

The blocking probability is the ratio of rejected packets to the arriving packets as given below:

$$p_{bloc} = (R_n - s)/R_n = (1 - p_{ca}p_{nb})P_K \quad (41)$$

Again, p_{ca} and p_{nb} are given by equations (24) and (29) respectively.



Minimum distance between two nodes=400 km

Maximum distance between two nodes=2000 km

Fig.(5.1) A fully connected MB communication network

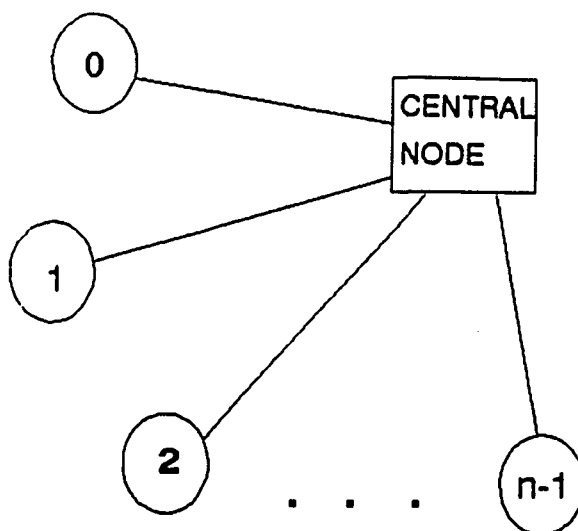


Fig.(5.2) Remote nodes sending data to a central node

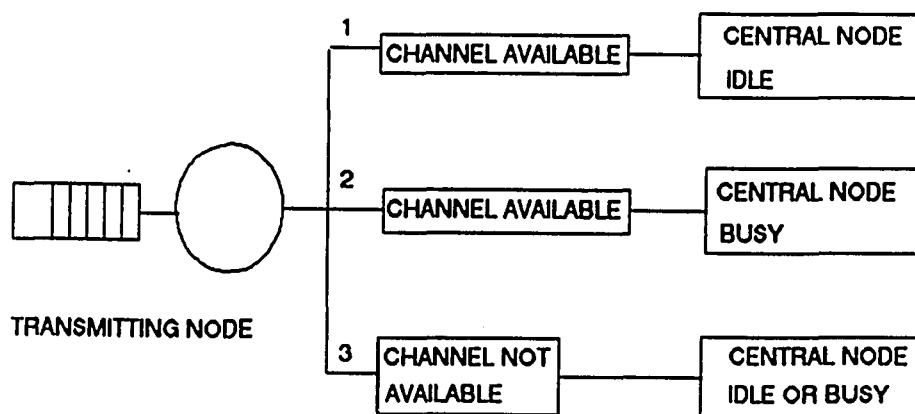


Fig.(5.3) The transmitting node in a network faces three possibilities

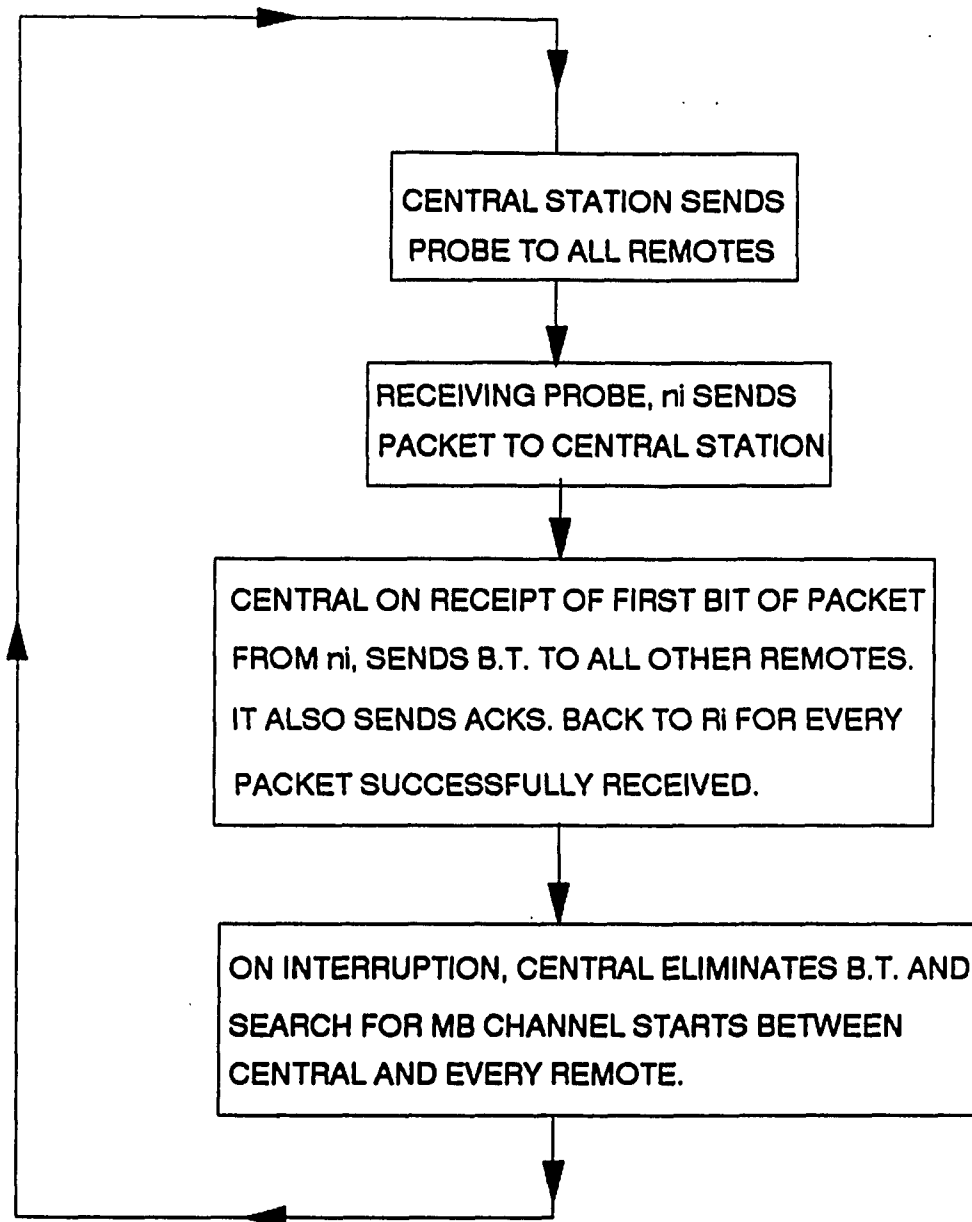


Fig.(5.4) Protocol flow chart, multi-node case

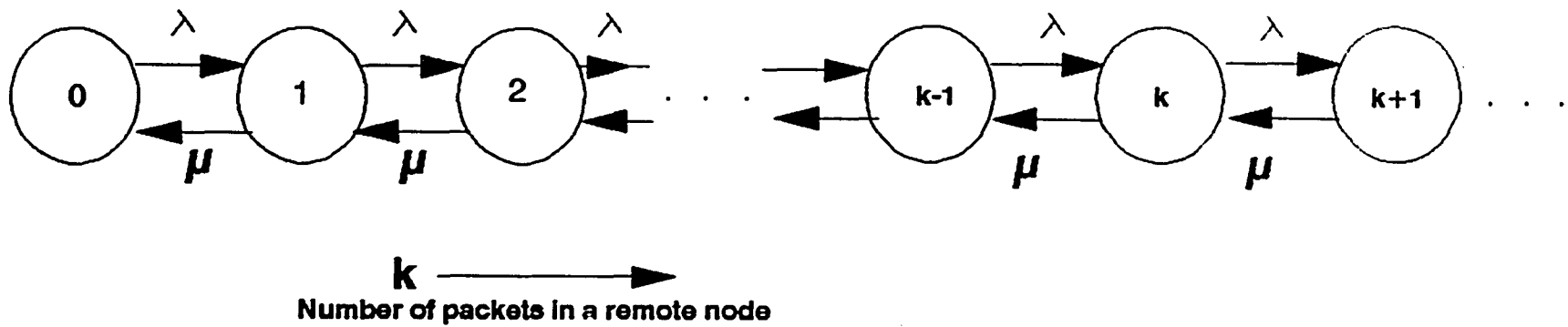


Fig.(5.5) Continuous Time Markov Chain for network case (infinite buffer)

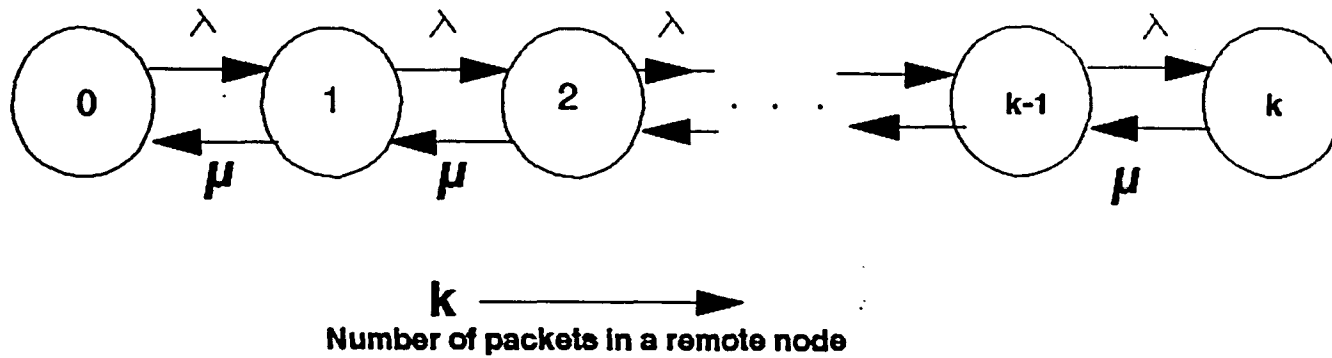


Fig.(5.6) Continuous Time Markov Chain for network case (finite buffer)

6 SIMULATION

There have been a few assumptions used in the numerical work. Some of the assumptions were made due to the conclusions made by some other people, which support the validation of the assumptions. A few assumptions were made to simplify the numerical analysis with the understanding that these assumptions would have a negligible effect on the main results. It was inspired therefore, to see how the results through a simulation model of a meteor burst communication system conform to the theoretical results.

Therefore, a simulation was performed using the simulating language, Simscript II.5, on VAX workstation in VMS operating system environment. This language has a structure containing sections like preamble to define variables, Main program calling routines and various processes required. The simulating language is English oriented and has many built in stochastic functions. The simulation was performed at a confidence level of 95%.

A Poisson packet arrival process and exponentially distributed packet length was set up. The disappearance of the meteor burst trail was simulated by the random interrupt environment available in the simulating package. This simulation was done for an average interruption rate of 0.25 int/second with an average interruption duration of 3.42 seconds which is the criteria for the early morning hours. The results for the average packet delay as varied with the offered load are shown in figure (4.13). The numerical results are also plotted in this figure. The simulation result showed a little rise in the total average packet

delay as compared to the numerical results for most values of the offered load except after 0.13, where after we see a little drop than the numerical value. This simulation was performed for the packet length of 2 Kbits and for the bit rate of 12 Kbps. Another simulation was performed for the network case. The results obtained were found close to the theoretical ones as shown in figure (7.7).

7 NUMERICAL RESULTS

Numerical results have been produced through the analysis performed using the two theoretical approaches. Average packet delay versus offered load curves based on completion time analysis are shown in figure (7.1) for peak morning hours. There are five curves for different packet lengths ranging from 2 kbits to 6 kbits. Similar curves for late evening hours are shown in figure (7.2). The graph goes upto about 0.16 for the morning and 0.025 in the evening, on the load intensity scale. This is due to the fact that the duty cycle of the channel is only nearly 17% and 2.5% in these two peak hours respectively. There is a continuous lowering of the curves for shorter packet sizes. This is because a shorter packet has more chance of being completely transmitted before a channel interruption comes across. We compare the early morning and late evening results in terms of the percentage of the maximum offered load values. We see a substantial increase in delay for the evening hours. This is due to the lower meteor arrival rate and larger interruption periods to the channel availability in these hours. The corresponding results based on continuous time Markov chain approach is shown in figure (7.3) for morning hours.

We see a similar pattern as given by completion time's approach. However, there are small differences in values in comparison, which is attributed to the following difference in assumptions. (1) The portion of a packet until an interruption occurs is wasted because the packet has to be re-transmitted. This portion of the waiting time is not accounted for in CTMC analysis but the completion time analysis takes care of this additional waiting time. (2) The CTMC analysis is based upon M/M/1 model while completion time analysis is based

on M/G/1 model. Although the data packets are assumed to be exponentially distributed, there is controversy about meteor trail duration. We have considered a general distributed service time in the completion time analysis.

Figure (7.4) shows three curves for the packet size of 2 kbits in the morning hours. Two of them are for the numerical analysis through the two procedures. The third is from the simulation. The simulation shows delay values fairly close to the numerical results. We see at average, a 1% increase compared to completion time and 3% increase as compared to Markov chain approach upto load intensity around 0.135 hereafters we see a little decrease in the simulation values.

The attempt has been made to increase the number of bits per packet while keeping the transmission time about the same. This is possible when the data is transmitted at higher channel speed. However, the bit rate cannot be increased beyond certain limits due to the signal to noise ratio constraints. Analysis has been done for bit rate of 12 Kbps. Figure (7.5) demonstrates throughput versus packet length in bits for an average packet delay of 40 seconds. Both of the two curves are for early morning hours, when the meteor arrival rate is more, $v(\text{average})=0.25$ met/sec. One curve is based on Completion time analysis and the other using the CTMC method. Throughput stays around its maximum value when the packet size ranges from 1 to 3 kbits. After that the throughput falls down rapidly. The optimum average packet size varies with the channel speed. This analysis was done for the channel speed of 12 Kbps. The packet length of around 2.5 Kbits has been found appropriate for this bit rate. In the evening hours, we see a peak throughput value at 1.2 kbits and then falls

down about the same way as in the morning hours (figure 7.6).

For the network case the delay-load intensity results are shown in figure (7.7). As expected the packet delay are increased as compared to the point to point case. This figure compares the numerical and the simulation results for different number of nodes. Both of the results have fairly close resemblance. Figure (7.8) shows the delay-throughput curves at a node when the input buffer is assumed to be of infinite length. The curves are drawn for three different values of q , which is the joint probability equal to $p_{ca}p_{nb}$.

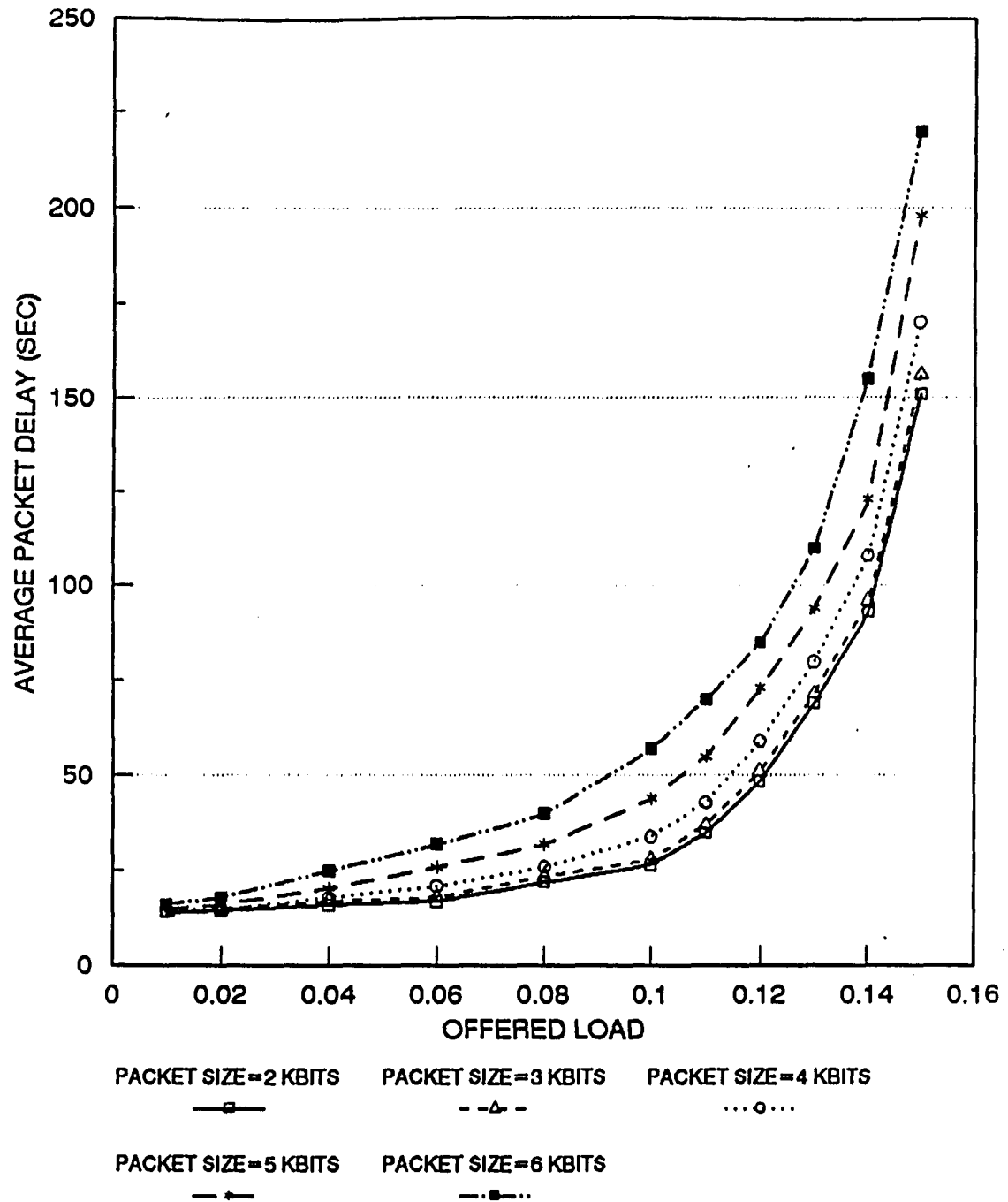


FIG.(7.1) AV. PACKET DELAY VS. OFFERED LOAD

$v=.25$ MET/SEC, $E(l)=3.42$ SEC, $C=12$ Kbps

EARLY MORNING HOURS ; COMPLETION TIME ANALYSIS

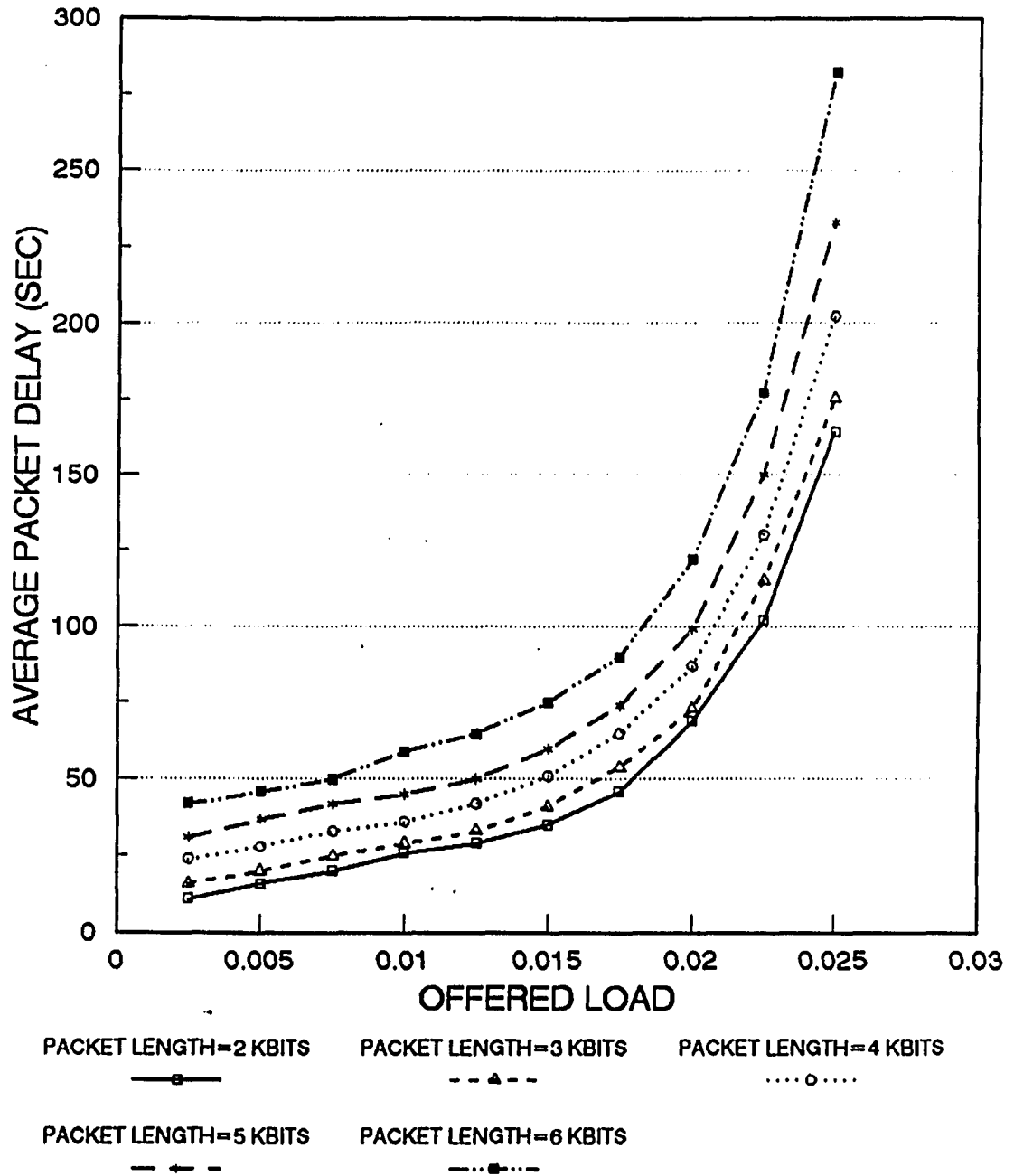


FIG.(7.2) AVERAGE PACKET DELAY VS. OFFERED LOAD

V=.05 MET/SEC., E(I)=19.42 SEC., C=12 Kbps
 LATE EVENING HOURS ; COMPLETION TIME ANALYSIS

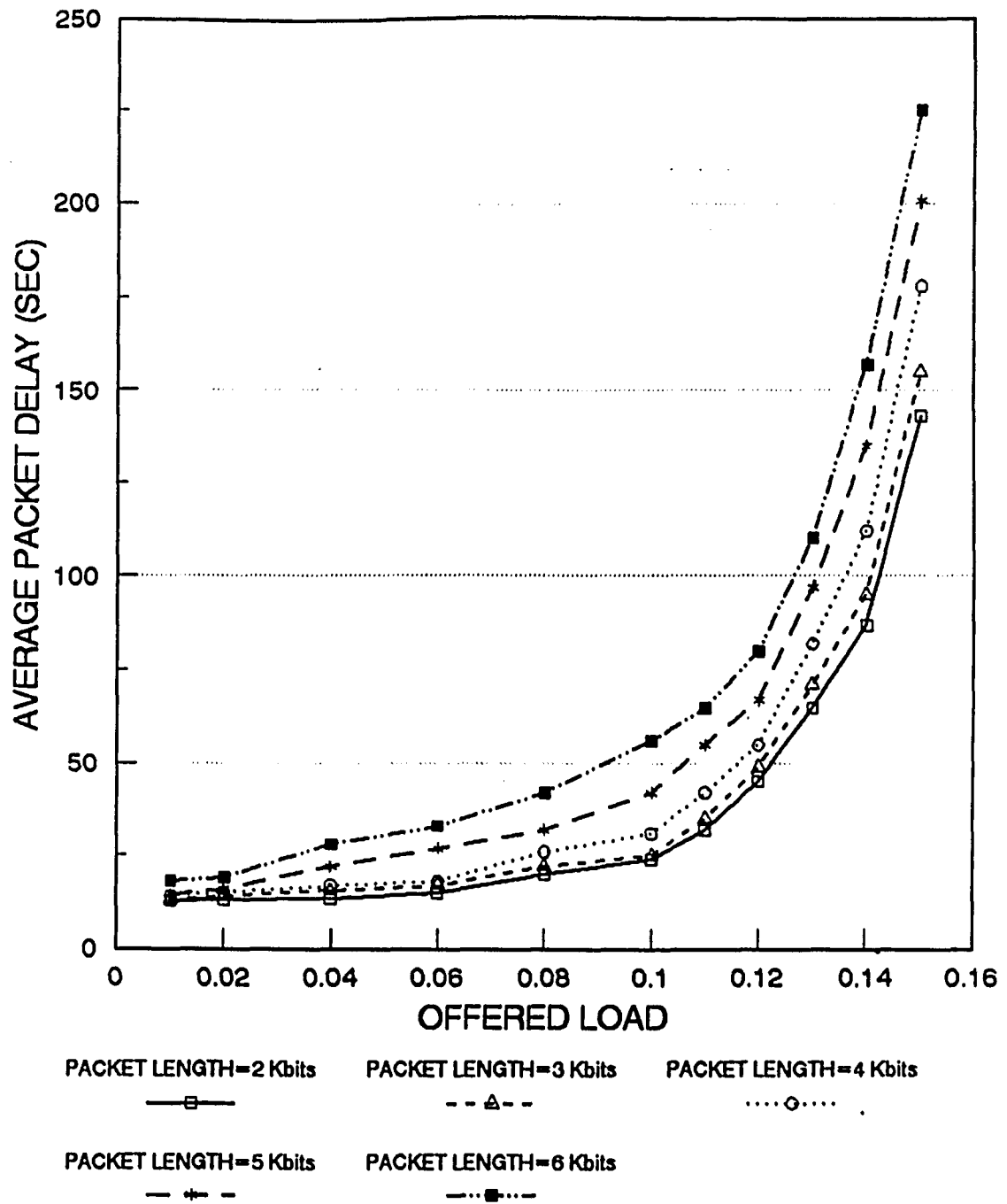


FIG.(7.3) AV. PACKET DELAY VS. OFFERED LOAD

$E(l)=3.42$, $v=0.25$ met/sec, $C=12$ kbps
 Early Morning Hours ; Markov Chain Analysis

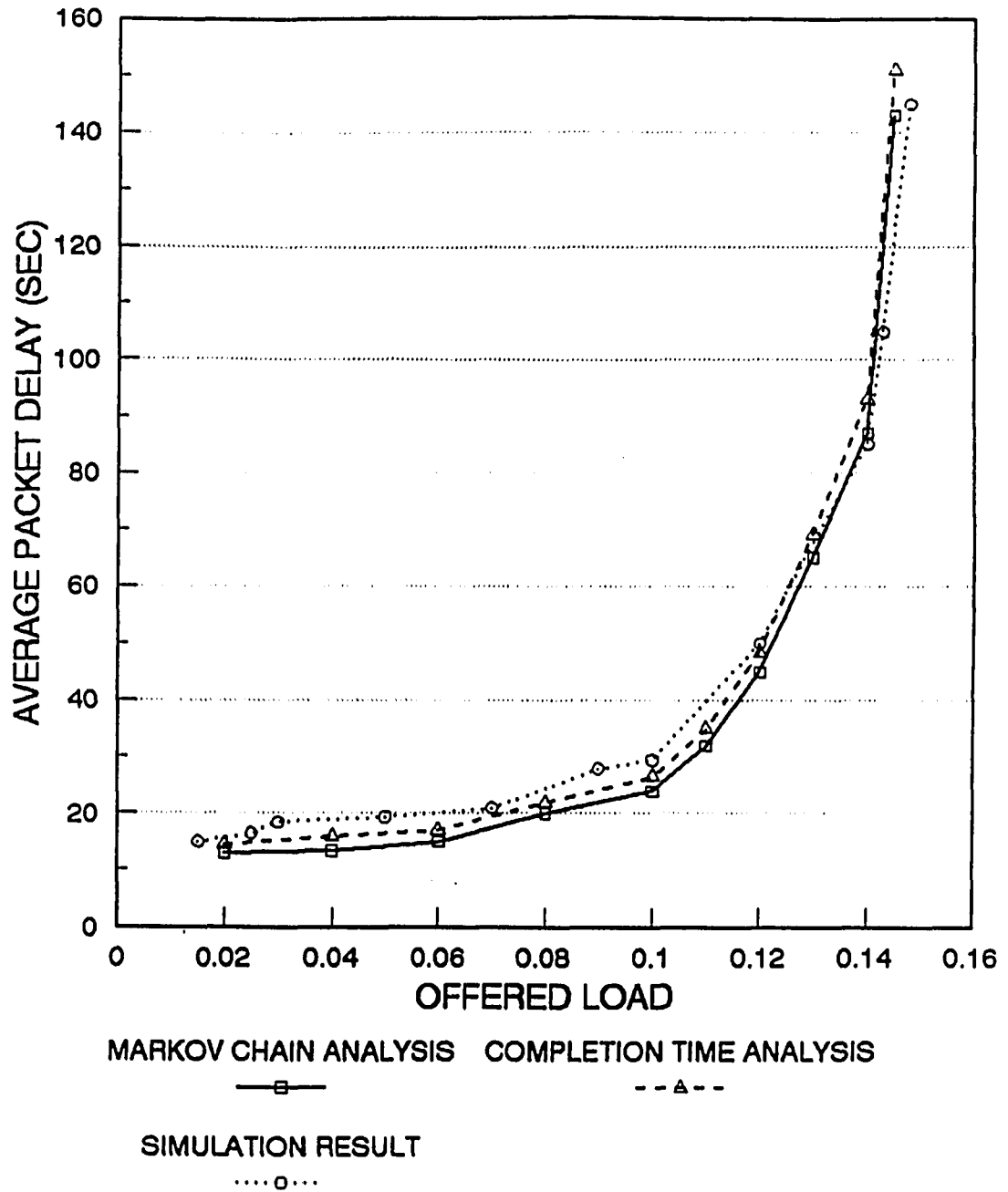


Fig.(7.4) Av. Dacket Delay vs. Offered Load

$v=0.25$ met/sec., $E(l)=3.42$ sec., MORNING HOURS

AV. PACKET LENGTH=2 KBITS

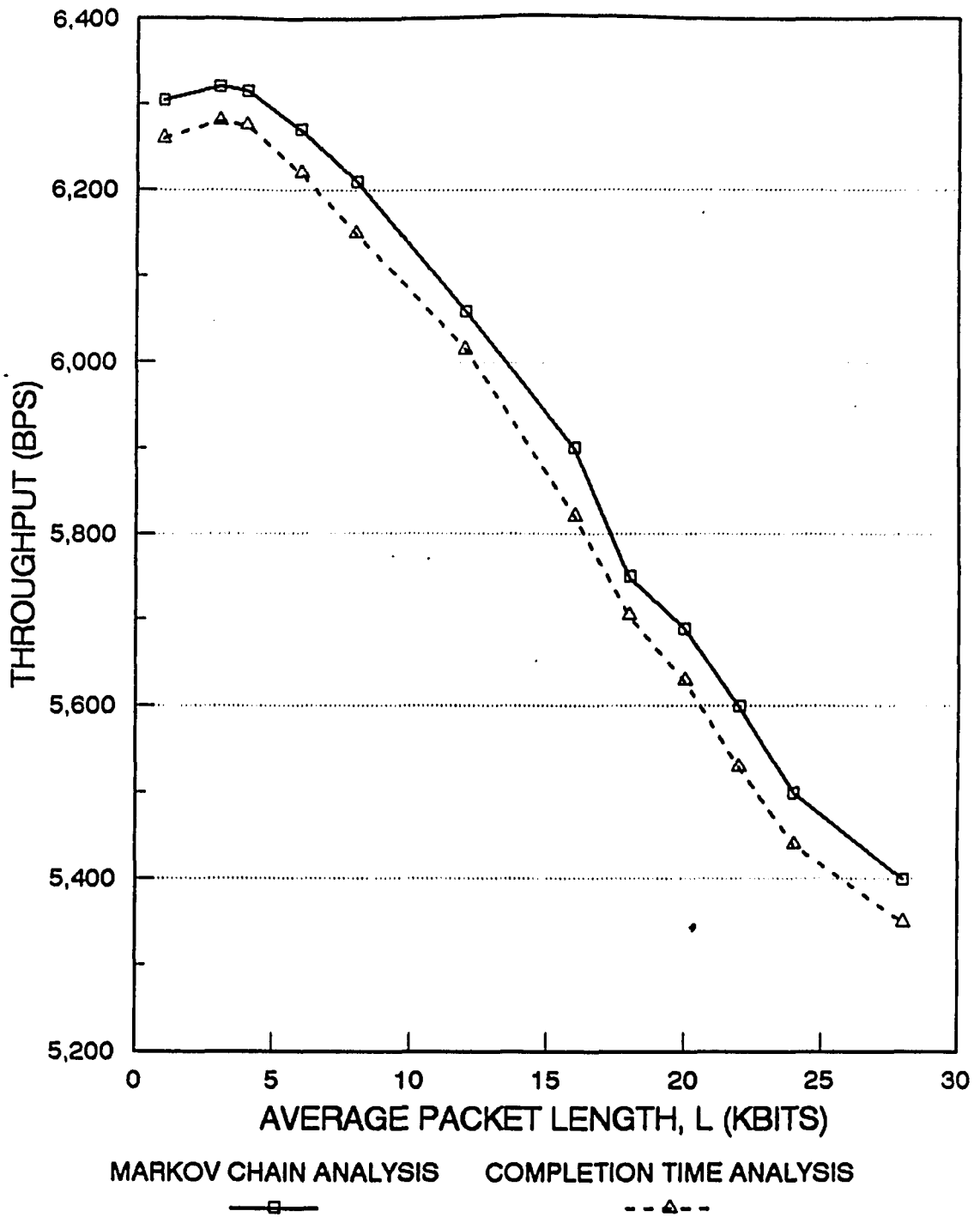


Fig.(7.5) Throughput vs. Average Packet length
 $E(D)=40$, $E(l)=3.42$ SEC., $v=0.25$ MET/SEC

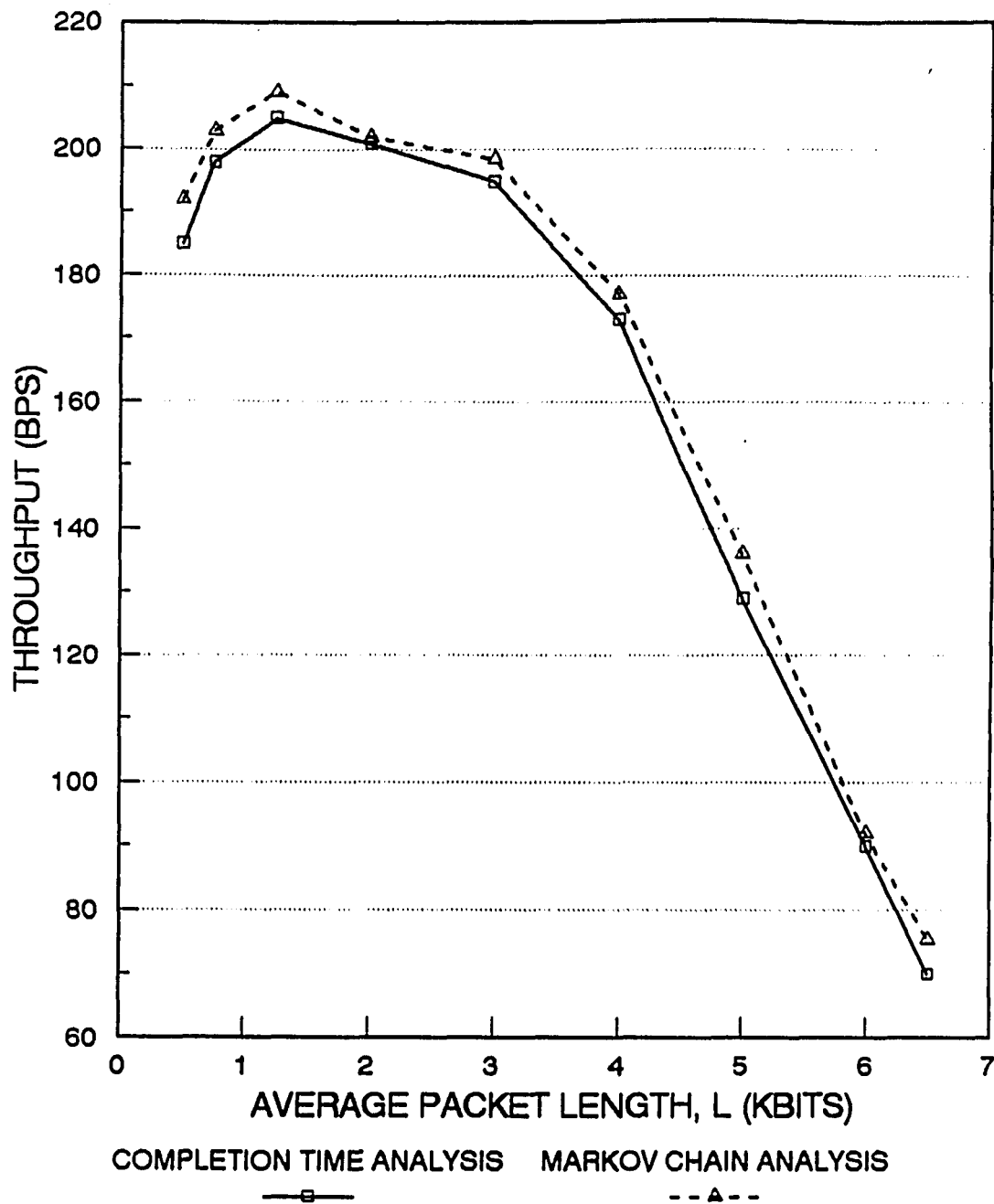


Fig.(7.6) Throughput versus Packet size

$E(D)=40$ SEC., $E(l)=19.42$ SEC., $v=0.05$ MET/SEC.

EVENING HOURS ; $C=12$ kbps

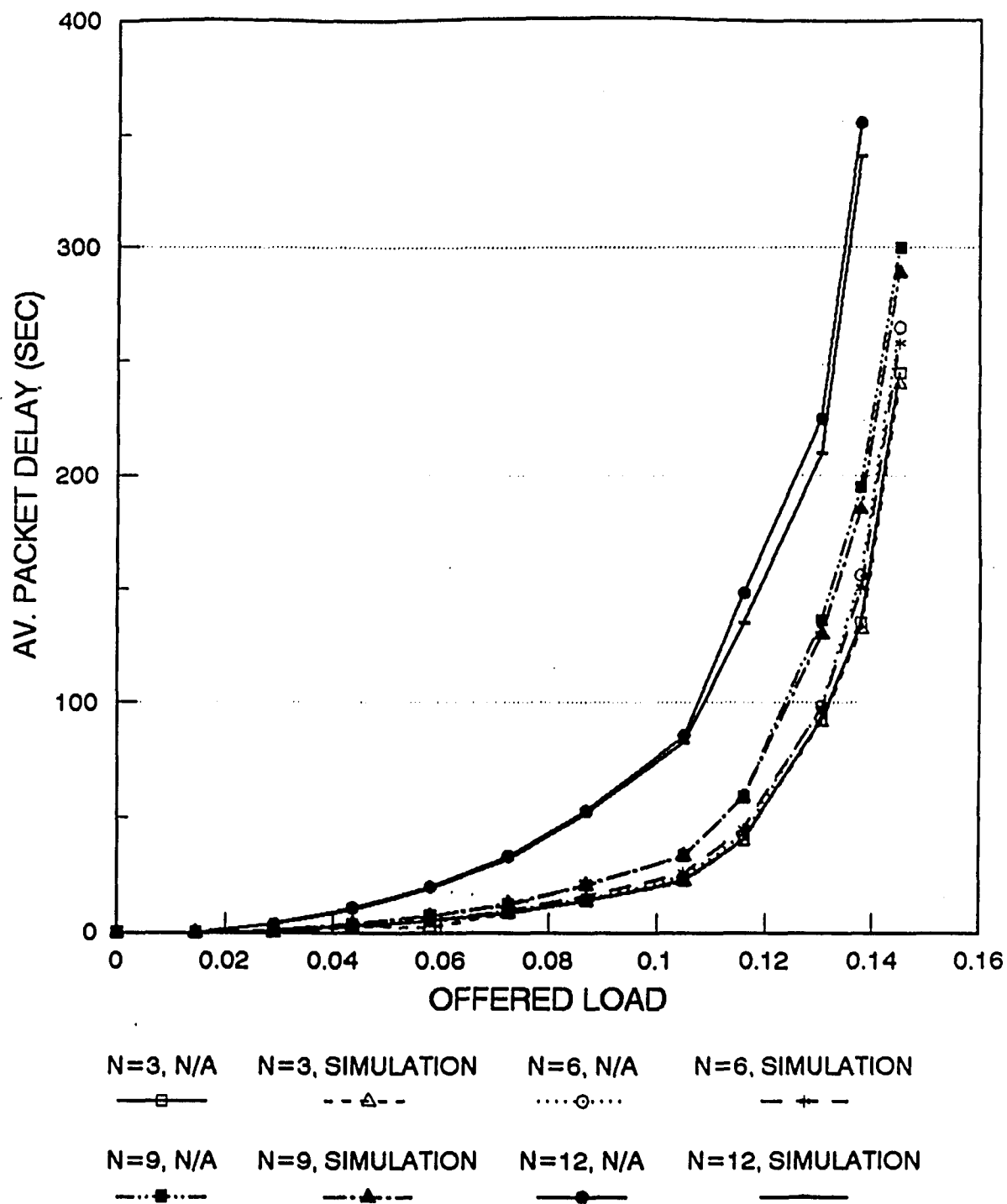


Fig.(7.7) Av. Packet Delay versus Offered Load

PACKET SIZE=6 KBITS ; EARLY MORNING HOURS

NETWORK CASE

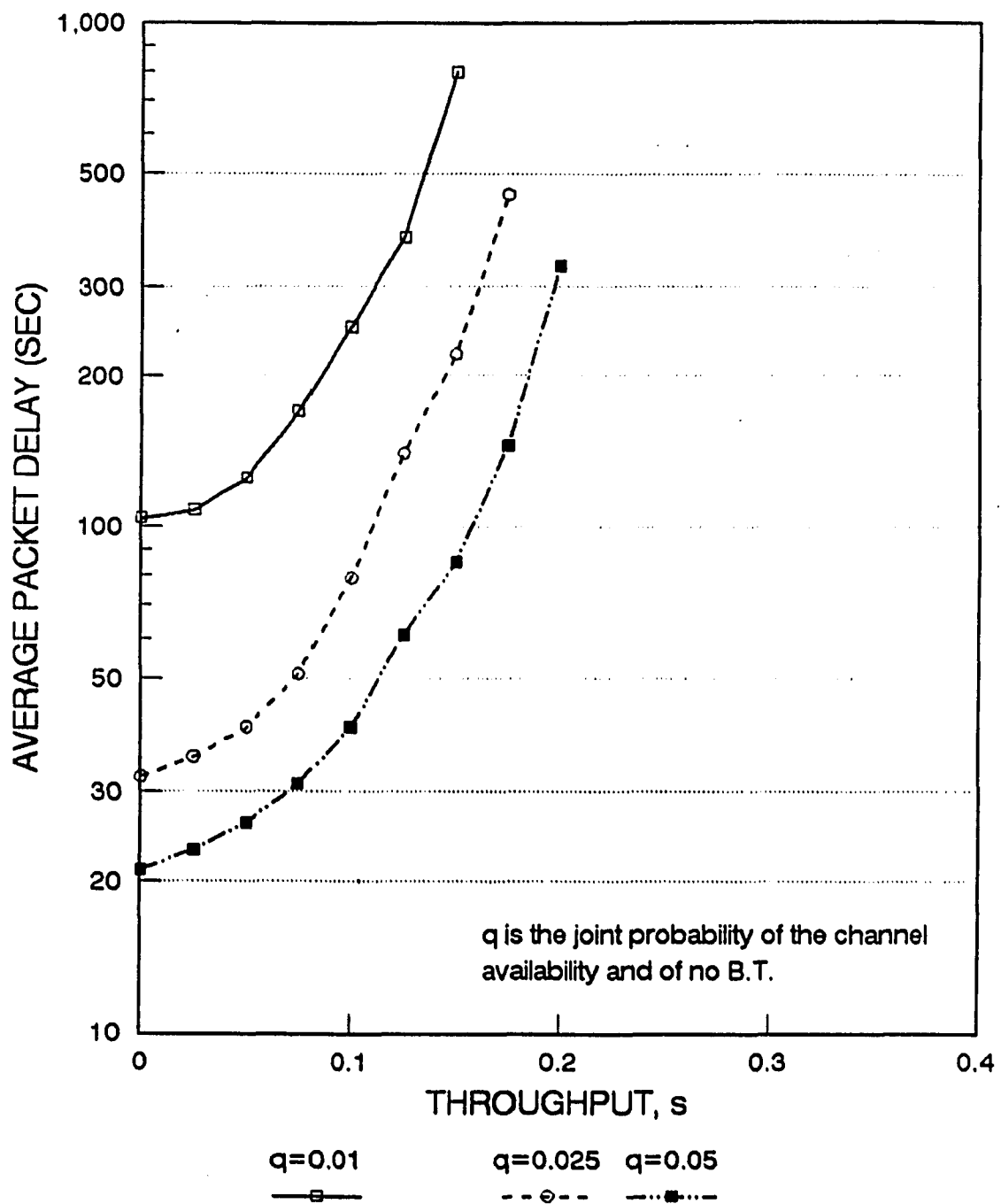


FIG.(7.8) AVERAGE PACKET DELAY VS. THROUGHPUT
INFINITE BUFFER

8 CONCLUSIONS AND FUTURE WORK

The interruptions to the MB communication system caused by the disappearance of the MB trails has been analyzed with the help of the results of Gaver [1] and by the continuous time Markov chain approach. Average packet delay has been computed for different packet sizes and it has been seen that the shorter packet size gives comparatively less average delays. This is because of the fact that the meteor burst channel has on and off nature and short period of existence. The short packet has more chance to be transmitted completely. Attempt has been made to increase the throughput by increasing the channel bit rate to 12 kbits. This increases the packet size keeping the packet transmission time about the same. It has been found that the early morning transmission has better performance as compared to the late evening hours which is attributed to the higher meteor arrival rate in the early morning. The throughput-delay curves taken for different five packet sizes also suggest a better performance for comparatively smaller packet size. A packet length of about 2 kbits gives maximum throughput. In the network analysis the multiple access protocol devised has given much improved performance as compared to the polling scheme used by other systems like SNOTEL. The delay-throughput curves suggest that the delays become asymptotic before 20% channel utilization. However, the meteor burst network can be very well employed to any applications where high delays are tolerable. Big buffer sizes at the nodes are suggested so that lower probability of blocking can be achieved.

The results produced on the bases of two methods of analysis, the one based on M/G/1 and the other based on M/M/1 queueing model, suggest that considering the MB trail duration

as exponentially distributed, is a valid assumption. The MBC system modeled through the simulation also gave validating results for the delay, throughput and the optimum packet values.

In case of high traffic input flow, the volume of the packets builds up rapidly in the buffer. It is very interesting to design an access control scheme that would limit the number of packets in the queue and avoid its exponential growth during the idle channel periods. Also, it is required is to look at some of the concerned parameters again in a trial to increase the bit rate to achieve a better throughput-delay values.

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