I.S.B.N.

A SIMULATION STUDY OF HIGH-CAPACITY CELLULAR LAND MOBILE RADIO COMMUNICATION SYSTEMS WITH ERLANG-B SERVICE

by

George H. Nehmé

A thesis
Presented to the School of Graduate Studies
in partial fulfillment of the requirements
for the degree of
Master of Applied Science
in
The Department of Electrical
Engineering, Faculty of Science
and Engineering

TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

This thesis considers the problem of channel assignment in Land-mobile Radio-Communication Systems. The performance of the hybrid channel assignment scheme under various loading conditions is evaluated by using simulation results of a cellular mobile communications system that has forty cells with Erlang-B service discipline.

Two different cases have been studied:

In case 1, the traffic is uniformly distributed over the entire simulated system. In case 2 a non-uniform spatial distribution of call attempts is examined. In addition, in case 2, two different situations are investigated. Firstly, the number of channels assigned to each cell in the system is the same and secondly the number of channels allocated to the central cell is always greater than in the surrounding cells.

The general conclusion obtained is that the hybrid system is superior to the fixed one in both the maximum traffic carried and spectral efficiency, for a 2% grade of service.

ACKNOWLEDGEMENTS

The author wishes to express his deepest gratitude to Dr. N.D. Georganas, his Thesis supervisor, for his continued assistance, good advice and encouragement without which this thesis would not have been possible.

The author also wishes to express his deepest appreciations to those who have contributed directly and indirectly to the task of producing this thesis. Appreciations are expressed to Mr. J.K.S Sin for his assistance and moral support, and to Mr. R. Le Henaff, Administrative officer of the department of Electrical Engineering, University of Ottawa.

The financial assistance provided by the Department of Communications and the University of Ottawa is gratefully acknowledged.

Chapter I

INTRODUCTION

The potential for communicating with non-fixed points over the horizon without the use of wires was soon recognized following the invention of radio in the late 1800s and its development in the early 1900s. The use of mobile radio has spread dramatically as an aid to communicate with land vehicles, aircraft and even with people using portable equipment [1].

This growth has led to the development of the mobile system for common-carrier offering to the public, the High-Capacity Mobile Telecommunications System (HCMTS)(1)

Present-day mobile telephone service (MTS) is the provision of voice handwidth(2) communications between a mobile unit and any point in the Direct Distance Dialing (DDD) network.

---

(1)the newest mobile system known as Advanced Mobile Phone Service (AMPS) is currently being implemented by AT&T in Chicago, Illinois.

(2)some users may also wish to transmit data over the high-capacity system.

The ultimate objective of mobile communications is to enable a mobile user to communicate instantly and effectively with anyone else. The fundamental problem has already surfaced: lack of frequency bandwidth to handle the service demand in regions of the frequency spectrum where technology can provide reasonably economical hardware and systems.

Shortly after World War II, the Federal Communications Commission (FCC) in the U.S. made available some bandwidth in the 40, 150, and 450 MHz bands for various recognized and special uses. As time passed the number of designated channels in the upper two bands was increased by the simple expedient of reducing the frequency separation between channels. Thus the first allocation at 150 MHz in 1946 was for three channels spaced 120 KHz apart. The spacing was shortly reduced to 60 KHz, and then to 30 KHz in the early 1960s. Similarly, at 450 MHz the channel spacing was initially 100 KHz, reduced to 50 KHz in the early 1960s, and to 25 KHz in the late 1960s.

In 1970, the FCC (Docket 18262) decided to make available new frequencies (806 to 902 MHz and 928 to 947 MHz) for land mobile radio service, to reserve certain portions of the 806-947 MHz band (821-825, 845-851, 806-870, 890-902, & 928-947 MHz), to allocate portions of the band to safety and special Radio Service (806-821, 851-870 MHz) and to allocate the 902-928 MHz frequencies to Fixed Industrial, Scientific and Medical applications. The remainder of the band (825-845, 870-890 MHz) is allocated to Mobile Radio Telephone Cellular Systems. The 825-845 MHz band is used for the reciprocal operations of mobile transmission and cell site reception. The 870-890 MHz range constitutes the mobile receive/cell site transmit range of frequencies.

From our discussion thus far, it is obvious that the high-capacity system has been the key concept that has been emerging over a long period of time. The first concept to be appreciated as necessary to an efficient, large capacity operation is trunking. Trunking is the ability to combine several channels into a single group so that a mobile can be connected to any unused channel in the group for either any incoming or outgoing call. One problem that bothered early planners was to achieve full trunking advantage without requiring each mobile unit to be able to tune to every one of the channels in use for this service throughout the transmission area. The second concept is the realization of cellular systems. The cellular concept with spectrum re-use could substantially increase traffic capacity. Each channel frequency can be used for many independent conversations in many cells which are spaced far enough from each other to avoid undue interference.

1.1 REVIEW OF CHAPTER CONTENTS

The major part of this thesis is concerned with the simulation study of a cellular high-capacity land-mobile radio system using the Hybrid Channel Assignment Scheme with Erlang-B service discipline. Each chapter begins with an introduction, which the reader may find helpful.

Chapter 2 is a discussion of the cellular system. The basic elements of the cellular concept are discussed first, starting with a review of the cellular mobile radio telephone system in section 2.2. Section 2.4 discusses the cell splitting, while section 2.5 is a discussion of the major classes of land mobile radio systems. The descriptions of system operation and hand-off actions are explained in the remainder of chapter 2.

Chapter 3 provides an overview of the traffic analysis for mobile radio systems. The various terms, e.g. Erlang ,grade of service, call holding time, the call attempt rate, the Erlang-B (Blocked-Calls-Cleared) , Erlang-C (Blocked-Calls-Delayed) and the Hybrid Erlang-B/Erlang-c (Blocked-Calls-Held) disciplines are discussed.

Chapter 4 is addressed to the basic channel assignment schemes. A way to allocate the radio channels of the assigned frequency band to the geographical cells is introduced. Two general categories of this method, using either a fixed or a dynamic channel assignment in a given cell, are treated from the standpoint of layout options and traffic handling capabilities. Section 4.5 concentrates on the Hybrid Channel Assignment Scheme.

Chapter 5 provides an overview of the simulated system, with uniform and non-uniform traffic for case 1 and case 2 respectively. The development of the simulation model is described in section 5.1 and states the assumptions which are made for the two cases. Section 5.2 is reserved for a detailed description of the simulation flow-chart.

Chapter 6 is addressed to the simulation results, regarding the performance of the system, for the case of uniform traffic. Section 6.1 introduces the simulated system, while section 6.2 gives the input parameters to the simulation model. The simulation results are presented in section 6.3. In addition, chapter 6 provides a selective comparison between the Hybrid and Fixed Channel Assignment Schemes. The spectral efficiency of the Hybrid System as compared to the Fixed System is presented in Subsec. 6.3.3. The last section embodies the interpretations of the first part of the thesis regarding the uniform spatial distribution of offered traffic in the transmission area.

Chapter 7 reports the results of a simulation study for the second case using the Hybrid Channel Assignment Scheme with Erlang-B service and non-uniform traffic offered to the cells. Sections 7.2 and 7.3 consider the performance of the system with the different assumptions used. Section 7.4 analyses the results regarding the spectral efficiency of Hybrid Systems with respect to the Fixed Systems, in the central cell, as also in all the surrounding cells. In that section the traffic in the central cell is assumed 20% higher than that in each surrounding cell. We first consider there that 33.3% of the total number of channels is given to each cell. Then this percentage is increased in the central cell to 40%, and decreased to 30% in its surrounding cells. From the two cases we determine what is the effect of increasing or decreasing the percentage of the total channels in any particular cell in the system area.

Finally, Chapter 8 presents the general conclusions of this thesis.

Chapter II

THE CELLULAR CONCEPT

2.1 INTRODUCTION

This chapter shows how a cellular system operating within a limited frequency spectrum can meet the objectives of a large-scale mobile-telephone service, designed with attention to cost performance.

Since the 1940's, mobile radio system engineers have attempted to design systems that would satisfy all the following objectives:

1. Large subscriber capacity;
2. Efficient use of spectrum;
3. Nationwide compatibility;
4. Widespread availability;
5. Adaptability to traffic density;
6. Regular telephone service and special services, including "dispatch";
7. "Telephone" quality of service; and
8. Affordability.

The early mobile radio communications systems were designed along the concept of "Global Coverage" [4]. Mobile radio engineers have sought the highest mountain or building within a proposed service area for their high-power antenna location, in order to "cover" the largest area possible (Fig. 2.1). Additional receivers eventually had to be distributed within the area to service the mobile-to- base link in low signal regions, because it was not practical to transmit the same power from the mobile units. In typical systems using a single base-station site, shadowing leads to "holes" in the coverage area. If such a situation is deemed sufficiently serious, the hole may be filled in through use of a satellite base station, so as to have a less obstructed path to the problem area. Such a technique is not desirable in small-cell systems, where one satellite station per cell can raise site costs to prohibitive levels. The need to operate and grow indefinitely within an allocation of hundreds of channels has been the primary driving force behind the evolution of the cellular concept. The main propagation features in the mobile radio environment are:

1. multipath due to scattering or reflections from buildings and other obstructions, also other vehicles, and

2. shadowing of the direct line-of-sight path by intervening features of the terrain.

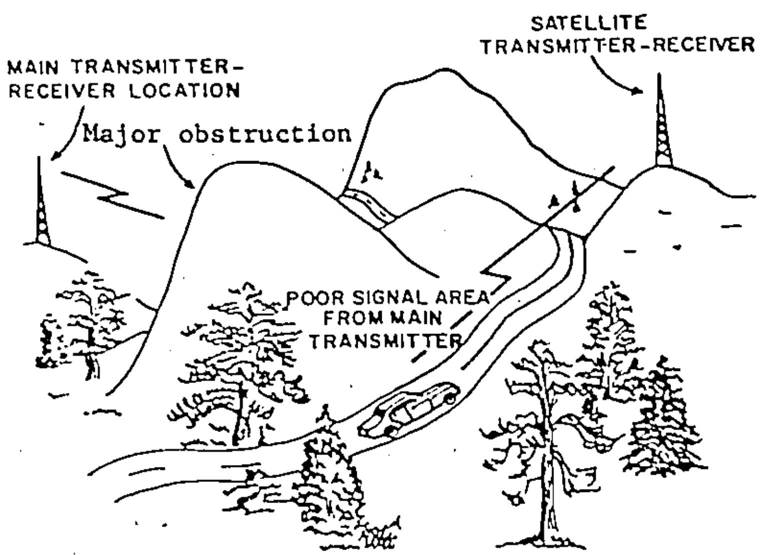


Fig. 2.1 - Major obstruction and use of a satellite base station to fill an area of poor reception.

2.2 BASIC ELEMENTS OF THE CELLULAR CONCEPT

The most conspicuous attribute of a high capacity system is its size. The heart of a high-capacity mobile communications system is the spectrum allocation. This system model assumes the availability of several hundred channels. The prime mechanism for serving large subscriber groups with limited spectrum is the use of small radio coverage zones or cells. Where the area covered from a single base station is small, it is possible to reuse the radio channels of that base several times in the same region. The cellular system consists of:

1. many small geographical areas (cells), each with antenna(s) and low power transceivers and a controller.

2. a central office which monitors vehicules and automatically switches calls.

and provides for

1. increased capacity through frequency reuse

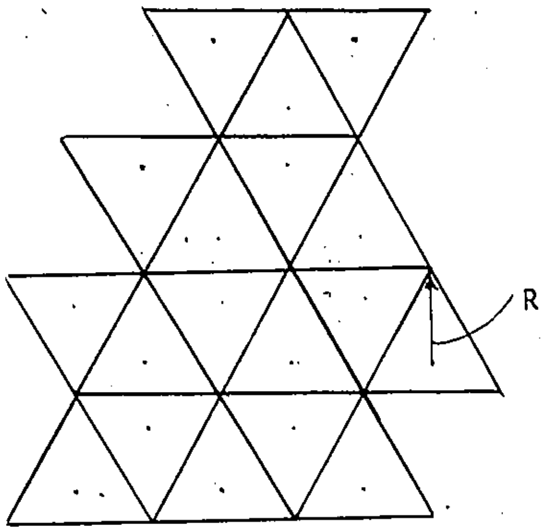
2. expansion through subdividing cells.

2.3 CELLULAR LAYOUT

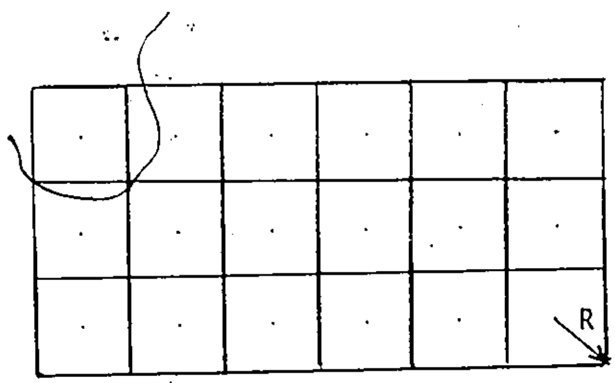
In the cellular mobile radio telephone system, a large number of radio cells are arranged on a service area. A reasonable degree of geographical confinement of channel usage is necessary to prevent co-channel interference problems [4]. As shown in Fig. 2.2, there are three basic methods for assigning the radio cells of the same area over the service area. The most favorable method is the one shown in Fig. 2.2(c) because

1. the radio cell which each base station covers is largest in area; and
2. the overlapping between the adjacent radio cells is minimum.

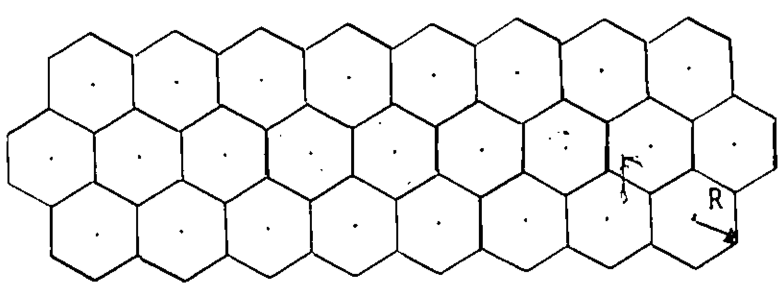
As a consequence the number of base stations may be minimized, whereby economical advantages may be obtained. The number of channels, hence transmitters and receivers in each base station, depends upon the traffic offered which in turn depends on a number of subscribers.



(a) Triangular cell



(b) Rectangular cell



(c) Hexagonal cell

Fig. 2.2 - THREE BASIC TYPES OF CELL CONFIGURATION.

Interpretation of the cellular mobile radio-communications system is given by Fig. 2-3. Each cell is served by a base station located at the center of the cell. Transmission to and from the mobile units are handled through low power FM radio transceivers located in each cell. The system radio plan uses frequency modulation (FM) techniques(1) and the FM capture ratio prevents interference between conversation in cochannel cells. The combination of all cells constitutes the total coverage of the cellular system. If we define a voicepath as one radio channel at a base station carrying one conversation, it may be said that small-cell systems can provide multiple voicepaths per radio channel in a service area, and thus can require less spectrum per voice path than large-cell systems. The number of cell radii between base radios using the same channel will be designated γ. The separation ratio (γ) cannot vary continuously but may assume discrete values consistent with the spacing between any two cell centers. This minimum separation (γ) is called the Minimum Reuse Interval and is given by

$$\gamma = D/R \qquad (2.1)$$

---

(1) AMPS (Advanced Mobile Phone Service of AT&T in Chicago) voice channels have an FM peak deviation of 12 KHz and a spacing of 30 KHz [18]. With this spacing, 666 duplex channels can be created out of a 40 MHz spectrum allocation.

where D is the geographic separation between the two base stations using the same channel simultaneously and R is the cell radius. The ratio of D/R required by a giving system is determined from system signal-to-interference (SIR) ratio and the characteristics of the system. The actual size of the cells, that is, the actual values of D and R, are determined from the following specified parameters:

1. density of traffic offered;

2. the total number of radio channels available to the radio system;

3. the allowable call blocking rate;

4. the channel assignment strategy implemented for system control [4];

5. radiated power; and

6. antenna height.

Cells which are separated by less than the minimum allowable cochannel reuse must be assigned different channels, which requires that the channel allocation be subdivided into sets. In Figure 2.3 a grid of hexagonal cells is shown separated into repeating groups, or "basic blocks". The cells of these blocks each require an independent channel set, and the basic block may be repeated as indicated to cover the desired service area [5,6]. The ratio D/R is related to the number N of channel sets required. N is determined by the relationship

$$N = (D/R)^2/3 \text{ ---(hexagons)--- } (2.2)$$

where N is an integer. certain values of N are possible in a hexagonal grid these correspond to values of the series:

$$i^2 + j^2 + ij, \text{ ------------ } (2.3)$$

where i and j ($i \geq j$), called "shift parameters", range over the positive integers.

For any value of (γ) there is an Interference Cell Group (ICG) associated with each cell. Channels assigned to a cell cannot be reused elsewhere within the ICG if already in use in that cell. The thick block contour in Fig. 2.3 represents the boundary of the ICG of the shaded cell. There are nineteen members in that ICG. The capital letter in each cell denotes the channel set allocated to be used there. As can be seen, any reuse of channel set A is prohibited within the ICG.

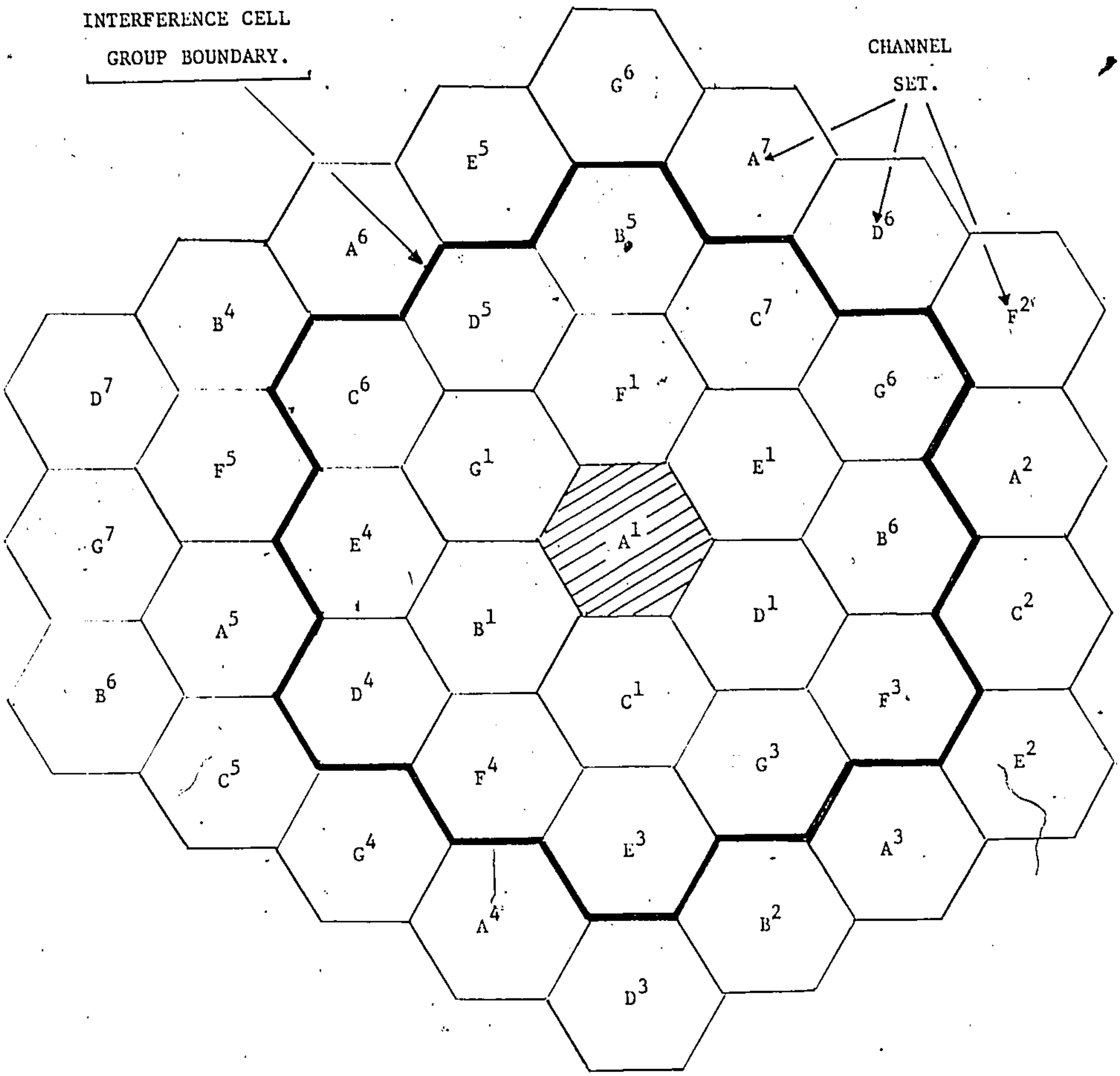


Fig. 2.3- A CELLULAR LAYOUT OF A HIGH-CAPACITY MOBILE RADIO SYSTEM.

2.4 CELL SPLITTING

The implementation of the cellular system requires the construction of an essential regular array of land transmitter-receiver stations, called "cell sites" in the High Capacity Mobile Telecommunications System(HCMTS). For this idealized array of cell sites, an accompanging pattern of regular hexagonal cells can be visualized in at least two different ways:

1. cells whose centers fall on cell sites, "center-excited" cells for large cell configurations, or
2. cells half of whose vertices fall on cell sites, "corner-excited" cells.

The cell sites will use transmitter and receiver antennas whose patterns are omnidirectional in the horizontal plane. In a practical system (AT&T), cell sites will have three faces with 120 degree sector antennas, rather than an omnidirectional(2) antenna as shown in Figure 2.4. Through frequency reuse, further growth in traffic within the cell will require a revision of cell size so that the area can be reduced in discrete steps through the addition of new base sites, while leaving the existing ones in place [5,19].

----

(2) In the earlier years of growth, large cells with omnidirectional antennas are used. The paging and access functions are "combined" on the same setup channels.

The process is called "cell splitting". The distance between adjacent cell sites is reduced. Wherever cell splitting occurs, new cell sites are located midway between old cell sites. As shown in Figure 2.4, the previously existing cell sites together with the new ones form a hexagonal cellular lattice. Special care must be taken to guarentee the cochannel reuse ratio D/R. Cells of about one-mile radius are possible today. The lower bound on cell splitting is controlled by the amount of data processing required to keep track of moving vehicles and to switch voice paths as the mobiles move from cell to cell. The upper bound of cell size is a function of the transmitter power, channel bandwidth, receiver design, minimum required SNR, antenna heights and gains and is dependent on whether diversity considerations are employed. The need for a method of serving customers in a single local coverage area, while using a limited spectral allocation, has spurred the evolution of the hybrid channel assignment scheme, as an alternative of "cell splitting", as it will be discussed in chapters 6 and 7.

● :Previously Existing Cell Site

• : New Cell Site installed during Cell Splitting

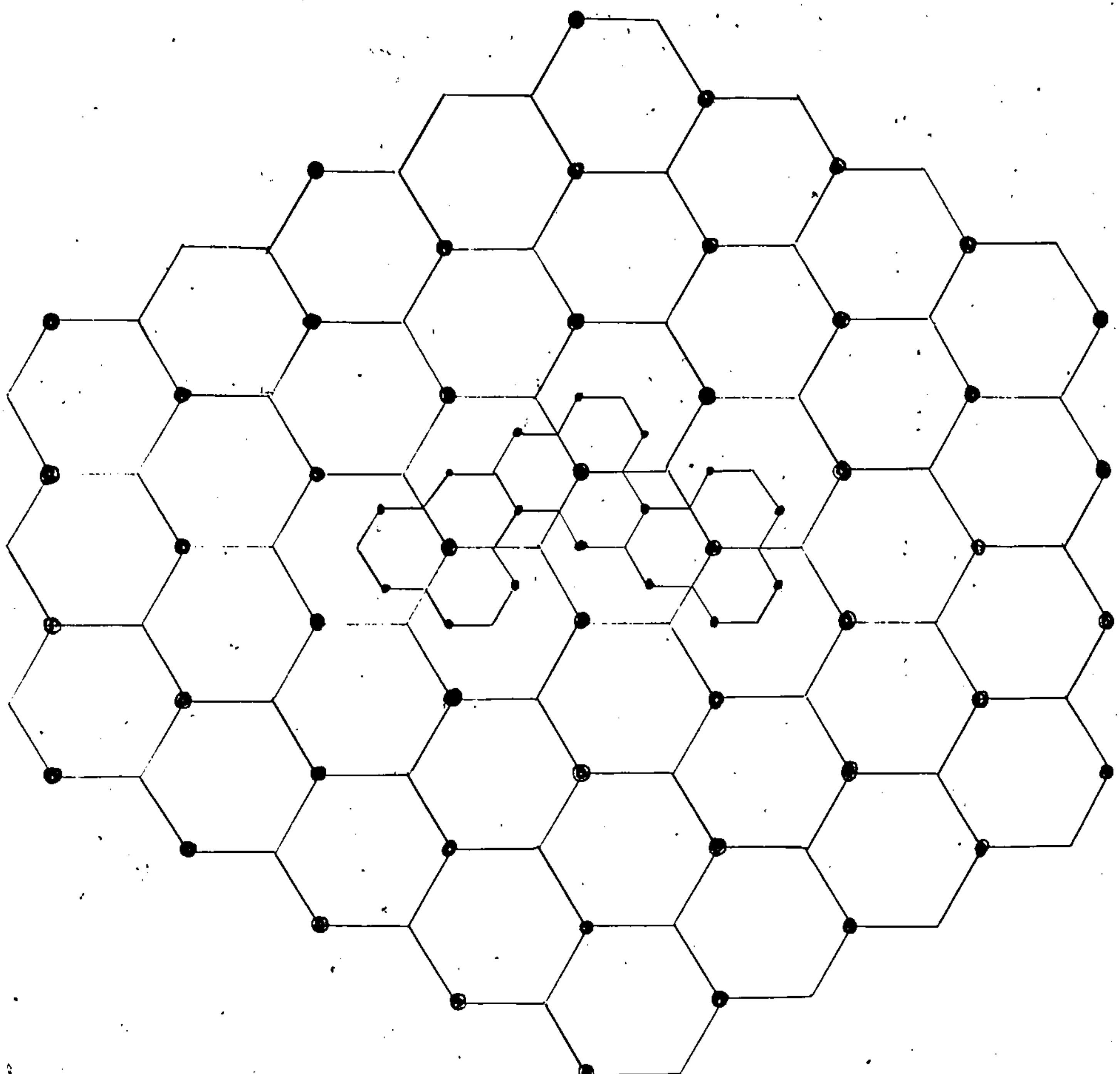


Fig. 2.4 - OVERALL CELL-SITE PATTERN.

2.5 MAJOR CLASSES OF LAND MOBILE RADIO (LMR) SYSTEMS

This section discusses the essential properties of small-cell systems. In general small-cell systems possess essential properties which distinguish them conceptually from large-cell systems on other than a cell-size basis. The most economical cell plan for any system capacity uses cells which are small enough to serve the maximum density of mobiles while using all channels assigned to it.

2.5.1 Properties of Small-cell systems

1. In small-cell systems the individual cell size is conceptually unimportant. A mobile will utilise one base transmitter and receiver from the cell it is in at the moment.

2. Population distribution becomes important, since the city centers may be experiencing their maximum densities, while the population of a large city center continues to increase. Small-cell systems can spread out with the population, by reusing the same channels in the service area. To this point the small-cell systems result in spectrum savings (economy).

3. To maximize the effects of channel reuse, it is necessary to use the hexagonal lattice. Small cells can be expected to demonstrate better

signal-to-noise performance than large cells, while the largest cells will have what is considered to be the limiting acceptable performance.

4. The approach to small-cell-system design yields varying spectral efficiencies. At lower levels of demand, the efficiency is completely dependent upon subscription and related traffic levels [5,7,17]. However, at higher demand on capacity, the small-cells are much more efficient than all the other systems reviewed.

2.5.2 Properties of Large-cell Systems

Large-cell systems provide coverage on all channels in the service area, causing the cell size to be the size of the service area. The base stations, for large-cell systems, are few and widely separated, thus the chance that the mobile will leave the cell and lose signal during a conversation is minimized. The most apparent characteristics of large-cell systems are:

1. Private Systems

In the 900 MHz band [17], the most likely configuration for a privately-operated system will be repeater based to assure good propagation. For operations in the 900 MHz band, all traffic is carried on the same channel (and thus extracts only one voice-path from each channel). In such systems, high quality service is attainable only by maintaining very light loading on the assigned channel, as well as by maintaining large geographic separation between co-channel systems.

2. Shared repeater systems

These are private systems. Each user bears a lower cost, but at the expense of a large number of mobiles on his channel, because the interconnection facilities are shared among a large number of users.

3. Single-channel systems with automatic control

Same as in (2) above, the access to the system is controlled by a central computer unit. The distinction of this system is that all users, mobile or fixed, must request and be granted permission to transmit whether or not the channel is in use.

4. Multi-channel trunked systems with automatic control

These systems are similar to single-channel computer-controlled systems but utilise several channels trunked together. Trunking allows each customer to be placed on the first channel that becomes available after channel access has been requested.

2.6 SYSTEM OPERATION

The spectrum(3) congestion problem complicates matters in the design of mobile radio communications systems and has to be solved. One of the most favoured and commonly discussed techniques for increasing the efficiency of frequency spectrum utilization is the adoption of a cellular structure. The transmission area to be covered by the mobile radio system is divided into a number of non-overlapping cells or zones. In the center of each zone is a fixed base station. Each of the base stations in the coverage area contains a group of low-power transmitters/receivers that communicate with the mobiles in its zone over the channels assigned to its zone.

The three major system control elements of HCMTS are:

---

(3) present improved mobile telephone systems are small by comparison and are limited by a lack of spectrum.

1. the mobile telecommunications switching office (MTSO)

2. the cell site

3. the mobile unit

The (MTSO) serves as the central coordinator and controller for HCMTS and as the interface between the mobile and the wire-line network. The MTSO must:

1. coordinate the grid of cell sites and moving subscribers.

2. administer radio voice channels allocated to the system.

3. maintain the integrity of the local HCMTS system as a whole.

4. provide the switch connections between mobile subscribers.

The cell sites process the signals to make them suitable for transmission between the wire-line network and the radio network for all the mobile telephones interfacing with it. On the other hand, the mobile unit is tunable on system command to any channel in the RF spectrum allocated to HCMTS. Interconnection of these three major control elements is shown in Fig. 2.5. The mobile telephone communicates with a nearby cell site over a radio channel assigned to that cell. The cell site, in turn, is connected by land-line facilities to the (MTSO). Each of the non-mobile subscribers (or dispatchers) to the system is also connected, by leased line, to this (MTSO). This allows for a complete connection between any mobile unit and any fixed subscriber. As Fig. 2.5 indicates, a considerable amount of data is exchanged between pairs of HCMTS control elements. The control channels also carry data for control or to inform the base stations of mobile call originations or to inform the mobiles of incoming calls (paging) and of their initial channel assignment.

The mobile equipment consists of a control unit, a transceiver, a logic unit, and two antennas. The control unit contains all the user interfaces, such as a handset, various pushbuttons, and indicator lights. The transceiver uses a frequency synthesizer to tune to any allocated channel. The logic unit interprets customer actions and system commands and controls the transceiver and control unit. The transceiver and logic unit are integrated into a single package. A single antenna is used for transmission. Two antennas together are used to provide space diversity for reception.

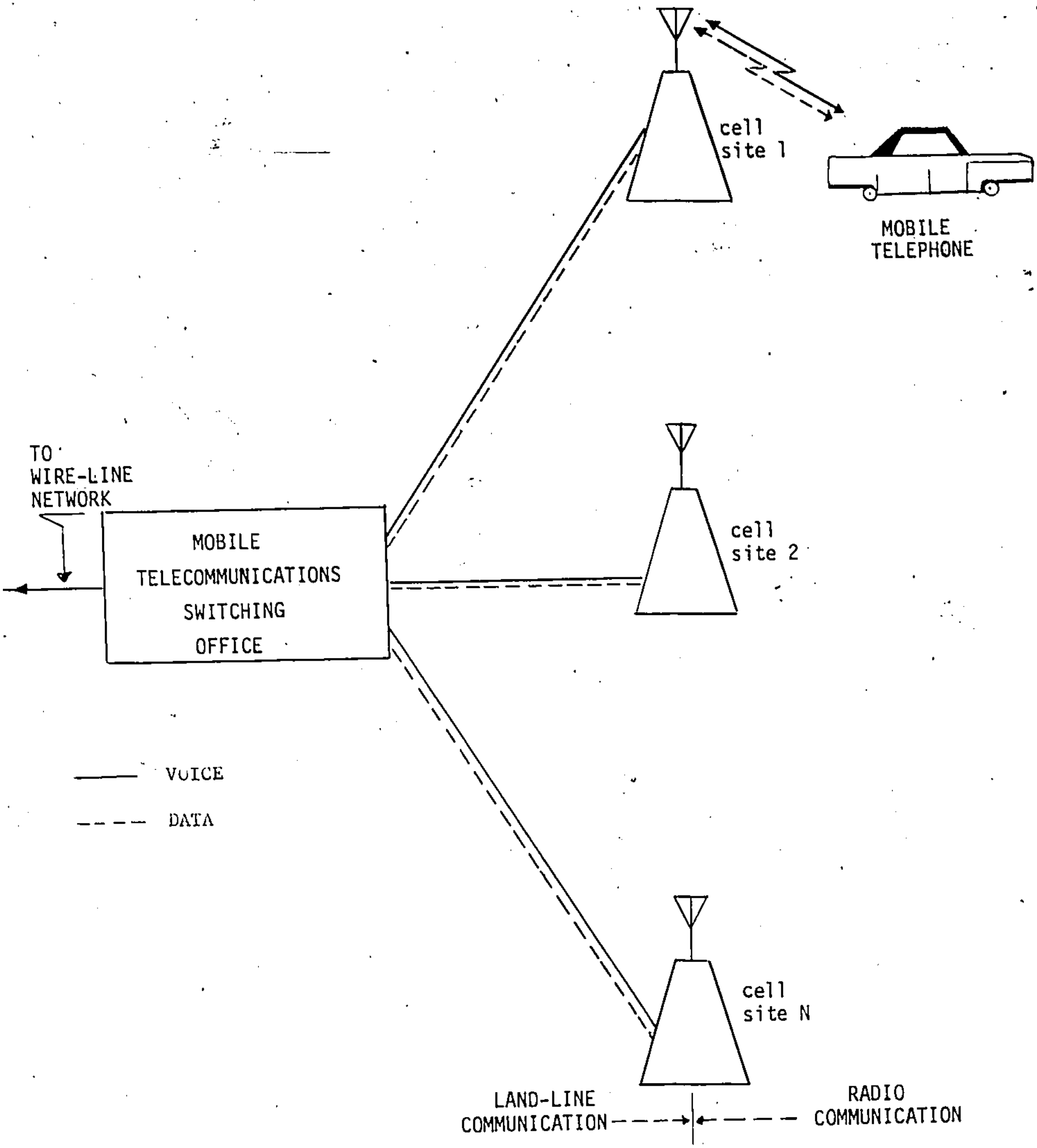


Fig. 2.5- HCMTS System Control Elements.

2.6.1 Hand-Off action

Figure 2.6 depicts the various actions required to establish the process of hand-off. All new system designs feature "Handoff", a method of providing continuous service to a mobile unit moving between cells while a conversation is in progress. The Handoff procedure is accomplished by instructing the mobile to change to an adjacent cell frequency, when the signal-to-noise ratio degrades to a predetermined level. This requires the MTSO to know at all times during a call the mobile's approximate locations. The hand-off process involves 3 operations:

1. New channel preparation:

   . location information gathered by the cell site serving the mobile, as well as by surrounding cell sites, is transmitted to the MTSO over the various cell site land-line data links. The MTSO selects an idle voice channel (and an associated land-line trunk) at the receiving cell site and informs the new cell site to turn on its radio.

2. Mobile retune command:

   a message is sent to the current serving cell site informing it of the new channel for the mobile in question. The serving cell site transmits this information to the mobile over the voice channel.

3. Channel/path reconfiguration:

the mobile sends a brief burst of signaling tone and turns off its transmitter. It then retunes to its new channel. The old cell site places an on-hook signal on the trunk to the MTSO. The MTSO reconfigures its switching network, connecting the other party with the appropriate land-line trunk to the new serving cell site. The new serving cell site places an off-hook signal on the associated land-line trunk. The MTSO interprets these two signals (off-hook on new trunk, on-hook on old trunk) as a successful handoff.

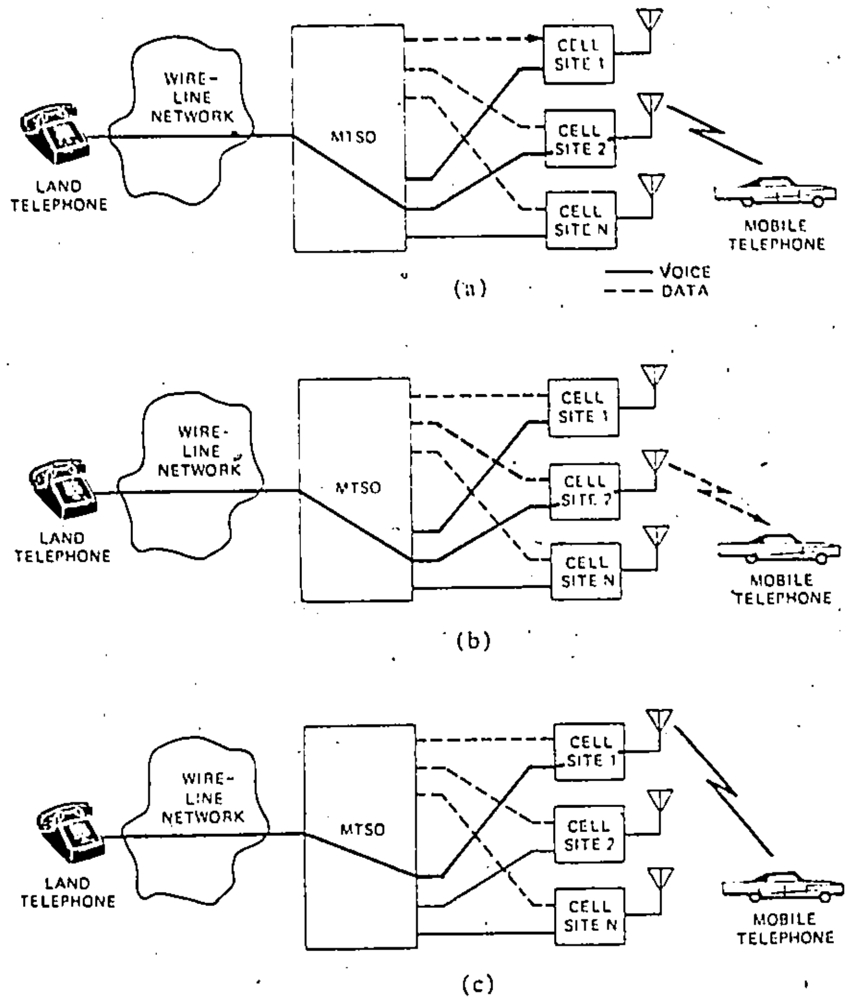


Fig. 2.6 – Handoff sequence. (a) New channel preparation.
(b) Mobile retune command.
(c) Channel/path reconfiguration.

Chapter III

TRAFFIC ANALYSIS FOR MOBILE RADIO SYSTEMS

3.1 INTRODUCTION

The formulas of conventional traffic theory apply quite well to normal telephone systems. Traffic theory is intended to enable the quality of service provided by a communication system to be predicted from information about the traffic to be carried and the resources available. The traffic formulas are applicable both to large cell systems, and the individual small cells of a small-cell system. The basic parameters involved in the provision of facilities are the grade of service, the call attempt rate, call holding times and the number of channels.

3.1.1 Erlangs

The traffic volume in telephone systems is measured in a unit called the Erlang. An Erlang is the amount of traffic one trunk can handle in one hour, if it is busy all the time. An Erlang is equal to 3600 call-seconds.

The number of erlangs received is given by :

$$\frac{\text{No.of calls per hour x mean holding time per call (seconds)}}{3600}$$

3.1.2 Grade of Service

In a telephone system a call will be blocked if, at the instant when the system tries to establish a connection, there are no idle paths through an exchange, no available channel, or no available registers to set up a connection. The usual way of describing the blocking characteristics of a system is to state the probability that a call will be blocked when there is a given traffic load. The probability of blocking a call is referred to as the 'grade of service'.

3.1.3 Offered traffic

The product of the call attempt rate and call holding times is the 'offered traffic'. This product denotes the amount of time that a quantity of callers desires the use of facilities.

3.2 BLOCKED-CALLS-CLEARED DISCIPLINE (ERLANG-B)

This type of situation can occur when congestion arises. In this case the busy signal may be caused by the fact that the called party is 'busy', but it is possible that there are no free paths or equipment in the exchange, or the lines between exchanges are fully occupied. The Blocked-Calls-Cleared (BCC) queuing discipline is a very important concept for telephone-traffic engineering. Arrivals which occur when a channel is idle are served immediately. An arrival that occurs when all channels are busy is blocked, leaves the system, and does not return in the same period, say the busy hour.

The call durations (holding times) are assumed to be independent and identically distributed according to a negative-exponential distribution and have mean ($\frac{1}{\mu}$). The calls are arriving in a Poisson fashion with a mean arrival rate of (λ calls/hour). As shown in Figure 3.1 there are m identical servers (channels) each having identical holding time.

The facility utilization (ρ) is given by:

$$\rho = \frac{a}{3600m} \qquad a = \frac{\lambda}{\mu}, \qquad \text{------(3-1)}$$

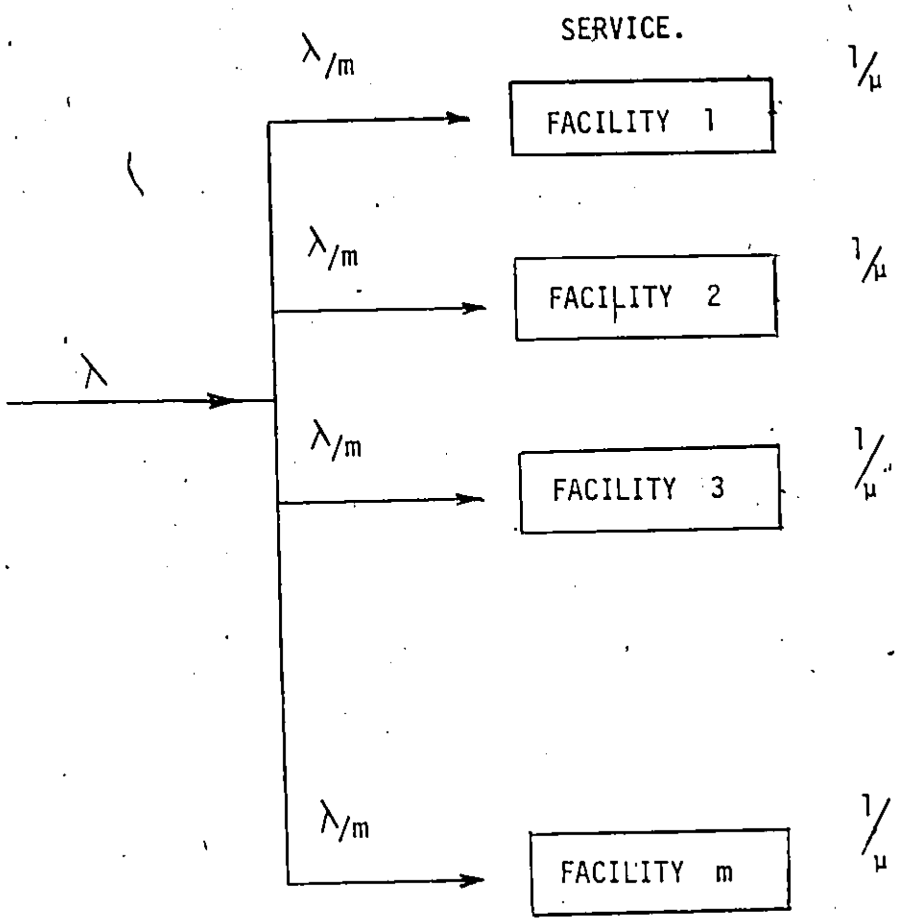
or

$$m \cdot \rho = \frac{a}{3600} \qquad \text{(in Erlangs).}$$

The Erlang-B blocking probability is given by the formula [2]

$$P_B = \frac{\dfrac{(m.\rho)^m}{m!}}{\sum_{k=0}^{m} \dfrac{(m.\rho)^k}{k!}} \qquad \text{----(3-2)}$$

The average queuing delay is zero because no queues form.



m identical servers (channels).
Each has mean service time of $1/_\mu$ sec

Fig. 3.1 A QUEUEING MODEL FOR THE BCC SERVICE DISCIPLINE.

3.3 BLOCKED-CALLS-DELAYED DISCIPLINE (ERLANG-C)

The blocked-calls-delayed (BCD) or Erlang-C model arises when blocked calls are allowed to queue up and wait for service in the order of arrival. Calls arriving to find an idle channel are served immediately. The number of channels is limited, and if all are in use the call will have to wait until one becomes free. Calls do not defect from the queue.

The two queueing models shown in Figures 3.2a and 3.2b assume the same call characteristics.

Figure 3.2a depicts the situation when the calls are served by the first server which becomes available. The queueing time in the case of Figure 3.2b is found to be greater than if the calls were able to choose the first server which becomes free [2]. The utilization factor of each server is given by equation (3.1). The probability of delay for the model in Figure 3.2a is given by the Erlang-C formula:

$$P_C = \frac{1 - \left[\dfrac{\sum_{k=0}^{m-1} \frac{(m.\rho)^k}{k!}}{\sum_{k=0}^{m} \frac{(m.\rho)^k}{k!}}\right]}{1 - \rho\left[\dfrac{\sum_{k=0}^{m-1} \frac{(m.\rho)^k}{k!}}{\sum_{k=0}^{m} \frac{(m.\rho)^k}{k!}}\right]} \qquad (3.3)$$

3.4 HYBRID ERLANG-B/ERLANG-C

Between Erlang-B and Erlang-C Formulas there is an intermediate assumption called blocked calls held (BCH). Such a system is often described by assuming that arrivals that occur when all channels are busy remain in the system for one holding time (BCH). If a channel becomes available during the holding time, a waiting customer seizes the channel for the remainder of the holding time. Otherwise, the customer leaves the system.

The blocking probability is found to be [2]

$$P_H = \sum_{k=m}^{\infty} \frac{(m.\rho)^k}{k!} \cdot e^{-m \cdot \rho} \qquad \rho = \frac{\lambda}{\mu} \qquad (3.4)$$

where m is the number of servers and (ρ) the utilizatioon factor of each server as given by equation (3-1). The assumptions concerning arrivals and service times are the same as in the Erlang-B model.

It is seen that the three assumptions (blocked calls delayed,held and cleared) have different influences on the theoretical probability, in each case, of calls being blocked.

1. If blocked calls are delayed (BCD model), they are allowed to wait in the system and occupy the full

holding time. Hence the blocking probability is the highest of the three disciplines.

2. If blocked calls are held they occupy some channel time and they occupy nearly the full holding time if the probability of no idle channel is low.

3. for a given load the probability of blocked calls is the lowest among the three assumptions, when blocked calls are cleared from the system.

The Mobile telephone service is closely described by the blocked-calls-cleared assumptions. The International Consultative Committee for Telegraphs and Telephones (CCITT) has recommended the international use of Erlang-B [3]. The Dispatcher service is closer to the blocked-calls-delayed assumption.

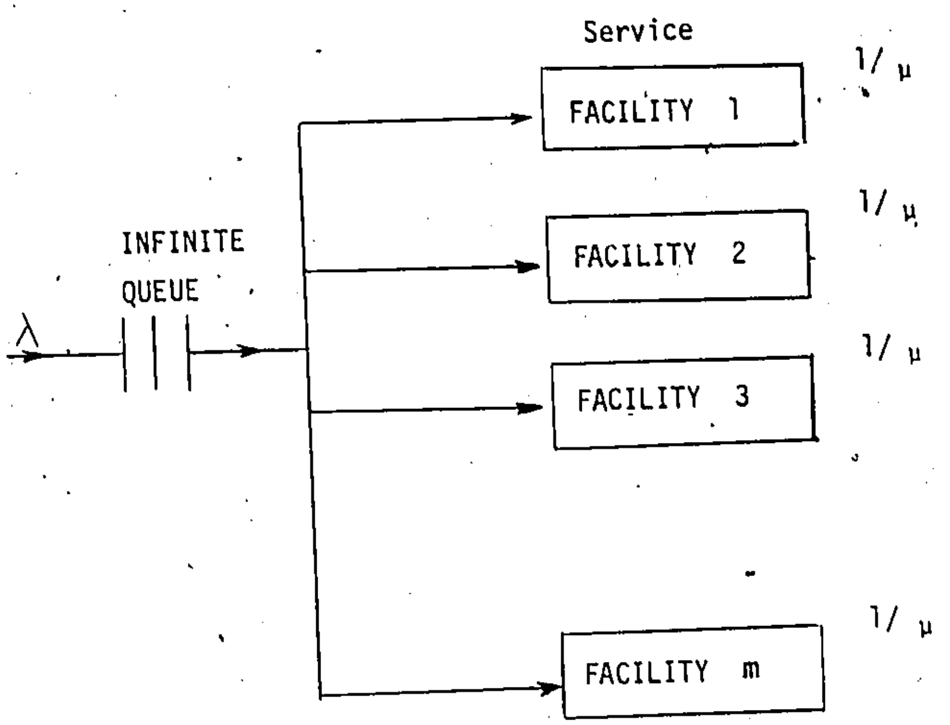


Fig. 3.2a - A MULTISERVER QUEUE WITH m SERVERS.

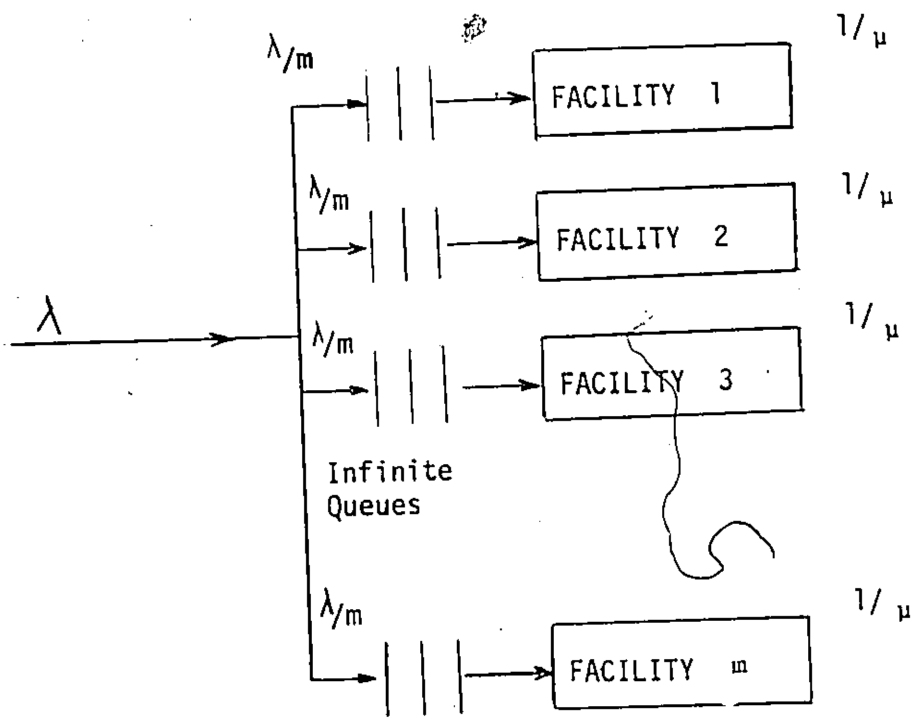


Fig. 3.2b - m SINGLE-SERVER QUEUES IN PARALLEL.

Chapter IV

CHANNEL ASSIGNMENT SCHEMES

4.1 INTRODUCTION

The problem of frequency channel assignment is becoming more important due to the finite spectrum allocation for the land mobile communication. Different techniques have been studied to use that portion of the frequency spectrum more efficiently without incurring excessive cochannel interference. The channel assignment approach was proposed and evaluated [6,8-10].

This chapter first presents different channel assignment methods. One such method is the Fixed Channel Assignment (FCA) technique that reserves specific sets of channels for use in specific cells. Another channel assignment scheme is the Dynamic Channel Assignment (DCA). The DCA techniques do not assume a fixed relationship between channels and cells. Because of the complex interaction between cells and channels in (DCA) systems, performance data can be obtained only by computer simulation. The improvement in the efficiency of channel usage resulting from mixing fixed and dynamic channel assignment techniques leads to the Hybrid

Channel Assignment Scheme to be illustrated in the final section of this chapter.

4.2 STATISTICAL LAYOUT

Figure 4.1 depicts such a channel-reuse situation along a single line in one dimension. It is assumed that the radio channels can be reused every fourth base station without producing cochannel interference; also, only one base station is allowed to serve a mobile unit. In Fig. 4.2 M-N indicates the channels available at each base station for a system example with 20 channels and a reuse interval (Y) of every forth base station.

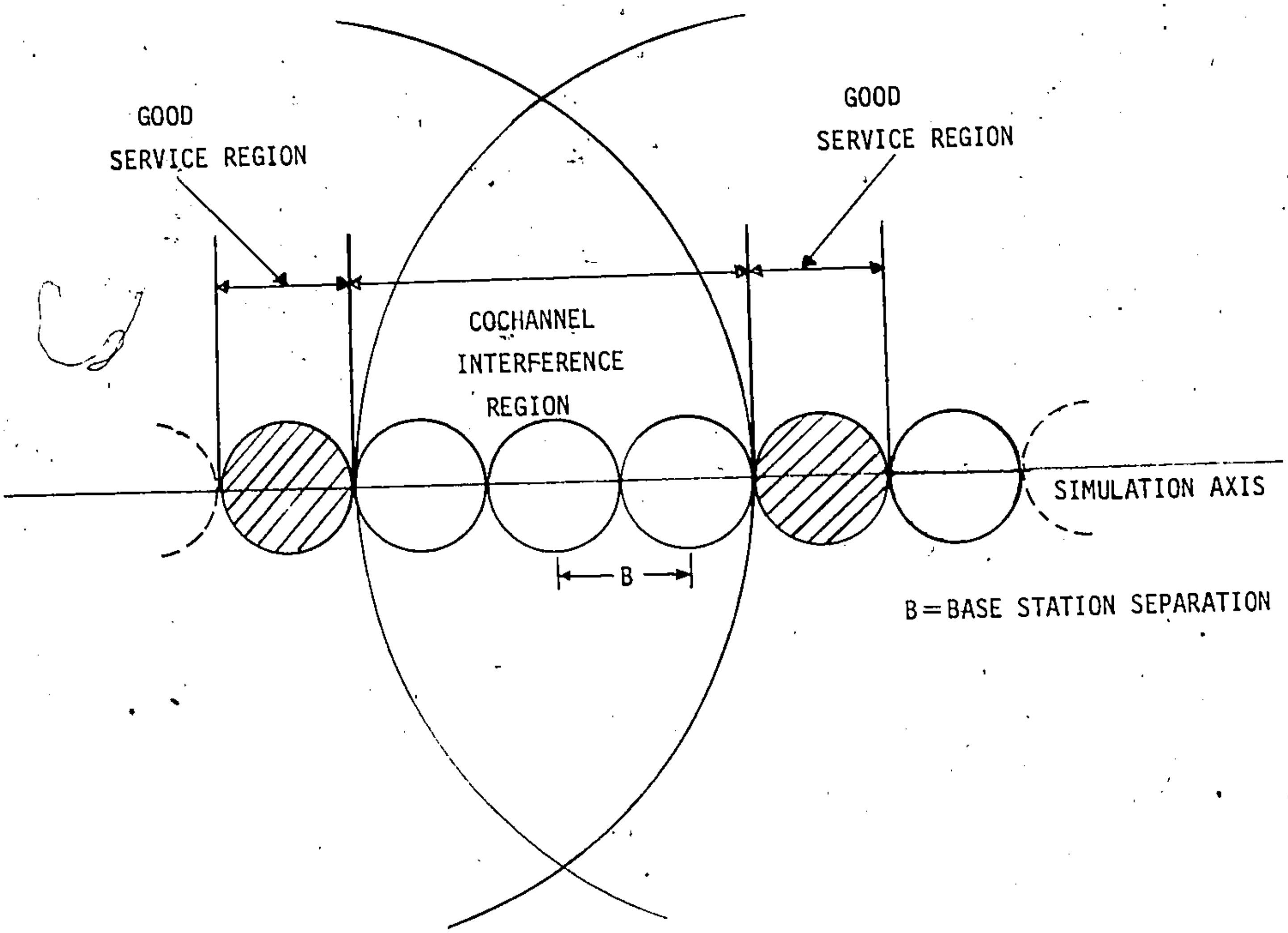


Fig. 4.1 — Illustration of channel reuse

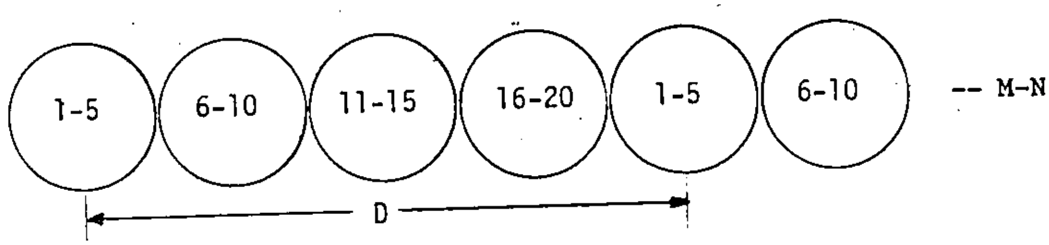


Fig. 4.2 — Fixed-channel assignment system example.

Similar cochannel interference situations exist in Figure 4.3 at base stations A and B if mobiles located at P and Q transmit on the same frequency;

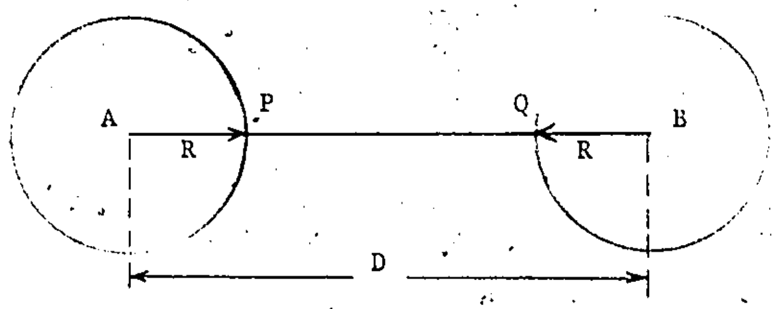


Fig. 4.3 - An illustration of frequency reuse by two base stations separated by distance D

Then the average signal to interference ratio, S/I, taking into account both the Rayleigh and Log-normal distributed fading and any diversity improvements,(1) is equal to [4,9]

$$[(D-R)/R]^{n} \qquad (4.1)$$

If there are other base stations located a distance D from A and all received signal statistics are independent at P, then in general [4]

$$\frac{S}{I} = \frac{1}{\sum_{i=1}^{M} \frac{1}{(R_i)^n}} \qquad (4.2)$$

---

(1) A brief explanation is provided in Appendix A

where the Ri are the distances from the observation point to the M base stations. The power level of the signal radiated from A is sufficient to provide an adequate signal-to-noise ratio at points located a distance R or greater from A.

The AMPS transmission quality objective was quantified for design purposes that at an S/N ratio of 18 dB,(2) most listeners considered the channel to be good or excellent.

4.3 FIXED CHANNEL ASSIGNMENT (FCA) SCHEME

In fixed channel assignment systems a subset of the channels available to the radio system is permanentely assigned for use within each particular cell. In this case there is a definite relationship between cells and channels that can be used there at any time. In the fixed channel assignment, channels can be used in designated cells keeping the distance between cells using the same channels constant.

The total available radio channels in the system area are divided into a number of channel sets. There is a minimum number of channel sets required to serve the entire service area. This minimum number (N) of channel sets is governed by the minimum re-use distance (Υ) in the following fashion [4,7]:

---

(2) A cell of 8 miles allows the system to meet the requirement that S/N ratio be above 18 dB over 90% of the service area [19].

$$N = 1/3\ (\gamma)^2 \qquad (4.3)$$

where N can assume only integer values 3, 4, 7, 9,...etc. The N channel sets are then assigned to the cells in the system respecting the minimum reuse distance (γ). All the N channel sets will be of the same size if the customer offered traffic has a spatial uniform distribution. Traffic varies by more than an order of magnitude, even in adjacent cells in some cases. In this case some of the channels not needed in the outlying cells within a mutually interfering group of cells can be allocated on the fixed basis to the reserved channel subsets of the cells near the peak. This tailoring technique is sometimes referred to as fixed or static "borrowing" of channels from outlying cells [11].

Efficient use of fixed channels requires simultaneous assignment (reuse) of a radio channel in radio coverage areas that are spaced as close together without incurring excessive cochannel interference. If all fixed channels are in use, a new call initiated in cell i is immediately blocked, and will be disposed in a manner according to the service discipline adopted in the service area.

The main advantage of the Fixed Channel Assignment Scheme lies in the fact that the channels are used to the maximum possible number of times within the system area, thus increasing the channel occupancy.

4.4 DYNAMIC CHANNEL ASSIGNMENT (DCA) SCHEME

The most general form of dynamic channel assignment [6,9-11] assumes that any channel can be used in any coverage cell and all the channels are kept in a central pool. However, a channel in use in one cell can only be reassigned simultaneously to another cell in the system if the separation between the two cells is greater than or equal to a specified mimimum separation D/R(3)

Channel search for a channel to assign in a particular cell at a particular time involves searching through all channels allocated to the central pool. If no such channel is found, service cannot be provided in the cell at that time. Usually more than one channel in the radio system is available for assignment and different optimizing strategies for choosing which one should be chosen have been illustrated. These strategies may be based on criteria such as the order of search, the weighted distance to other cells using the same channel, the number of times the channel is used at the minimum reuse distance D/R, or even in random selection. Some strategies and their relative performance under certain constraints are provided in Appendix B .

----

(3) Making D/R as large as possible benefits transmission quality. On the other hand, making D/R as small as possible, serves the objectives of large capacity and low cost.

Dynamic channel reassignment [12] switches the channels assigned to some calls in progress so that the separation between cells simultaneously using the same channel is nearly optimum. The status (in-use or not) of each channel in each cell must be stored in a readily accessible form and must be updated with each status change. Base-station radio equipment used with dynamic assignment must be switchable from channel to channel as channel assignments in the cell change.

4.5 HYBRID CHANNEL ASSIGNMENT (HCA) SCHEME

The previous discussion of the fixed and dynamic channel assignment schemes should provide some insight into the operation of a Hybrid Channel Asssignment Scheme (HCAS) which is simply a combination of the two [6,9]. In the HCAS the total number (T) of available radio channels is first divided in N channel sets. Some of the channels available to the system are assigned on a fixed basis. That is, certain channels can be used only at specified base stations, assuming a static assignment scheme. N is the minimum required number of channels sets governed by equation (4.3).

If the offered traffic is uniformly distributed over the cells, then each cell will have an equal number of fixed channels allocated to it. However, if the offered traffic is not distributed spatially evenly, then the fixed channels will vary in number from cell to cell. A complete description of these studies is included in the second case studied in the thesis.

The average number of channels per cell will be given by:

$$M = T/N. \quad (4.4)$$

After the preliminary division of channels, each of the N channel sets is partitioned into a number of fixed channels(F) per cell and a number of dynamic channels (D) per channel set, therefore

$$M = F + D \quad (4.5)$$

The channel set (D) contains channels that can be used in any cell in the system, to handle any statistical fluctuations in offered traffic, using the DCA scheme. Thus there are altogether ND dynamic channels in the central pool. All the fixed channels are to be used in their nominal cells. A search is made first through the fixed channels allocated to the assigned coverage area. If there is a fixed channel available in the assigned transmission area, that channel is assigned to serve the call attempt. If all fixed channels are in use, a channel search is made through the dynamically assignable channels and will borrow the eligible dynamic channels from the system pool to service the calls provided that the cochannel interference constraint is conformed at the time of borrowing. If no dynamic channel is available, the call will be disposed of in accordance with service discipline adopted.

Let the optimal channel partition F:D yield the best system performance, then the average number of channels per cell is given by [6,9]

$$m = F + \frac{NDj}{I.C} \qquad (4.6)$$

where I.C is the number of cells contained in the Interference Cell Group (ICG) of the cell. Therefore it is very important to understand the meaning of average number of channels per cell before and after the division. The average number of channels per cell, after the division, is less than before the division. The number of calls that can be handled at the same grade of service has improved substantially, as can be seen later on.

For Erlang-B service , systems adopting the hybrid channel assignment scheme give better performance than the two other systems at low traffic loadings. As the systems become heavily loaded the fixed channel assignment scheme prevails over the other schemes [6,29,30].

Chapter V

DESCRIPTION OF SIMULATED SYSTEMS

5.1 DEVELOPMENT OF THE SIMULATION MODEL

This chapter reports the description of a simulation study of a cellular high capacity mobile telecommunications system, employing the Hybrid Channel Assignment technique; with first uniform (case 1) and then non-uniform (case 2) traffic.

The system simulated is described in detail and is shown in Fig. 5.1. It consists of forty hexagonal cells arranged to completely cover a large area.

5.1.1 Case 1: Uniform Traffic

The following general assumptions made pertain to the case of uniform traffic:

1. for an hexagonal cellular layout the relationship between D/R and the number of distinct channel sets, N, required is given by

$$D/R = \sqrt{3N}.$$

In the simulation model N is taken to be 3 and consequently the minimum reuse distance (γ) is equal to 3 cell radii. Also, the number (I.C) of members in the I.C.G equals 7.

2. all cells are of uniform size and shape

3. the call holding time, in any cell, is assumed to be exponentially distributed,with a mean of 120 secs.

4. the calls in each cell are assumed to have a Poisson distribution with the same known arrival rate

(λ calls/hr). Thus the loading will be

$$\lambda . \frac{120}{3600} = \frac{\lambda}{30} \text{ [Erlangs]}$$

5. The first available dynamic channel in the search, that satisfies the spacing constraint, is borrowed for use.

6. blocked calls are cleared,i.e.Erlang-B service discipline.

7. It is assumed that the mobiles are identifiable entities and can tune to any channel, as dictated by the base stations.

8. the base stations could transmit on any frequency at all times, as assigned to them by the MTSO.

9. the power level radiated from a base station antenna is sufficient to give an adequate SNR ratio at the cell's boundary. Thus the coverage limitation is due to the cochannel interference.

10. calls that are assigned to the channels remain on for the full call duration time specified by the exponential distribution.

11. there are no cell boundaries crossings for all calls-in-progress. This implies that calls use a given fixed channel and as specified in (4) above; are not forced to terminate prematurely because there are no available channels in the new cell.

12. there is no limit on available radio equipment at the base stations.

13. there is no limit on the number of available access channels.

5.1.2 Case 2: Non-uniform Traffic

The following assumptions pertain specifically to the non-uniform traffic case:

1. the same assumptions that were made in case 1 above (uniform traffic) also pertain to non-uniform traffic, except for assumption 4 which is excluded.

2. The calls in the central cell and its surrounding cells are assumed to have Poisson distributions with known arrival rates (λ_1 calls/hr) and (λ_i calls/hr), respectively.

3. The traffic in the central cell is always assumed X% greater than the traffic in the surrounding cells.

4. We first consider the same number of channels in each cell. Then, we consider that the number of channels allocated to the surrounding cells is always less than the number of available channels assigned to the central cell.

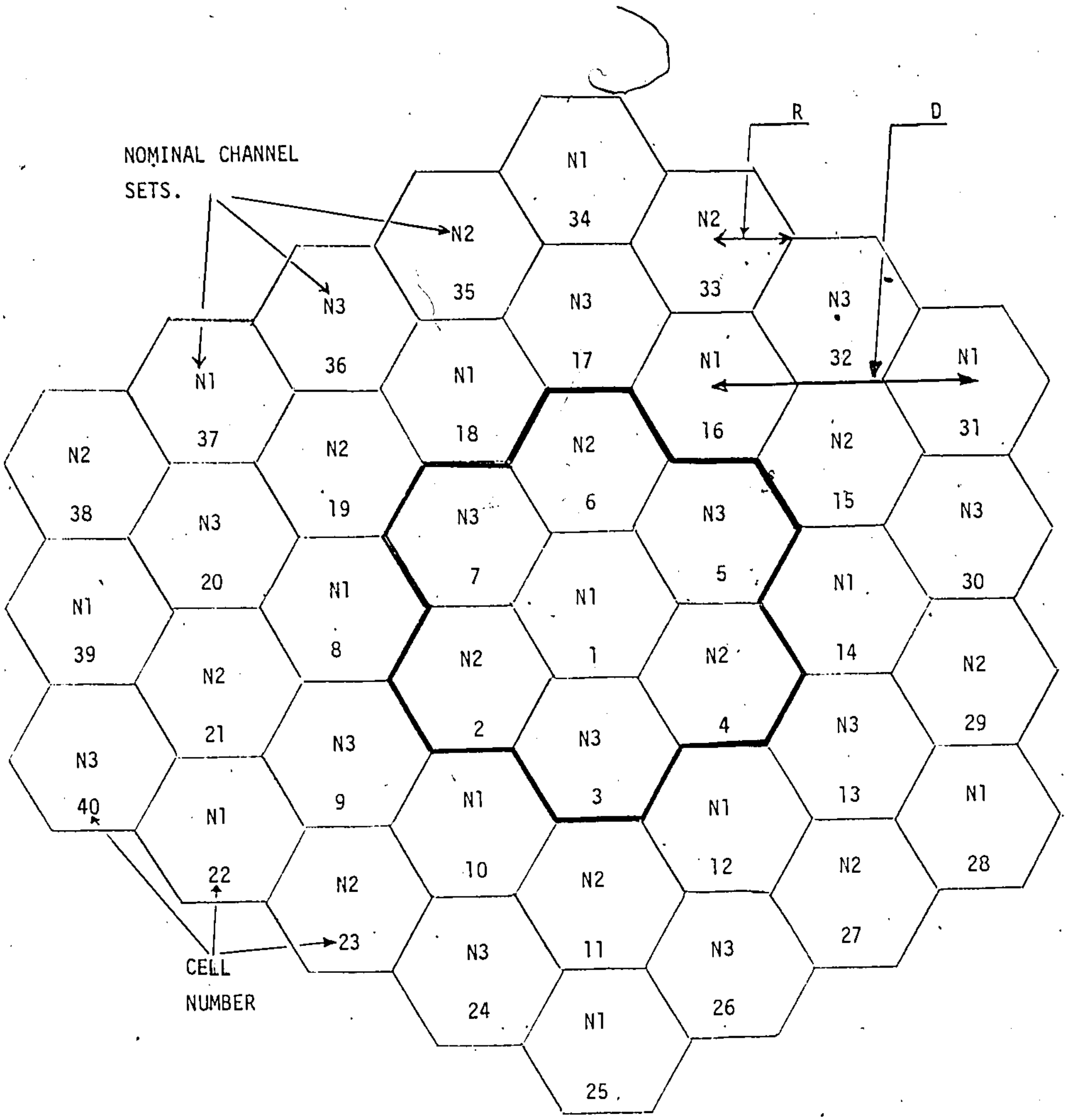


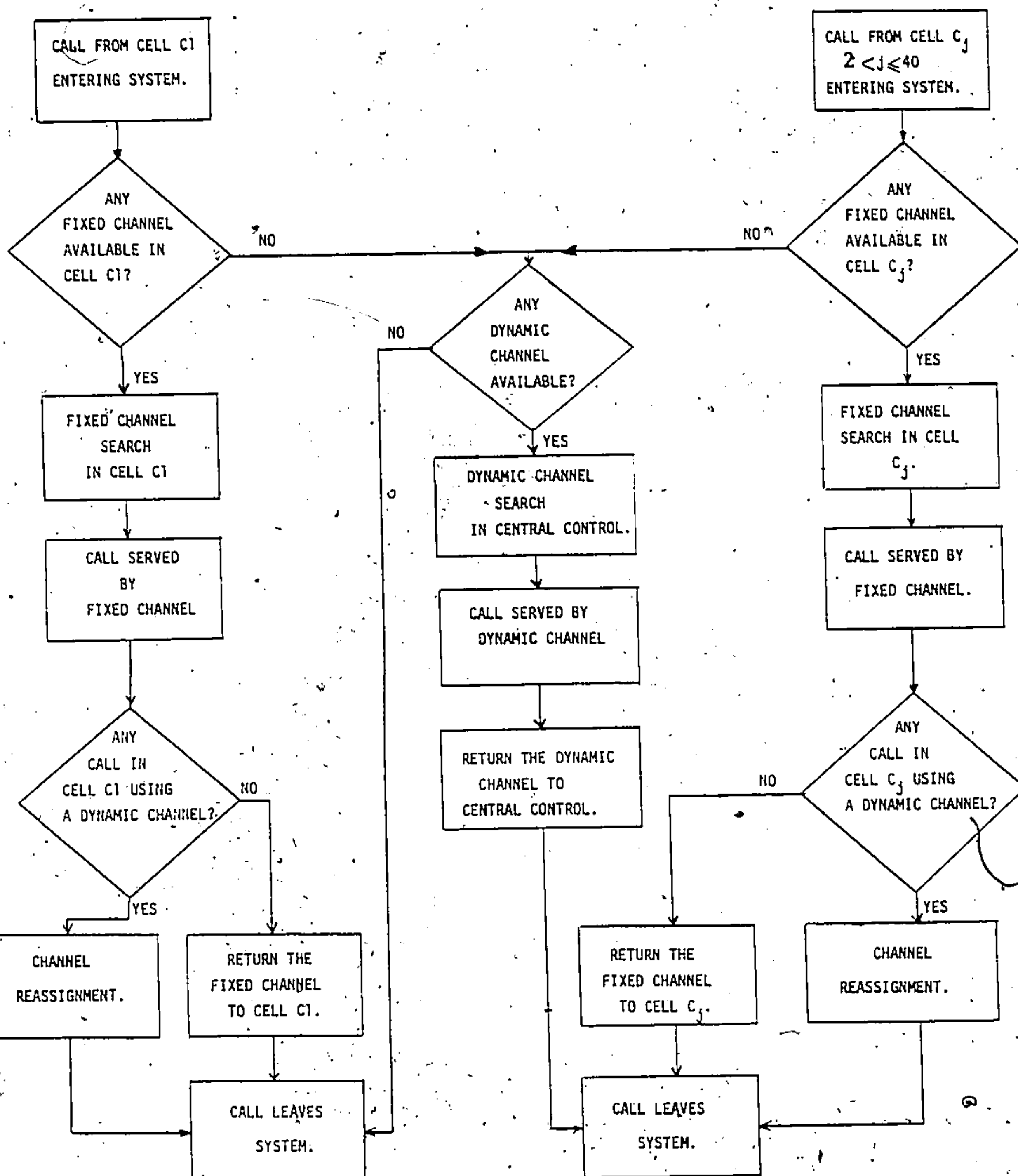
Fig. 5.1 The Cellular-Structured Mobile Radio System of 40 Cells that was simulated utilizing three Channel Sets N1, N2 and N3.

5.2 SIMULATION MODEL

The simulation model can be easly followed with the aid of the flow-chart in Figure 5.2. For an incoming call (say X) originating from central cell #1, the left hand branch of the chart is followed. If call X passes the availability test of the fixed channels in the central cell, it will search for the first fixed channel allocated to cell #1 and then it will receive immediate service by that channel. If call X finds all fixed channels occupied in the central cell, it will proceed to the next test on the availability of dynamic channels (belonging to any channel set in the system) which could be borrowed for use in cell #1 at that moment of time. On passing that test, call X will search for the first available dynamic channel satisfying the cochannel interference constraint and will then seize the channel for the full call duration time. Call X is blocked and forced to leave the system, if all voice channels are busy in the central cell. Upon completion of service by a fixed channel, call X releases the channel. Before returning the channel to cell #1, call X first checks if other calls from the same cell are currently being served by dynamic channels. If so, Channel Reassignment is initiated. In the channel reassigning process, call X hands-off the released fixed channel to the first such call in progress, thus freeing the dynamic channel which that call previously occupied. The reassigned call will continue to converse on the newly assigned fixed channel for the remainder of the call holding time, while call X leaves the system. The freed dynamic channel has to be returned to the central pool for the next assignment.

The processing of calls originating from cell Cj (2 ≤ j ≤ 40) can be followed by returning to the status check block at the top of Figure 5.2 and following the right hand branch. As indicated on the flow-chart, the assigned channel is similar to the channel assignment criteria in the left hand branch. The only restriction made is that the dynamic channels assigned to each channel set are belonging to the common system pool. If, after checking all radio channels in the system, no available channel is found, the call in any cell is blocked as indicated on Figure 5.2. Blocked calls are completely removed from the system and no other attempt to serve them is made.

Fig. 5.2 Flow-Chart For The Simulation Model Of The Cellular Mobile System Employing The Hybrid Channel Assignment Scheme With Erlang-B Service Discipline .



Chapter VI

SIMULATIONS RESULTS FOR CASE 1: UNIFORM TRAFFIC

The cellular system that was simulated is shown in Fig. 5.1. The simulation was done using GPSS/360 [14-16], and was run on the AMDAHL 470/V611. 40 cells were used because of constraints imposed by GPSS [14,16].

6.1 STIMULUS TO THE SIMULATED SYSTEM

The performance data are accumulated from the central portion of the system (20 middle cells). The traffic in this case is uniformly distributed over the cells. The results are representative of an infinite system. The reason for using an infinite cellular layout was to overcome the edge effects. Using a finite system, cells near the edges of the system will have fewer neighbouring cells to induce cochannel interference. The cells around the edges do not have enough neighbouring cells to cause calls to be blocked, whereas the centrally located cells have a lot of neighbouring cells and therefore every time the central cells wish to borrow, chances are the neighbouring cells will be using the desired channels. This gives rise to the central cells having higher blocking probabilities than those at the edges.

6.2 THE INPUT PARAMETERS TO THE SIMULATION MODEL

The following abbreviations below have been adopted and are used in the following sections:.

C1 = central cell.

Cj = cells surrounding the central cell C1 ($2 \leq j \leq 40$).

λ_1 = mean call attempt rate for C1.

λ_i' = mean call attempt rate for Cj.

$\lambda_1 = \lambda_i$,if the traffic is uniformly distributed in each cell.

f:d = channel division ratio on a "per cell" basis.

f = number of fixed channels.

d = number of dynamic channels per channel set.

$$Pb = \frac{\text{number of calls which fail to find a voice channel}}{\text{sum of calls which find/don't find a voice channel}}$$

= blocking probability of voice channels.

The denominator of Pb represents the total number of calls which enter the program simulator to find/don't find a voice channel assignment.

Table 6.1 summarizes the different system configurations simulated.

TABLE 6.1

DIFFERENT SYSTEM CONFIGURATIONS SIMULATED

AVERAGE NUMBER OF CHANNELS PER CELL IN SYSTEM WITH UNIFORM TRAFFIC & FIXED CHANNEL ASSIGNMENT SCHEME	CHANNEL PARTITIONS FIXED : DYNAMIC	TRAFFIC LOADINGS IN ERLANGS USED IN THE SIMULATION
10	10 : 0 8 : 2 7 : 3 6 : 4 5 : 5 4 : 6	5*, 5.5, 6, 6.75, 7, 8, 9, 10
18	18 : 0 16 : 2 14 : 4 10 : 8	11*, 12, 13, 14
21	21 : 0 17 : 4 15 : 6	13*, 14, 15, 16, 17, 18
25	25 : 0 22 : 3 20 : 5 18 : 7	17*, 18, 19, 20, 21, 21.5, 22
28	28 : 0 26 : 2 24 : 4 20 : 8	20*, 21, 22, 24
30	30 : 0 28 : 2 25 : 5 22 : 8 20 :10 15 :15	21.5*, 22, 23, 23.5, 24, 25, 26
35	35 : 0 33 : 2 31 : 4 28 : 7 25 :10	26*, 27, 28, 29, 30, 31

* Base load

6.3 SYSTEM PERFORMANCE

6.3.1 Maximum Traffic per Cell that each System can support

In the case of 10 and 18 fixed channels, on the average per cell, the Fixed Channel Assignment Schemes (i.e. the channel division 10:0 and 18:0) were simulated for the sake of validating the program. In Figures 6.1 to 6.7, the Y-axis represents the average blocking probability Pb in the twenty middle cells and is computed as mentioned in section 6.2. The X-axis represents the increase in load over the base loads for the desired grades of service which are interpreted here as the Pb. We first found from the Erlang-B traffic formula given by equation 3.2, the offered traffic, in Erlangs, required to give a desired grade of service with a certain average number of fixed channel per cell. The base load is termed as the required traffic which was used as the base for computing the increase in offered traffic. In the case for 10 channels, with a mean call holding time of 120 sec, the base traffic rate is 5 Erlangs. This is corresponding to the Pb of 0.018. Therefore, this figure of 5 Erlangs is used as the basis for the calculations of the percentage traffic increase.

In figure 6.1, the simulated results for the Fixed Channel Assignment Scheme were plotted along with the theoretical values obtained from the Erlang-B formula.

These results show that the simulator program was working as desired. This figure also shows that for load increases of up to about 24% above base load the 6:4 system gives the lowest Pb, whereas the channel division of 7:3 performs better for load increases beyond 24% above base load. The system that can support the highest traffic with 2% maximum blocking is 7:3 and this maximum traffic is 6.4 Erlangs.

From Figure 6.2 we find that for load increases of up to about 11.2 Erlangs, the 10:8 system gives the lowest probability of blocking. While the system having, on the average, 14 fixed channels per cell and 4 dynamic channels per channel set gives the best results with 2% maximum Pb and the maximum traffic in this case is about 13.2 Erlangs.

Figure 6.3 shows results obtained from simulation of a system that had base load offering of 13 Erlangs, on the average per cell. We again notice, from Figure 6.3, that for load increases of up to about 22% above base load (13 Erlangs) the 15:6 system gives the best results. While the system having, on the average, 17 fixed channels per cell and 4 dynamic channels per channel set gives the lowest probability of blocking. From the same figure we find that for load increases of up to about 16 Erlangs the 17:4 system gives the best results with 2% maximum Pb.

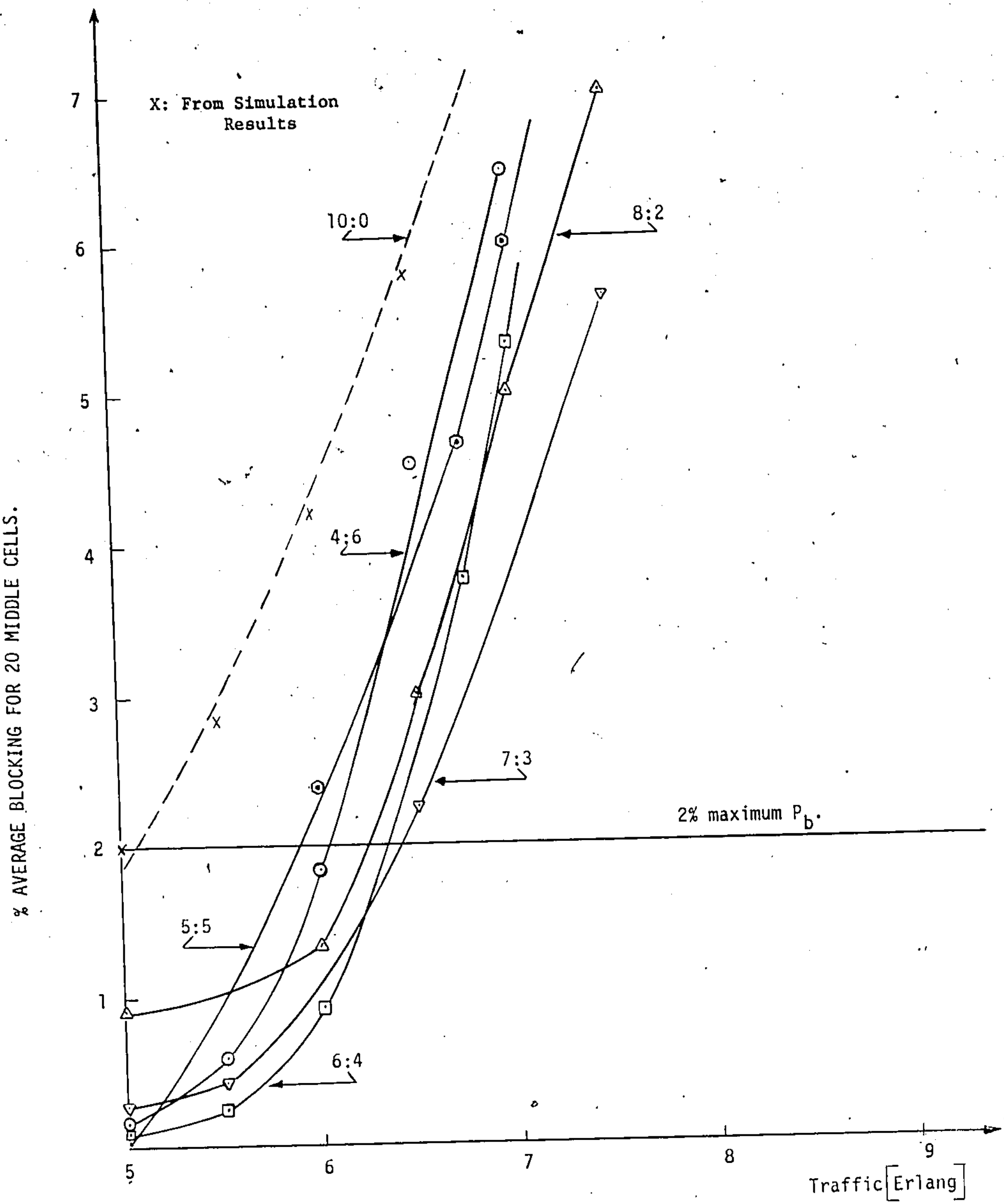


Fig. 6.1 Performance of System with initially 10 Fixed Channels per cell.

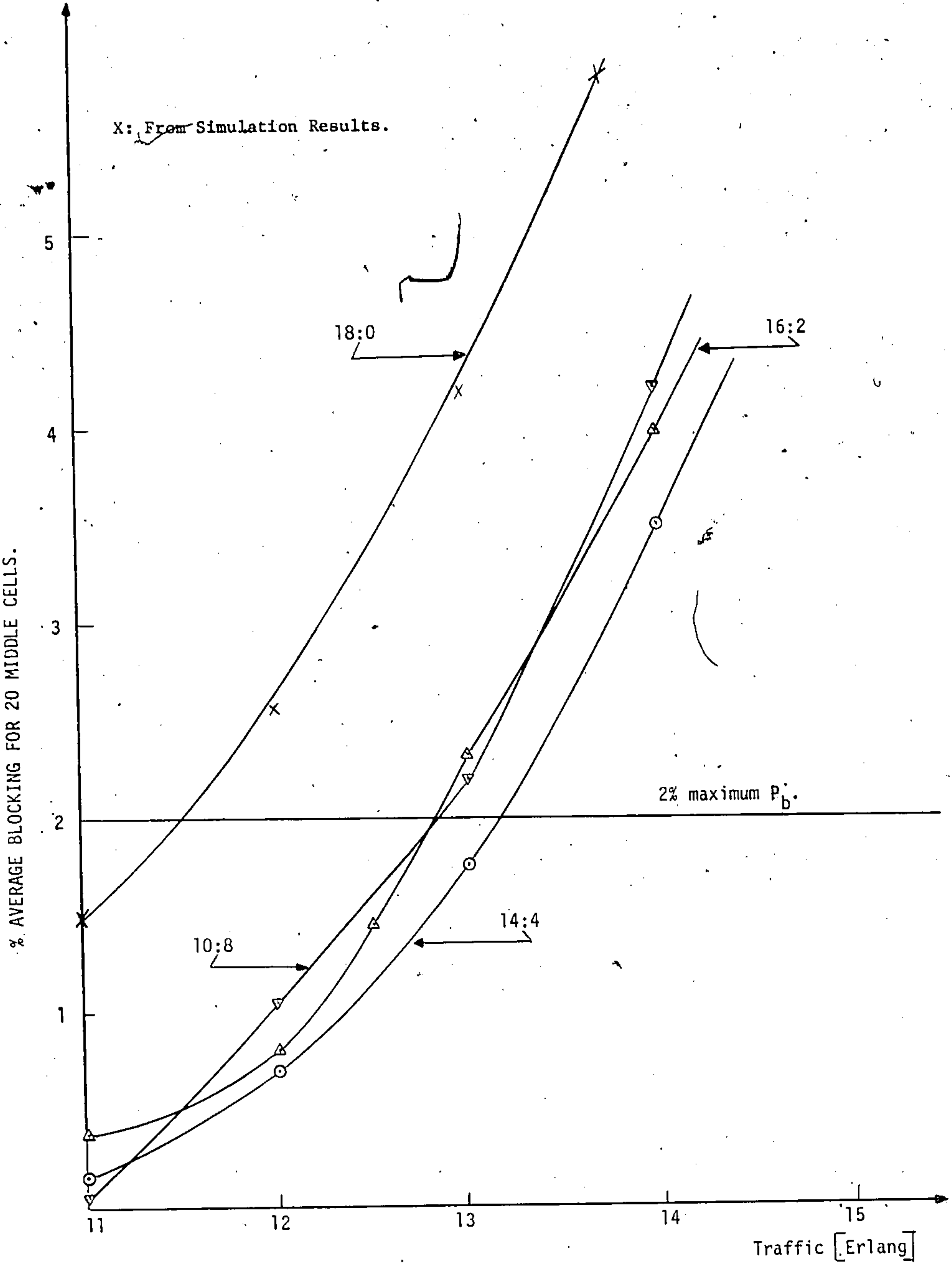


Fig. 6.2 Performance of System with initially 18 Fixed Channels per cell

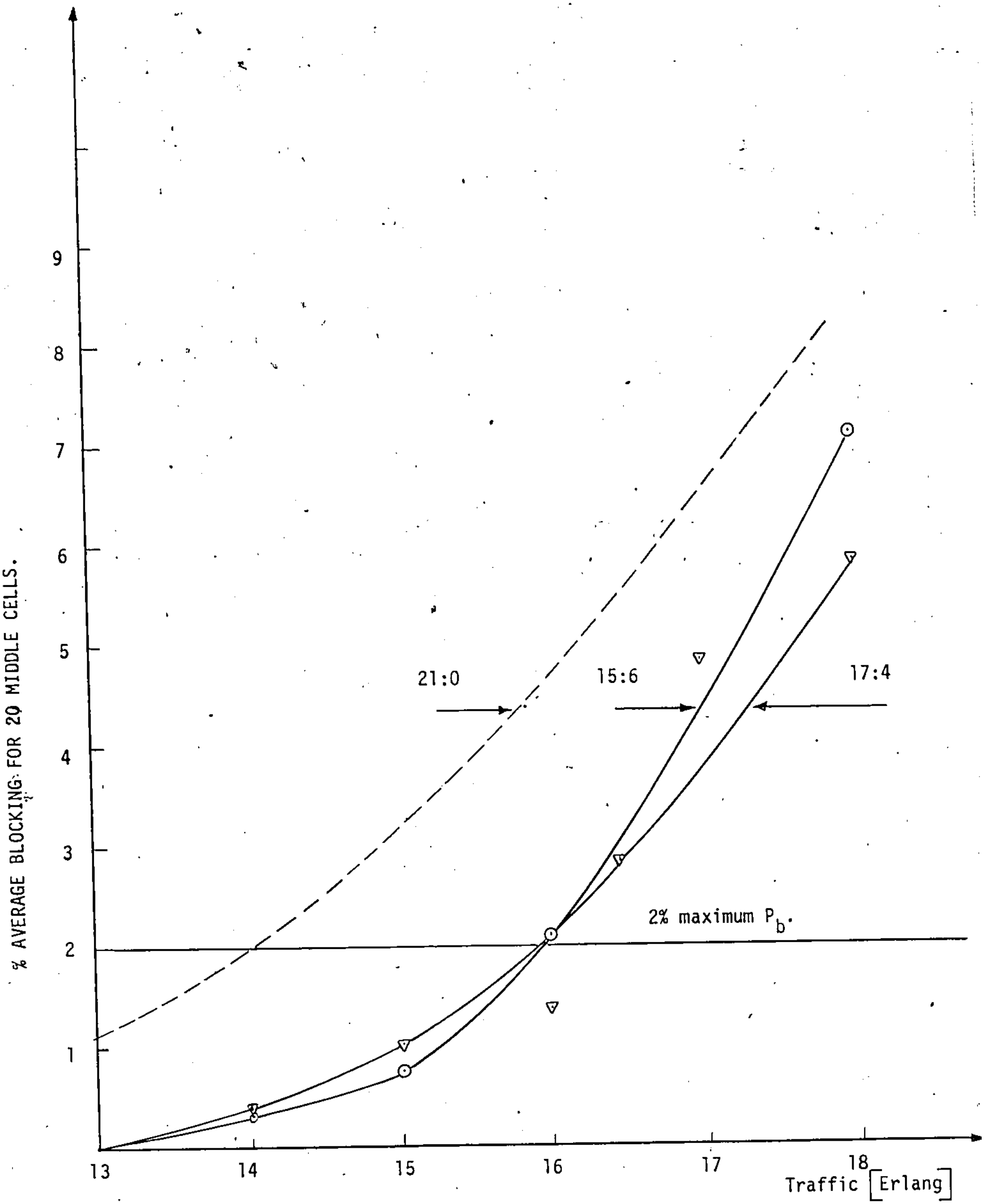


Fig. 6.3 Performance of System with initially 21 Fixed Channels per cell.

The performance of the different channel divisions used, with on the average 25 fixed channels per cell are presented in Figure 6.4. From this figure we once again observe that the 18:7 system can support the highest traffic with 2% maximum blocking, and this maximum traffic is 19.5 Erlangs.

Fig. 6.5 shows that with load increasing up to about 20.6 Erlangs the average number of blocked calls is the lowest for the system having 20 fixed channels per cell and 8 dynamic channels per channel set. Once the traffic is increased beyond that point, the system with, on the average 24:4 starts to bring the best result with 2% maximum Pb and the maximum traffic is 22.2 Erlangs.

From Fig. 6.6 we find that for load increases below 17% (about 25 Erlangs) above base load, the channel partition of 22:8 gives the best performance with 2% maximum Pb .

From Fig. 6.7, we once again observe that at low traffic loadings the 25:10 system having the most dynamic channels gives the lowest probabilities of blocking. On the other hand, the system 31:4 can support the highest traffic with 2% maximum blocking and this maximum traffic is 29 Erlangs.

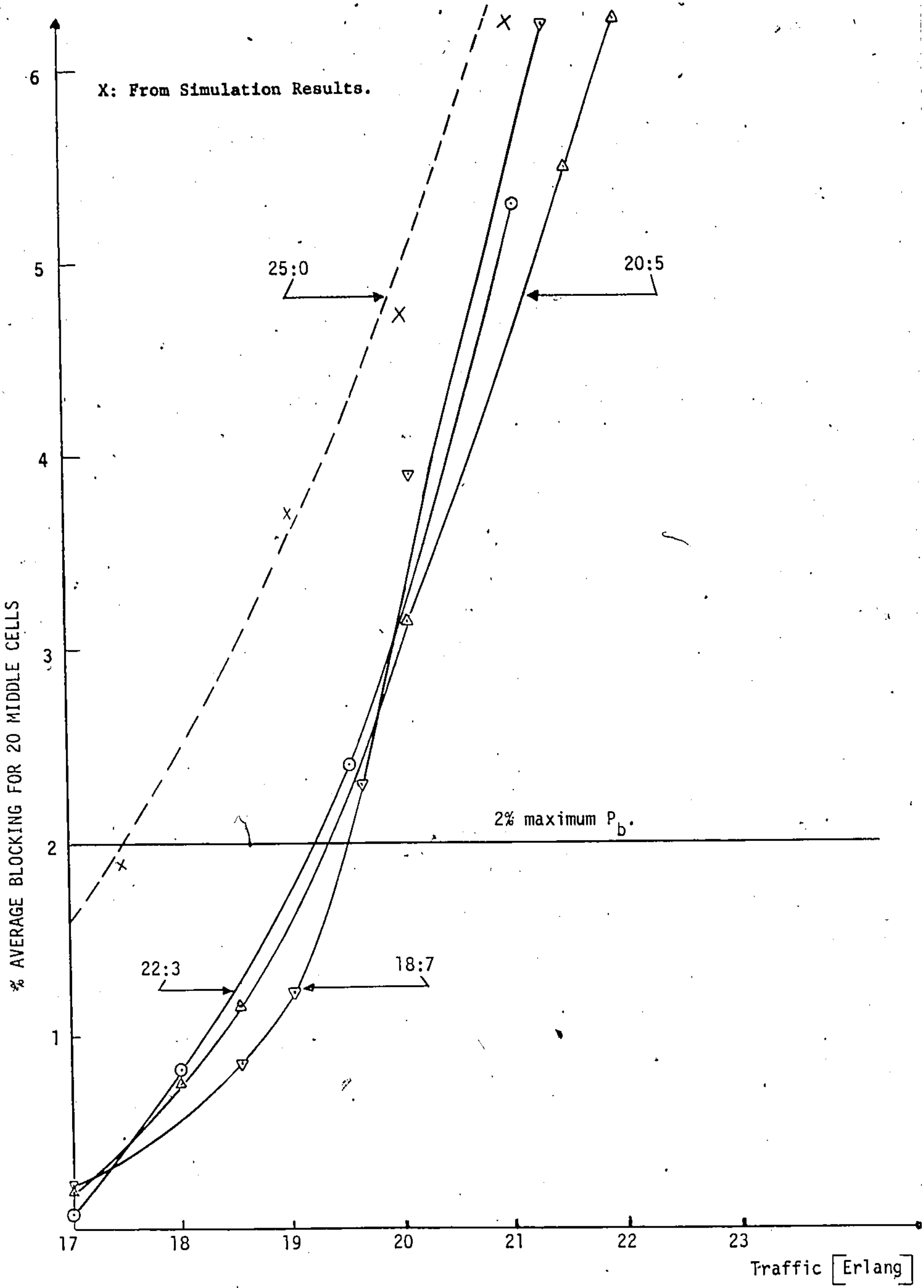


Fig. 6.4 Performance of System with initially 25 Fixed Channels per cell.

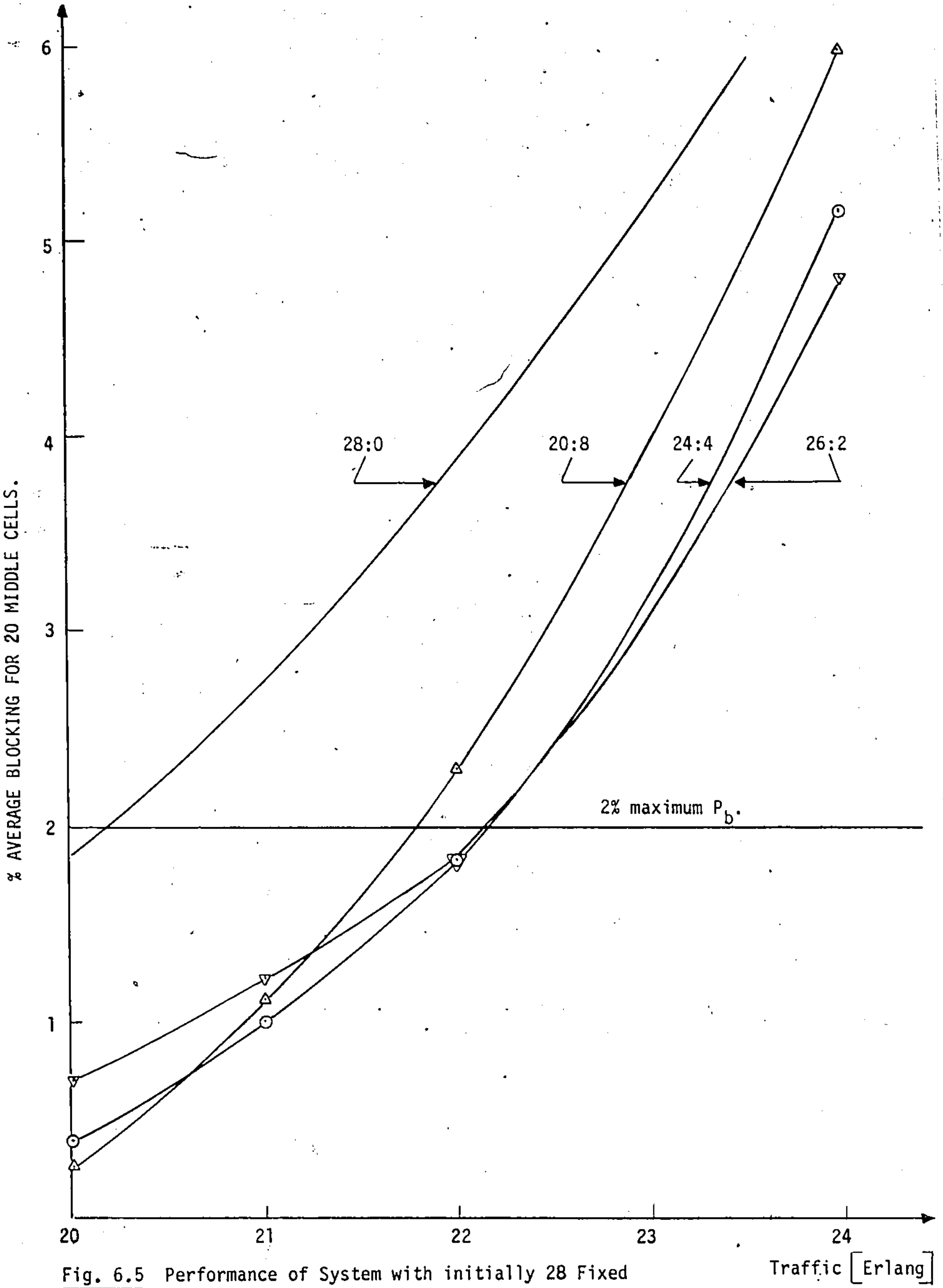


Fig. 6.5 Performance of System with initially 28 Fixed Channels per cell.

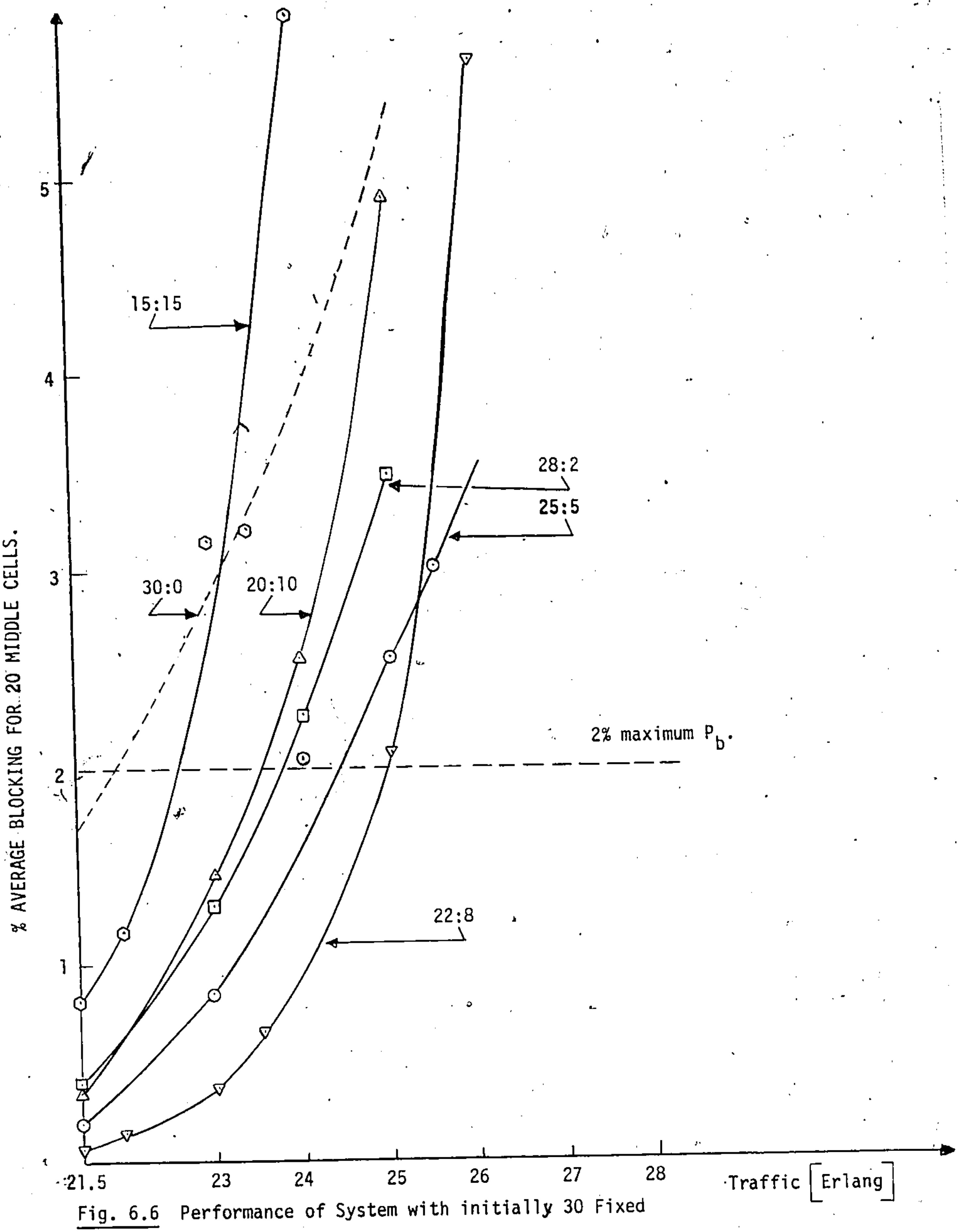


Fig. 6.6 Performance of System with initially 30 Fixed Channels per cell.

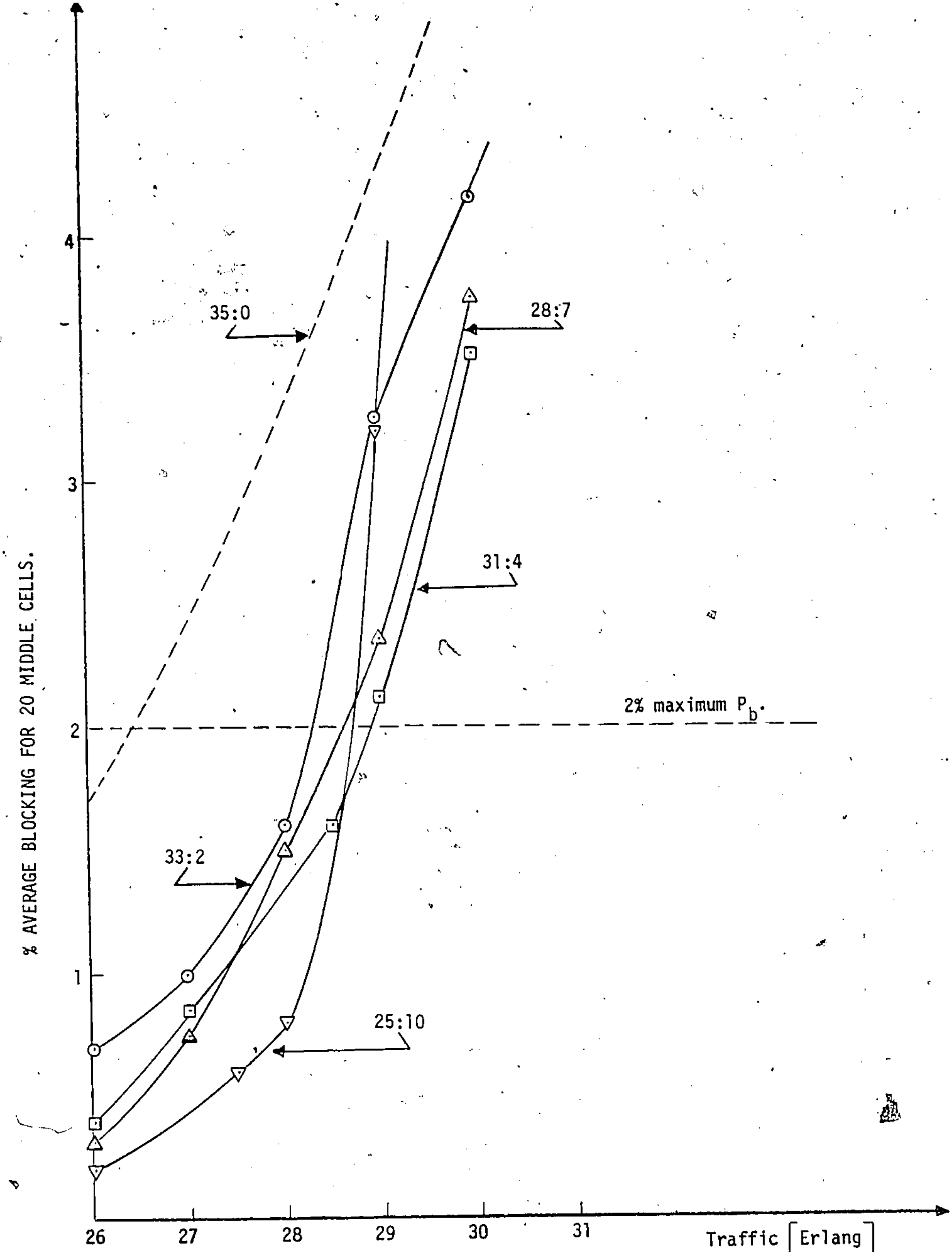


Fig. 6.7 Performance of System with initially 35 Fixed Channels per cell.

The performance of the different hybrid channel divisions with respect to the maximum traffic supported for 2% maximum Pb, is presented in Fig. 6.8. Note that only the optimum combinations of fixed and dynamic channels (i.e. best hybrid channels) are shown in Figure 6.8 for a specified total number of channels.

Figure 6.9 represents the simulation results of hybrid systems with, on the average, 70% fixed, 30% dynamic. Comparing Figs. 6.8 and 6.9 we observe that the 70%:30% Hybrid Scheme is extremely close to the "best" one in terms of the maximum traffic carried.

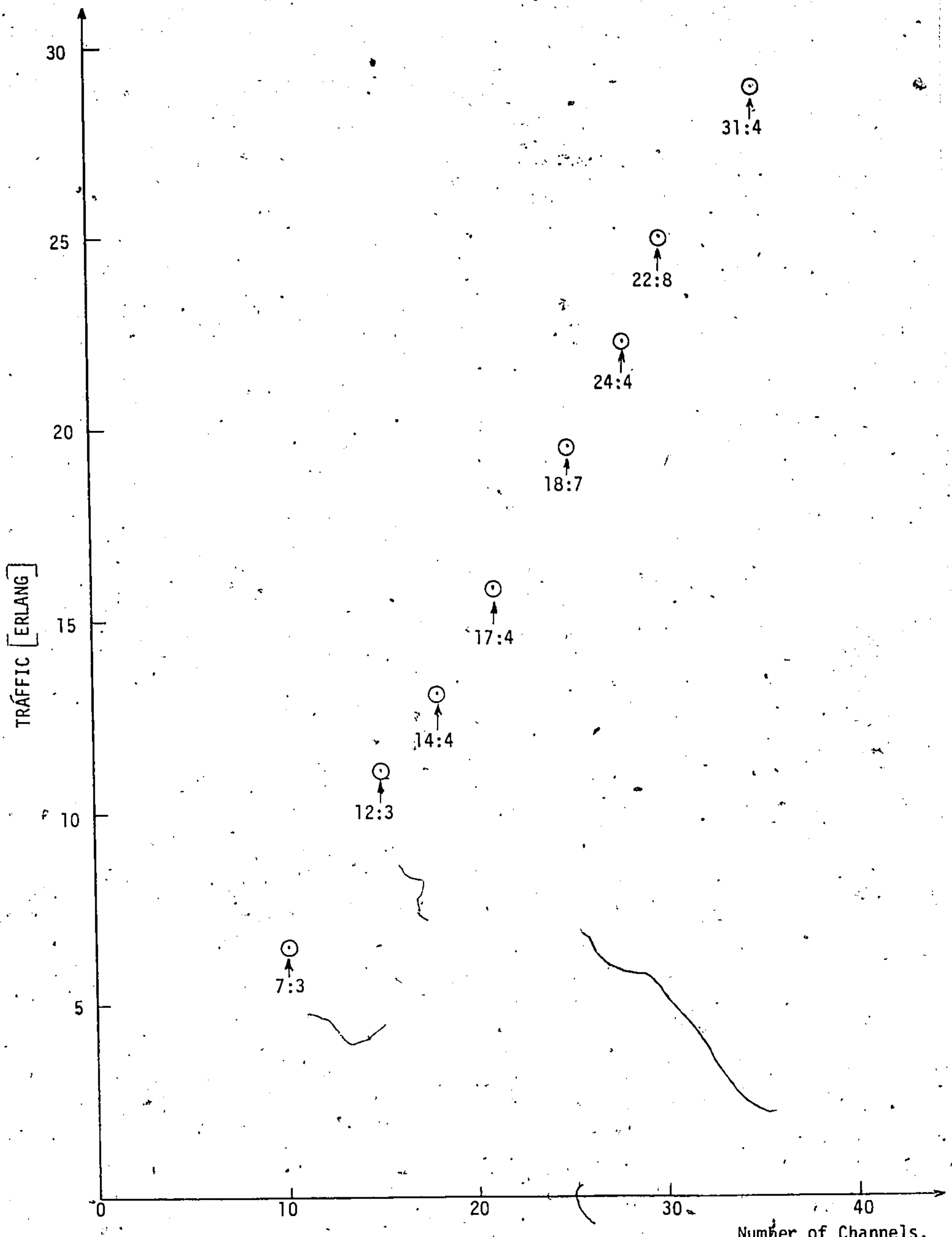


Fig. 6.8. Best Hybrid Systems obtained with a Maximum Blocking of 2%.

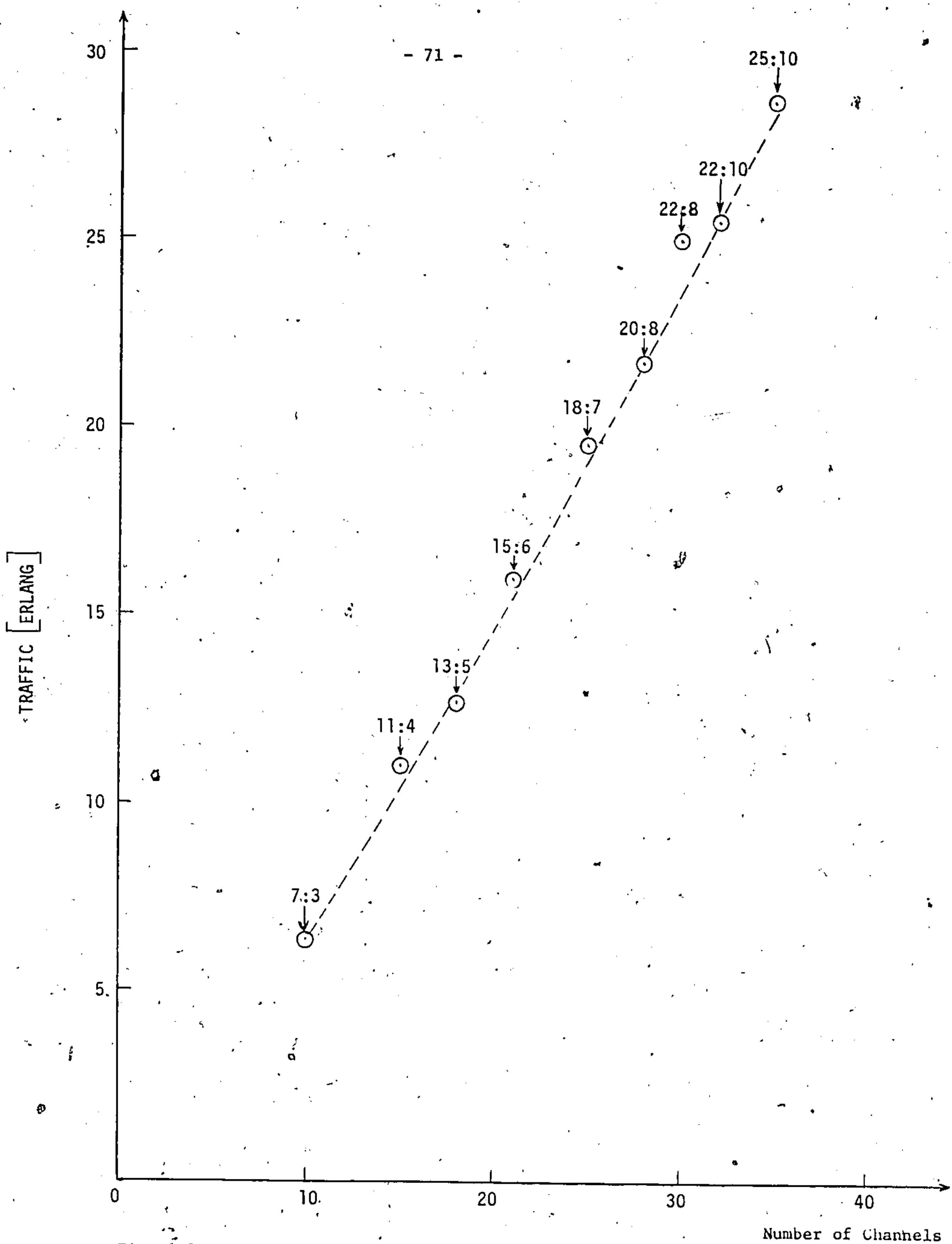


Fig. 6.9 - Best Hybrid Systems obtained with a maximum Blocking of 2% on the average (70% fixed, 30% dynamic)

6.3.2 Minimum number of necessary channels

In Figs. 6.10 to 6.14, the Y-axis represents the average blocking in the twenty middle cells and is computed as explained in section 6.2. The X-axis represents the increase of traffic in Erlangs.

First the simulation was done for the case of the channel partitions (80% fixed and 20% dynamic). This simulation results are represented in Figs. 6.10 and 6.11. For 2% maximum Pb, each partition gives the maximum traffic which can support.

Fig. 6.12 represents the channel partition (70% fixed and 30% dynamic). Once again, each partition gives the maximum traffic, while having a call rejection rate of no more than 2%.

Figure 6.13 shows the simulated results for the channel divisions (69% fixed and 31% dynamic). Each division gives the maximum traffic which can support with 2% maximum Pb.

The simulated results for the Fixed channels Assignment Schemes are plotted in Figure 6.14.

The results presented above show a remarkable general performance of the various system configurations simulated in regard to the probability of blocking (i.e. 2%).

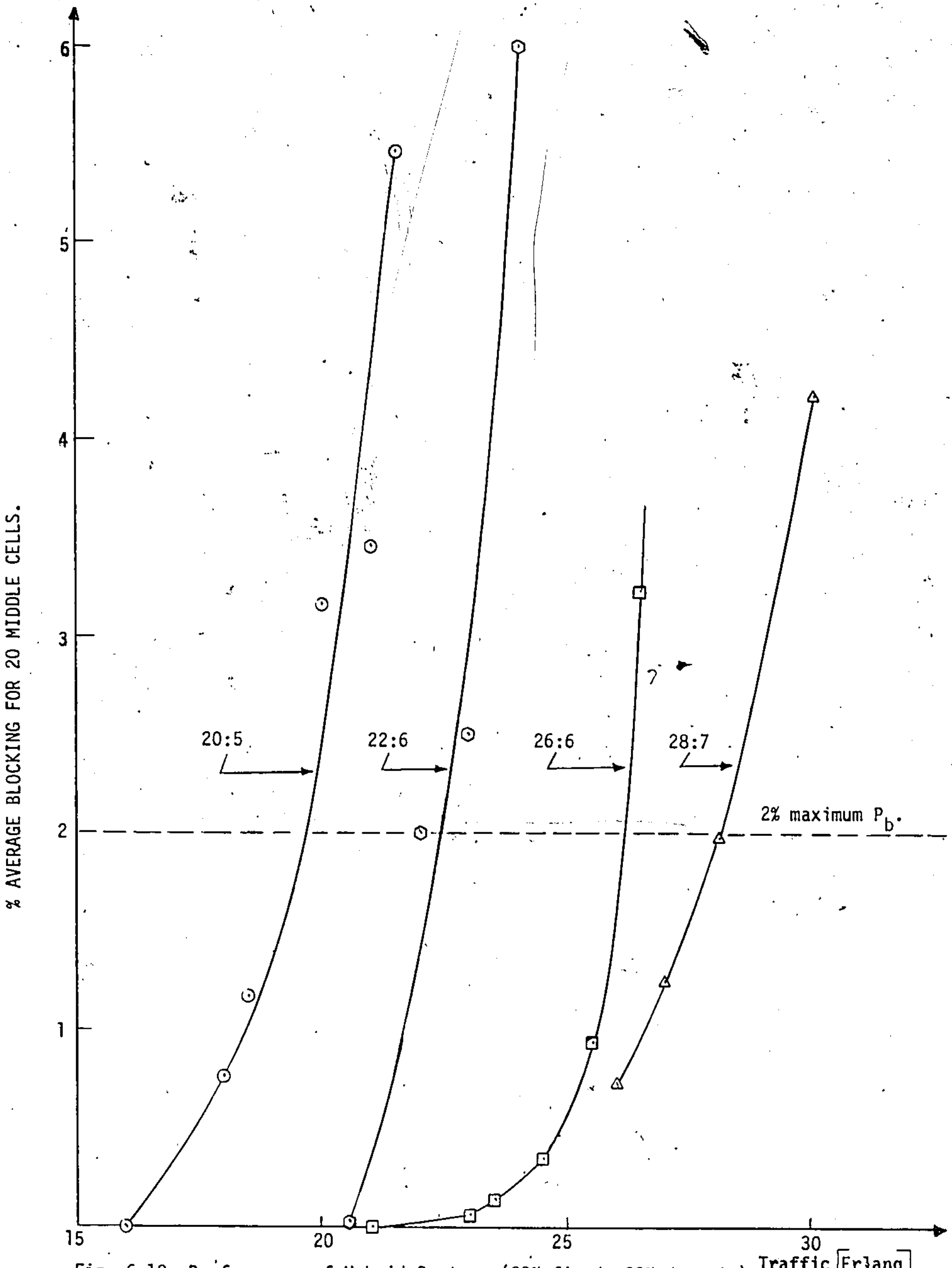


Fig. 6.10 Performance of Hybrid Systems (80% fixed, 20% dynamic) with 2% maximum P_b.

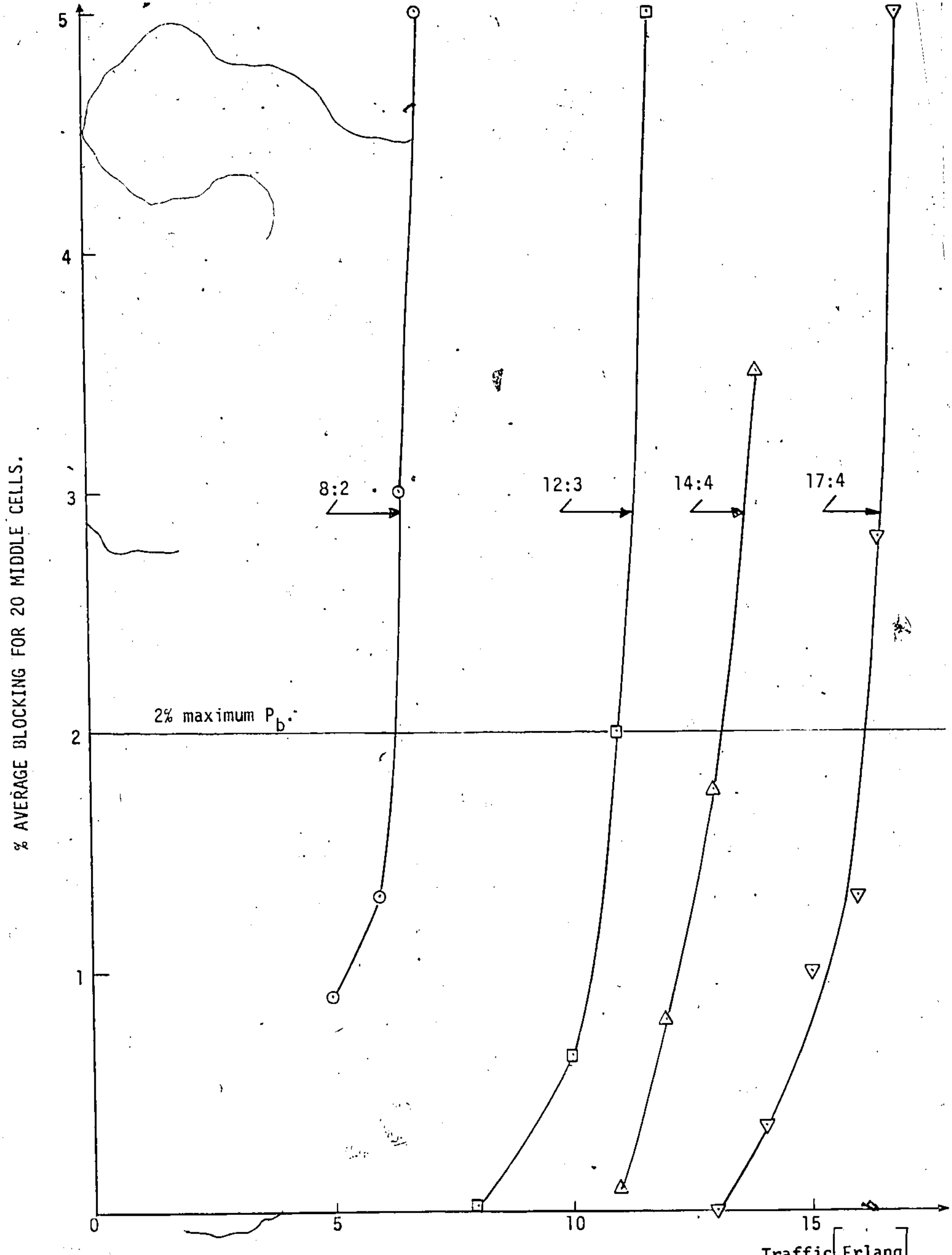


Fig. 6.11. Performance of Hybrid Systems (80% fixed, 20% dynamic) and 2% maximum P_b.

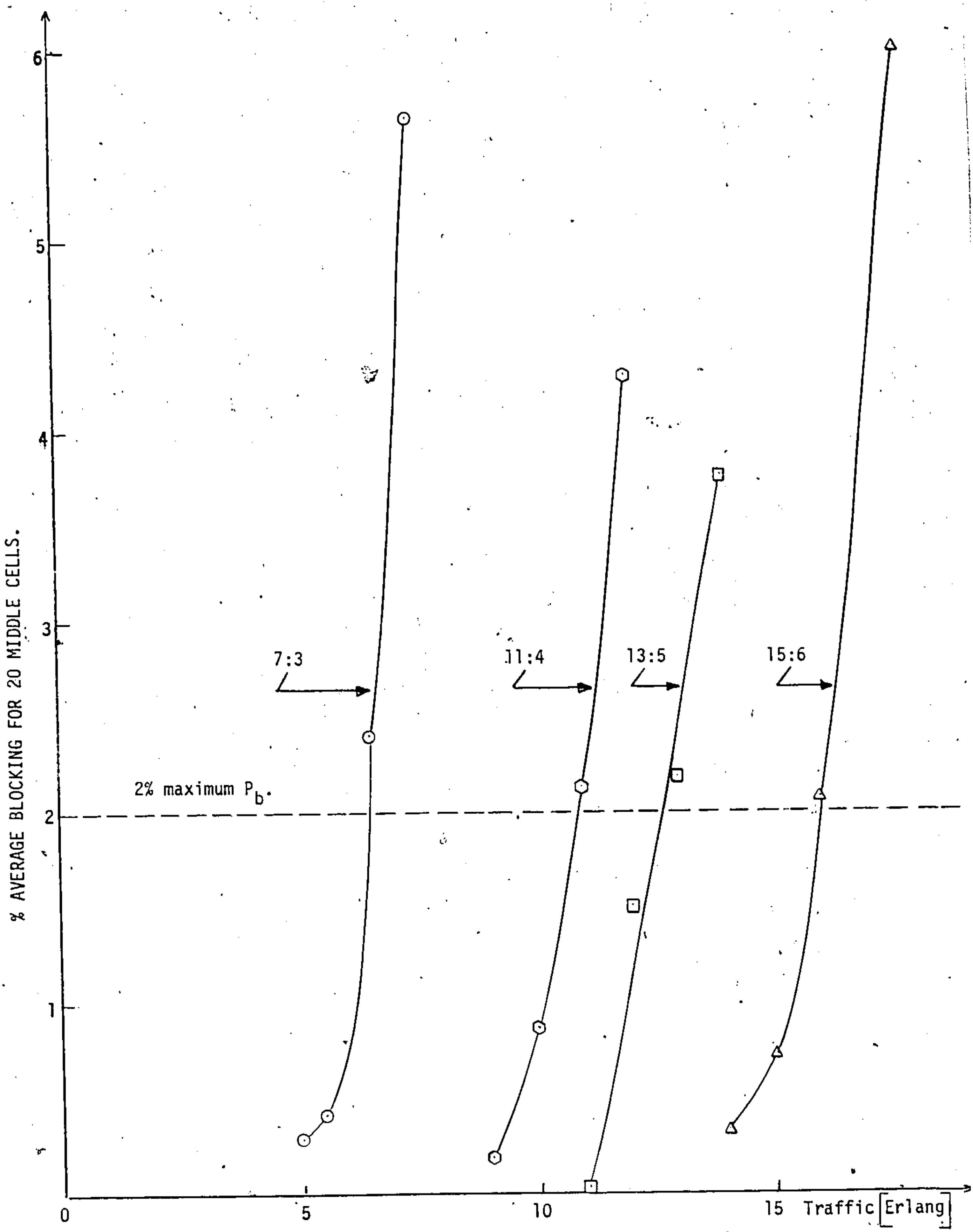


Fig. 6.12. Performance of Hybrid Systems (70% fixed, 30% dynamic) and 2% maximum P_b.

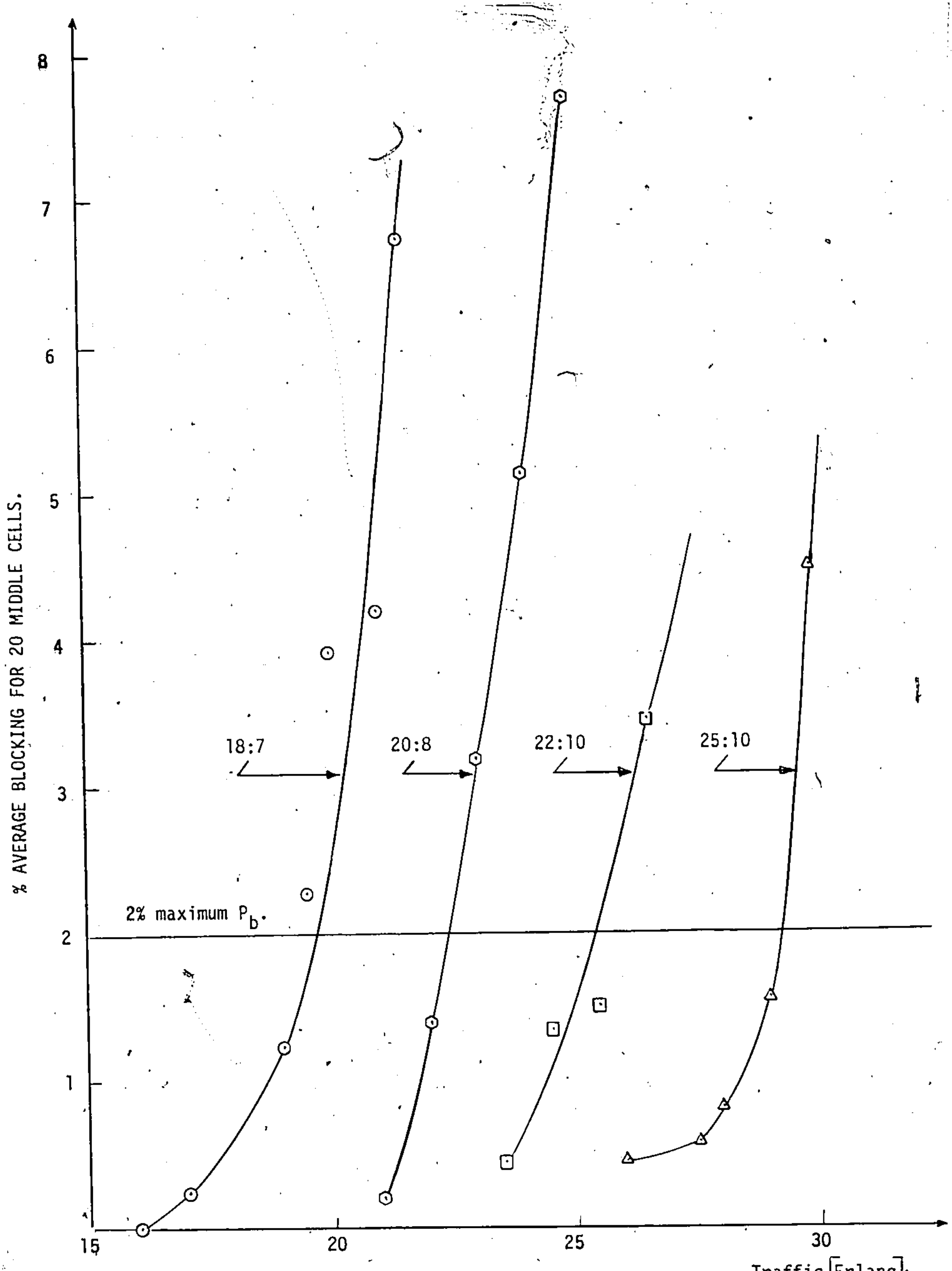


Fig. 6.13. Performance of Hybrid Systems (69% fixed, 31% dynamic) and 2% maximum P_b.

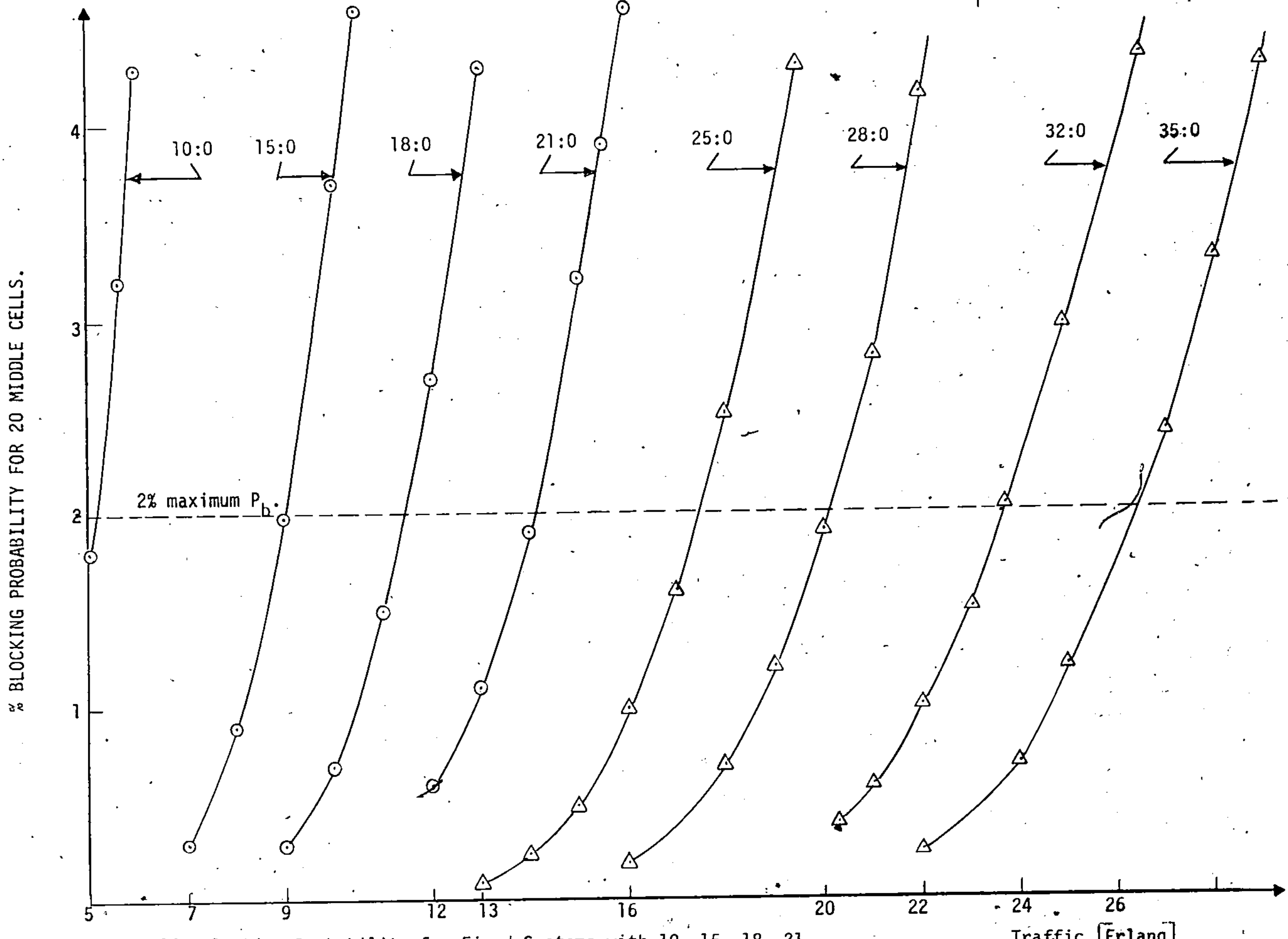


Fig. 6.14 Blocking Probability for Fixed Systems with 10, 15, 18, 21, 25, 28, 32 and 35 channels per cell.

6.3.3 Spectral Efficiency, Hybrid VS. Fixed

Figure 6.15 represents a comparison between the optimum Fixed and Hybrid systems with respect to the minimum number of frequencies required in order to provide a grade of service 2% or better. We found that the hybrid systems are in general more spectrum efficient than the fixed systems, for the same offered traffic and grade of service. For example, for a traffic of 9 Erlangs, the 11:4 hybrid system had a performance comparable to the 18:0 fixed system - a net saving of 3 channels per channel set (i.e. 9 channels in system area).

Figure 6.16 gives an indication of the improvement in spectral efficiency one can expect with a hybrid system as compared to the fixed channel assignment system. From this figure, we conclude that 15% is the total average of the spectral efficiency of the hybrid systems in comparison with the fixed systems simulated.

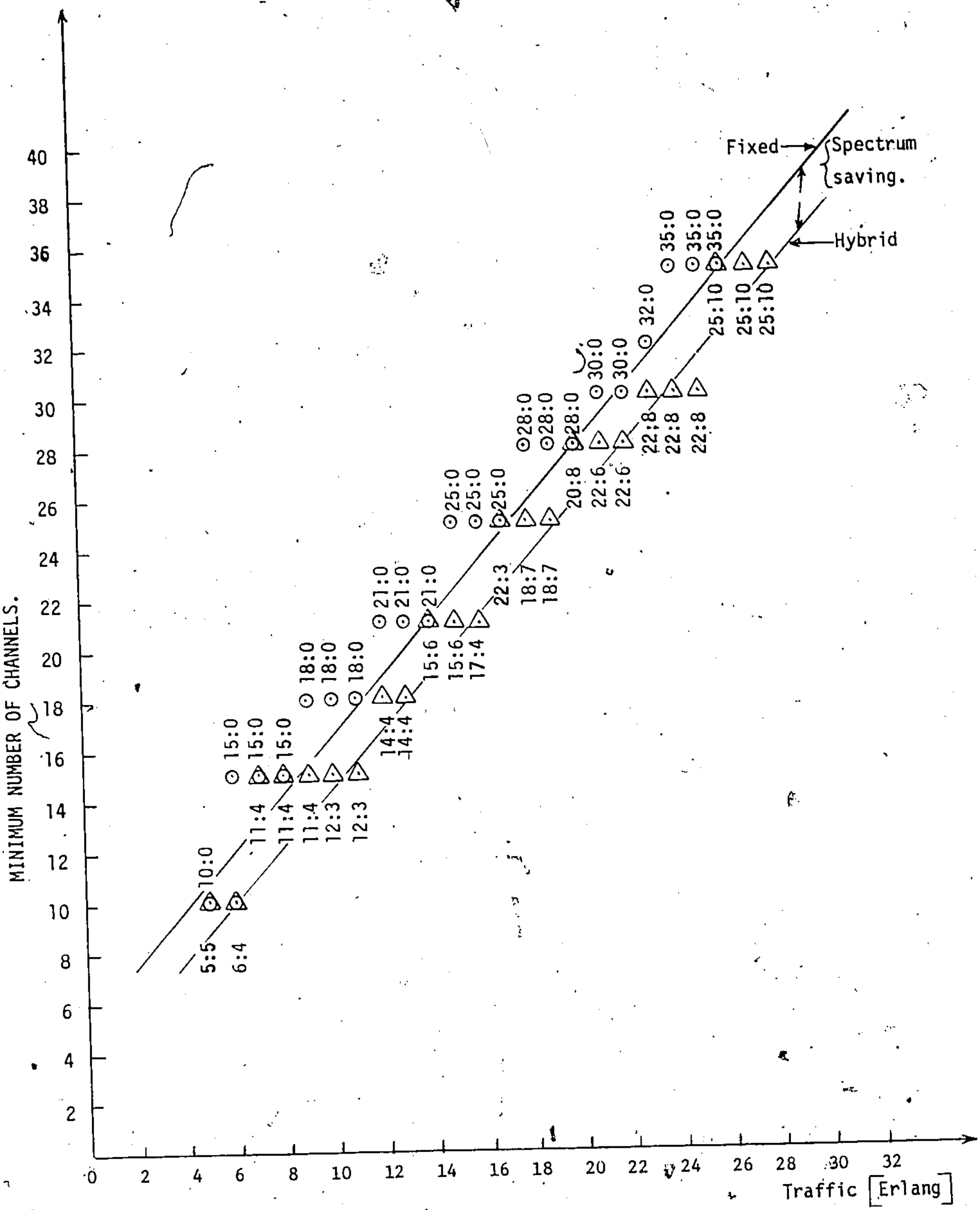


Fig. 6.15. Optimum Hybrid Systems with respect to the number of Frequencies required in comparison with the Fixed systems.

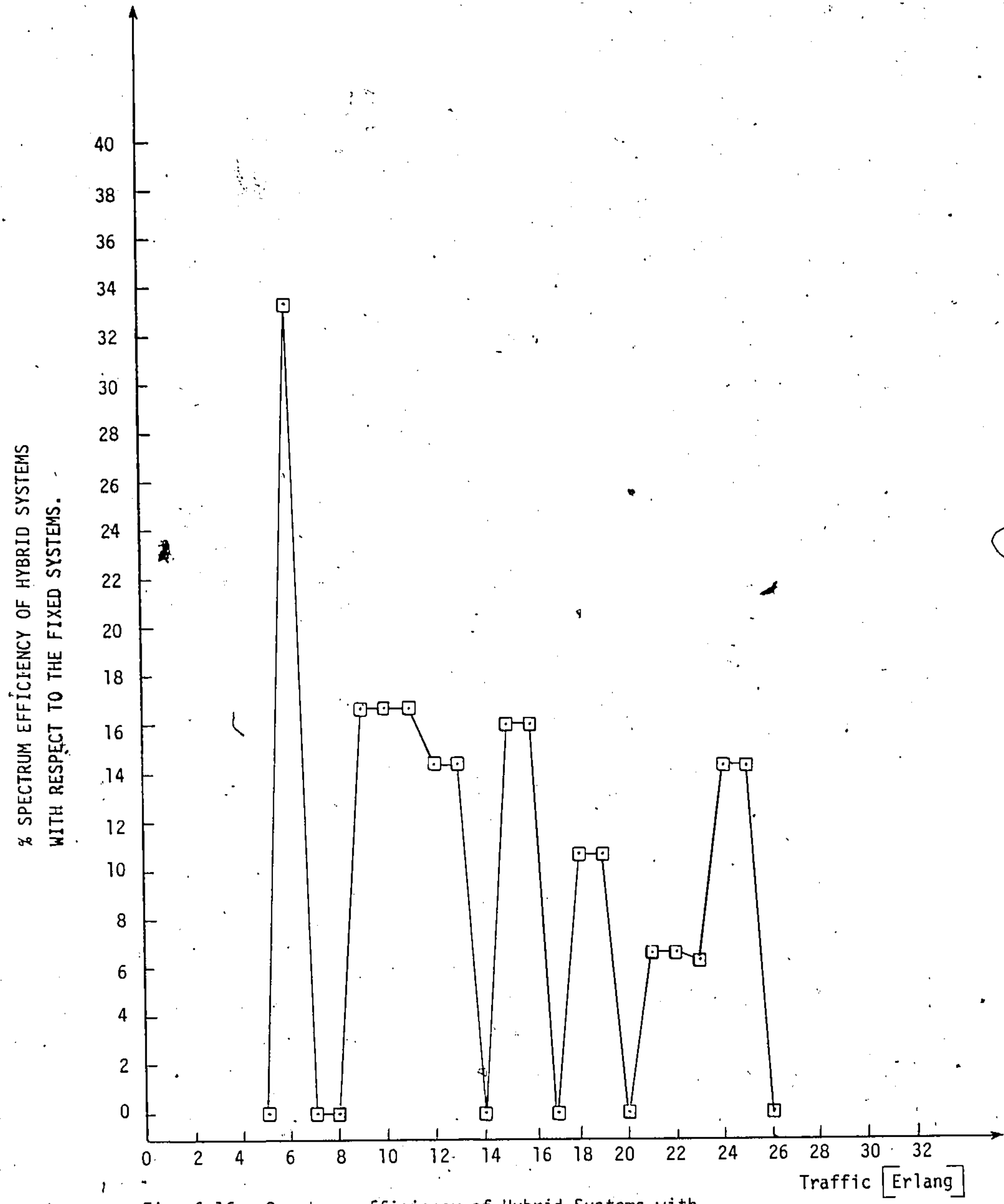


Fig. 6.16. Spectrum efficiency of Hybrid Systems with respect to the Fixed Systems.

6.4 INTERPRETATIONS

In this chapter we presented simulation results of a cellular land-mobile radio-communications system with Erlang-B service and traffic uniformly distributed in the service area. The two schemes, fixed and hybrid channel assignment, were compared as to the maximum traffic they can carry for 2% call rejection rate. We have found that the hybrid system (70% fixed, 30% dynamic) is very close to the best hybrid scheme in terms of maximum traffic carried.

In addition we have determined the minimum number of channels needed by each of the schemes in order to carry a given traffic and still keep a maximum rejection rate of 2%. Finally we have compared the spectral efficiency of hybrid systems with respect to the fixed systems. The saving in frequencies, when using the hybrid channel assignment, was on the average 15% as compared to the fixed channel assignment schemes. This important feature of the hybrid scheme may be used as an alternative to "cell-splitting" in the case of a fixed scheme.

We hope that these first results, obtained with a uniform traffic, will be of use to those designing cellular, land-mobile radio communication systems.

Chapter VII

SIMULATION RESULTS FOR CASE 2: NON-UNIFORM TRAFFIC

7.1 INTRODUCTION

This chapter reports the results of a simulation study of the case of non-uniform traffic distribution and in particular increasing traffic load in the central cell C1, as compared to all other cells. Erlang-B service is again assumed.

The simplest channel assignment technique, presented here as a starting point for the simulation, requires the division of the available channels into N equal sets first. The traffic estimated to C1 (City Center) is always greater than the traffic in the surrounding cells.

In a typical system, it is expected that the offered load will increase in C1 and a considerable number of channels will be used in the set N1 allocated to C1. But the same set N1 will be repeated simultaneously in other cells CN1 (where the traffic is lesser), under consideration of the minimum reuse distance (γ).

For the simulation model we consider the following cases:

1. same number of channels allocated to C1 and others.

2. different number of channels allocated to C1 and others.

3. fixed traffic for other cells Cj, changing for central cell C1.

Finally, two additional cases are considered separately while keeping the total number of channels in the service area fixed:

1. 33.3% of the available channels, in the service area, allocated to each cell

2. 40% and 30% of fixed channels, in service area, assigned to the central cell and each cell Cj, respectively.

The traffic in the central cell is assumed 20% greater than that in each cell Cj for the two cases assumed above.

7.2 SYSTEM PERFORMANCE-A

7.2.1 Performance of system with 30 fixed channels in service area

The same number of fixed channels is allocated to each cell. As shown in table 7.1, 10 channels are assigned in each cell. the base load in C1 is greater than that in each cell Cj.

Table 7.1

Min. Num. of channels in C1	Min. Num. of of channels in each cell Cj	base load in Erlangs for C1	base load in Erlangs for Cj at 2% Pb
10	10	5.53	5
10	10	6.22	5
10	10	7.00	5

Figures 7.1 to 7.4 represent some typical simulation results that we obtained.

7.2.1.1 Performance in C1

In the case of 10 fixed channels, on the average, per cell we found from the table of the Erlang-B traffic formula what traffic rate in Erlangs was required so as to have a given grade of service; that is:

1. for blocking probabilities of 3%, 5%, and 7.874% the traffic rates are 5.53, 6.22, and 7 Erlangs, respectively, in the central cell.

2. A different traffic rate (5 Erlangs) is assumed and the probability of blocking is 2% on the average per cell Cj.

Fig. 7.1 represents the percentage Pb in C1 only and is computed by simply finding the ratio between blocked calls to the total number of calls initiated in the cell in a given period of time. The X-axis represents the increase in Erlangs. The required traffic load (for a given Pb) is termed as the base load, which was then used as the basis for computing the percentage increase in offered traffic. Having determined the base load, the traffic was increased in all cells with the same percentage. As figure 7.1 indicated, the traffic in C1 is 9.6% greater than the traffic in the remaining cells. This figure also shows that for load increases above base load (5.53 Erlangs) the 8:2 system gives the best results with 2% maximum blocking probability and the maximum traffic is 6.9 Erlangs.

From Fig. 7.2 we find that the channel partition of 5:5 is more efficient for 2% maximum Pb and the maximum traffic is 6.85 Erlangs. This Figure also indicated that the traffic in C1 was 20% greater than the traffic in each of the surrounding cells.

With the assumed traffic in the central cell being 29% higher than the traffic in Cj, Fig. 7.3 shows that for load increases of up to about 10.2 Erlangs the channel pantition 5:5 gives the lowest probability of blocking. Once again, the same channel partition performs better with 2% maximum

Pb and the maximum traffic is 7.52 Erlangs. However, beyond 10.2 Erlangs, the 8:2 system yields the lowest probabilities of blocking.

7.2.1.2 Performance in Cj

Figure 7.4 represents the performance of the different channel divisions used in Cj, with an average of 10 fixed channels per cell. The Y-axis represents the average percentage blocking of the nineteen middle cells Cj (j=2,3,...,20). From the same figure we find that the channel partition 5:5 (in this case the traffic in Cj is 9.6% lesser than that in C1) performs better with 2% maximum Pb and the maximum traffic is 6.15 Erlangs. Beyond 23% (6.15 Erlangs) the 8:2 system performs better.

The same figure shows that for load increases above base load (5 Erlangs) the 8:2 system performs better with 2% maximum Pb and the maximum traffic is 6.3 Erlangs (the traffic in Cj in this case is 20% lesser than that in C1).

Once again, the channel partition 8:2 gives the best performance in the case of 2% Pb and 29% difference of traffic. The maximum traffic obtained is 6.2 Erlangs with 2% maximum Pb.

7.2.2 Interpretations

From our interpretation of the results so far, we found that for traffic increase up to about 23% (6.15 Erlangs) above base load, the system with most fixed channels in C1 performs better (the difference of traffic in this case is 9.6%). Inversely, the system with most dynamic channels performs better in Cj. Beyond 23% increase in traffic, we have found the same situation as with uniform traffic: the system with minimum dynamic channels performs better in C1 and Cj.

If the difference of traffic is 20%, the 5:5 system in C1 gives the lowest probabilities of blocking to about 7.8 Erlangs above base load (6.22 Erlangs). However, the 8:2 system in the surrounding cells outperforms the other channel partition 5:5.

On the other hand, the 5:5 system performs best in C1 when the load increases to 10.2 Erlangs (the traffic in C1 is 29% greater than that in each cell Cj). Beyond 10.2 Erlangs, the 8:2 system performs the best. Inversely, with the same difference in traffic, the system with most dynamic channels in Cj gives the lowest probabilities of blocking for load increases to about 5.4 Erlangs. Beyond 5.4 Erlangs, it is found that the 8:2 system gives the best performance.

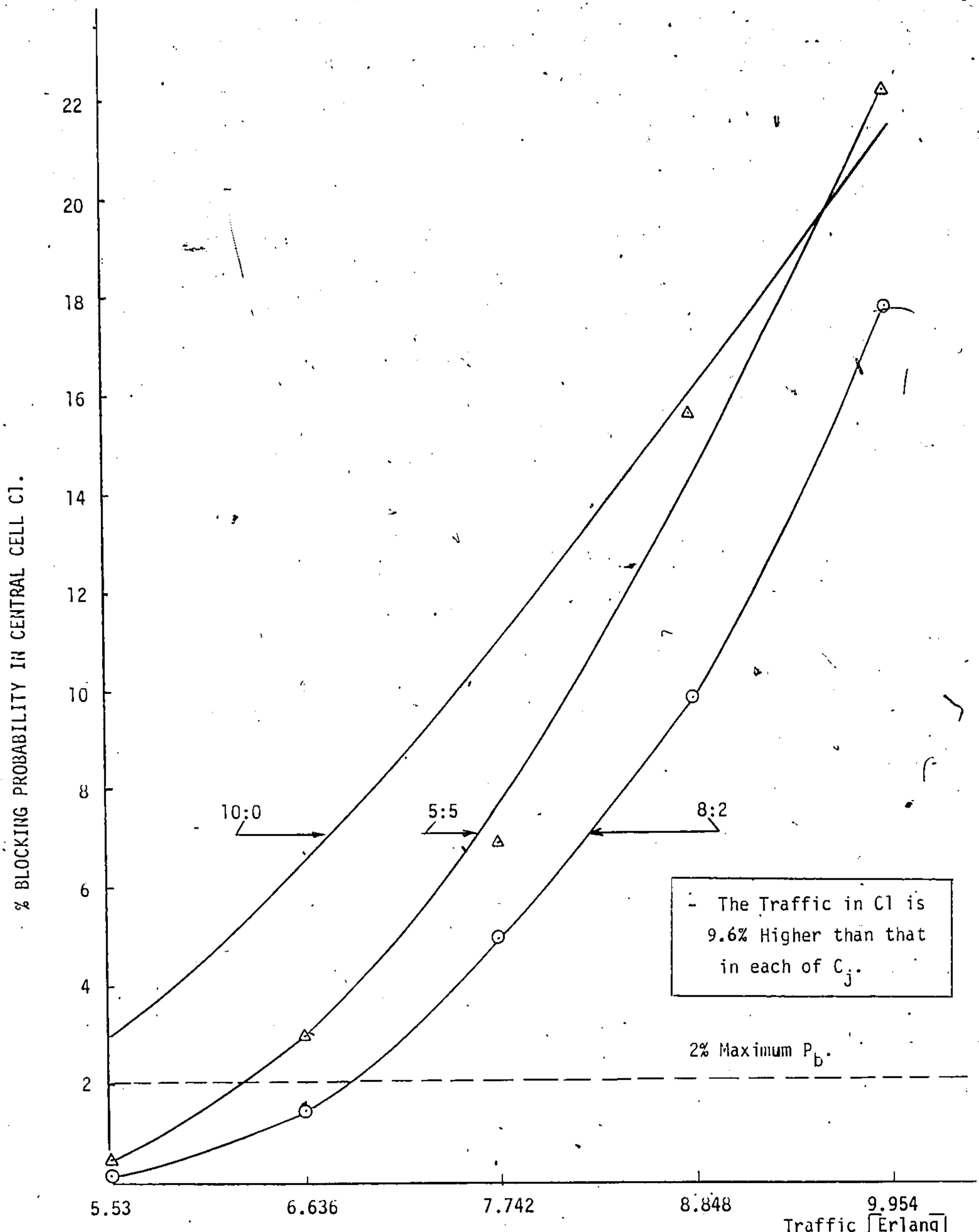


Fig. 7.1— Performance of System with initially 10 Fixed Channels in Central Cell C1.

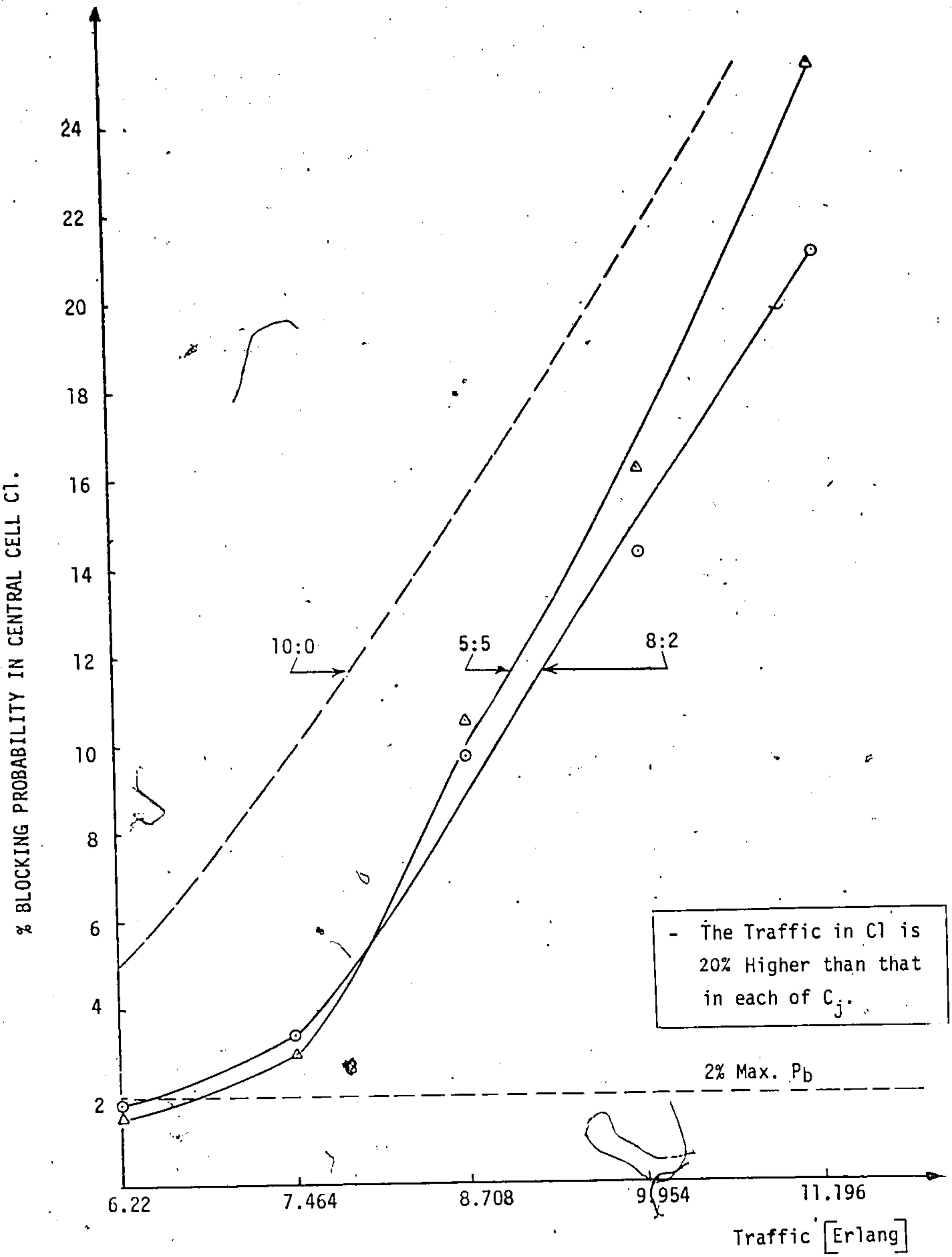


Fig. 7.2- Performance of System with initially 10 Fixed Channels in Cl.

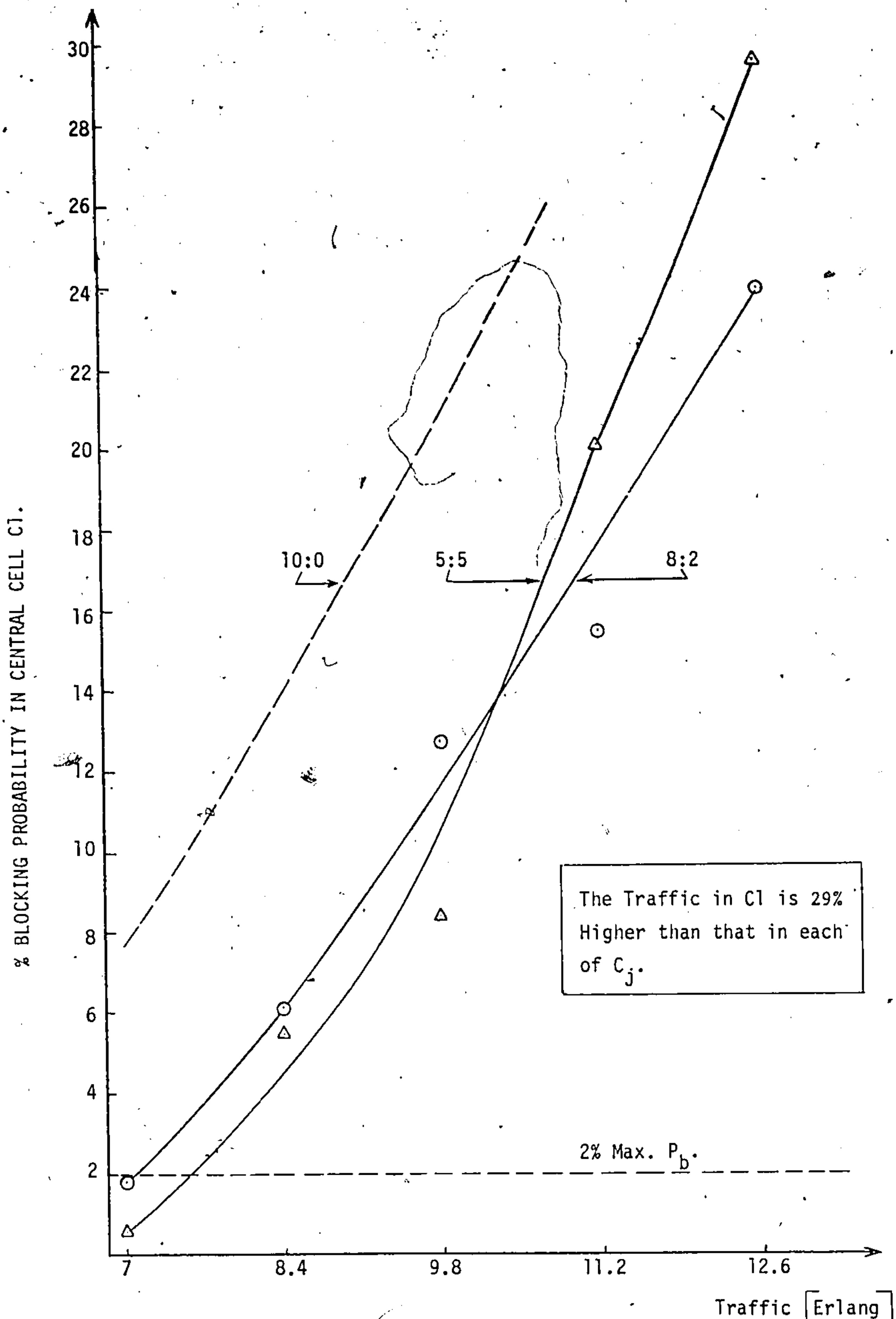


Fig. 7.3 – Performance of System with initially 10 Fixed Channels in Cl.

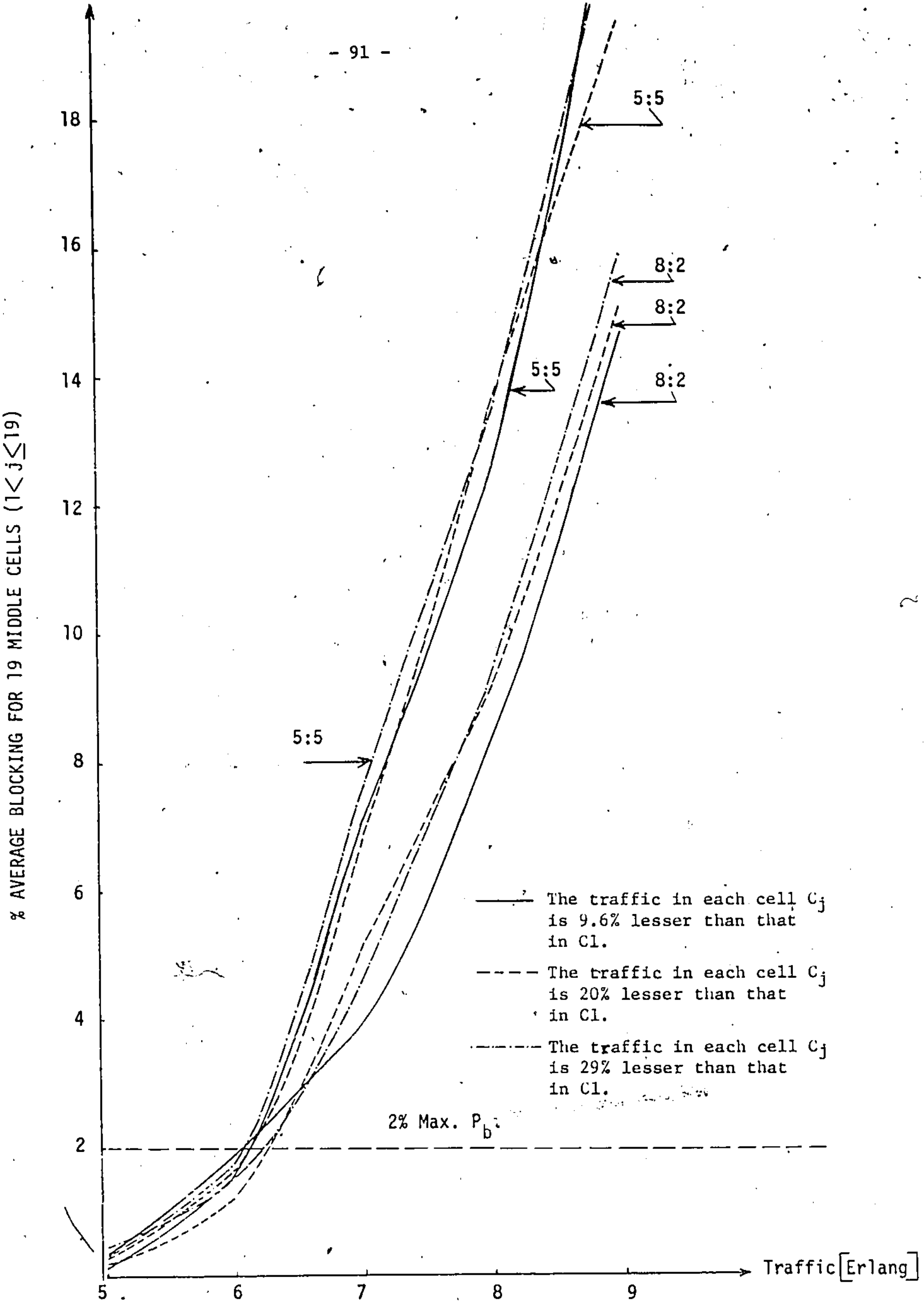


Fig. 7.4-Performance of System with initially 10 Fixed Channels per each of C_j ($1 < j < 40$).

7.3 SYSTEM PERFORMANCE-B

The interpretation given in this section is similar to the first section. The table 7.2 summarizes the different system configurations simulated.

1. The first two rows represent a simulated system with the same number of channels per cell.

2. The remaining rows represent different system configurations simulated. The central cell has a list of nominal channels which is greater than the number of channels in each cell Cj. The investigations which have been carried out, assume a base load of (X Erlangs) to achieve blocking probability of 2% in every cell in the service area.

TABLE 7.2

DIFFERENT SYSTEM CONFIGURATIONS SIMULATED

Average number of Channels in Cell Cl and Fixed Channels assignment	Average number of Channels per each set of C_j and Fixed Channel assignment	Channel partition for Cl.	Channel partition for C_j.	Traffic loadings in Erlang used for Cl.	Traffic loadings in Erlang used for C_j.
30	30	30:0 28:2 22:8	30:0 28:2 22:8	21.9*, 24.09, 26.28, 30.66, 35.04, 39.42, 43.8	23.1*, 23.1, 23.1, 23.1, 23.1, 23.1, 23.1
30	30	30:0 28:2 22:8	30:0 28:2 22:8	24*, 26.4, 31.2, 36, 40.8	21.9*, 24.09, 28.47, 32.85, 37.23.
20	10	20:0 16:4 12:8	10:0 8:2 6:4	13.2*, 17.16, 21.12, 23.76, 26.4, 29.04	5.08*, 5.08, 5.08, 5.08, 5.08, 5.08
20	10	20:0 16:4 12:8	10:0 8:2 6:4	13.12*, 17.16, 21.12, 23.76, 26.4, 29.04	5.08*, 6.6, 8.13, 9.14, 10.2, 11.18
30	20	30:0 28:2 22:8 18:12 28:2	20:0 20:0 16:4 12:8 16:4	21.9*, 28.47, 35.04, 39.42, 43.8	13.2*, 17.16, 21.12, 23.76, 26.4.
34	18	34:0 30:4 26:8 22:12	18:0 16:2 14:4 12:6	25.5*, 28.05, 33.15, 38.25, 43.35, 48.45.	11.5*, 12.6, 14.95, 17.25, 19.5, 21.85

* BASE LOAD.

7.4 PERFORMANCE OF SYSTEM WITH 30 FIXED CHANNELS PER CELL

Fig. 7.5 presents the simulation results for the system with an initial allotment of 30 fixed channels per cell, that is:

1. the central cell is assumed to have a variable traffic load with a base load 21.9 Erlangs to achieve Pb (0.02)

2. A fixed traffic rate of 23.1 Erlangs is assumed for Cj to achieve Pb (0.03)

7.4.1 Performance in C1

From Fig. 7.5 we notice that for load increases up to about 100% (43.8 Erlangs) above base load (21.9 Erlangs) in C1, the 22:8 system with most dynamic channels performs the best.

7.4.2 Performance in Cj

From the simulation results obtained, the average percentage blocking in each cell Cj is 1.6% for the 28:2 system. This percentage starts to increase at high loading rate (> 100% of traffic above base load [21.9 Erlangs] in central cell). The percentage blocking for 22:8 system is 1.348%. This percentage starts to increase in each cell Cj as the load increases beyond 60% above base load in C1 as shown in Figure 7.6.

Efficient channel reuse is achieved in these dynamic channels reassignment systems by switching calls initially assigned dynamic channels to fixed channels as soon as possible. The channel efficiency of the fixed channels is increased considerably because of the switching of calls from dynamic channels into them. For C1, Systems with most dynamic channels efficiently handle the random fluctuations in offered traffic as the load in C1 is increased to about 60% above base load (21.9 Erlang). Beyond 60% load increase, systems with most fixed channels performed best.

Figs. 7.7 and 7.8 represent other simulation results of the system with initially 30 fixed channels per cell, that is:

1. the C1 is assumed to have a variable traffic with a load of 24 Erlangs to achieve Pb (0.04)

2. a variable traffic rate of 21.9 Erlangs is assumed for Cj to achieve Pb (0.02).

3. the traffic in C1 is 8.75% higher than that in each Cj.

7.4.3 Performance in C1

From Fig. 7.7 we can obtain that for load increases up to about 26.3 Erlangs the 22:8 system, with most dynamic channels, performs better and the maximum traffic for 2% maximum Pb is 25.2 Erlangs. On the other hand, the 28:2 system gives the best results for load increases from about 26.3 Erlangs to 34.8 Erlangs. Beyond 36 Erlangs, it is found that 30:0 gives the lowest probabilities of blocking.

7.4.4 Performance in Cj

Fig. 7.8 shows that with load increasing in Cj up to 23.5 Erlangs the average number of blocked calls is the lowest for the (22:8) system having 24 dynamic channels. Once the traffic is increased beyond that point up to about 35.4 Erlangs, the system with, on the average, 28 fixed channels and 2 dynamic channels per channel set starts to bring forth the smallest average number of blocked calls. Beyond about 35.4 Erlangs, it is found that the Fixed Channel Assignment Scheme reign over all its competitors.

7:5 PERFORMANCE OF SYSTEM WITH 20 CHANNELS IN C1 AND 10 CHANNELS IN EACH OF Cj

The performance of the different channel divisions used, with on the average 20 fixed channels assigned to C1 only and 10 fixed channels assigned to each cell Cj, are represented in Figures 7.9, 7.10 and 7.11. The first figure refers to different conditions:

7.5.1 Variable traffic in C1 and Fixed in Cj

7.5.1.1 Performance in C1

From Fig. 7.9 we observe that at low traffic loadings up to a 120% (29.04 Erlangs) traffic increase above base load (13.2 Erlangs), the system with 16 dynamic channels in the system pool (12:8, 6:4, 6:4) gives the lowest probability of blocking.

7.5.1.2 Performance in Cj

In addition we found from the simulation results that Pb in the surrounding cells increases as the traffic in C1 is increasing. Hence, Pb increases from 0.0% at base load (13.2 Erlangs in C1) to 1.15% as the traffic increases in C1 for the system with 8 dynamic channels (16:4, 8:2). The Pb is increased from 0.057% at base load to 1.75% at higher load for the (12:8, 6:4) system with most dynamic channels as shown in Figure 7.10. These average probabilities are computed from the nineteen middle cells only.

7.5.2 variable traffic in C1 and Cj

7.5.2.1 Performance in C1

The simulation results show that for load increases to 42% (18.74 Erlangs) above base load (13.2 Erlangs) the two plots shown in Figure 7.10 with different channel divisions (16:4, 8:2) and (12:8, 6:4) are extremly close and give approximately the same Pb . On the other hand the (12:8, 6:4) system performs better for load increases from 42% to about 75% (23.1 Erlangs) above base load. Again, beyond 75% increase in traffic the (16:4, 8:2) yields the best. The fixed system (20:0, 10:0) would have given the lowest Pb at maximum load.

7.5.2.2 Performance in Cj

Fig. 7.11 represents the performance of the system with initially 10 fixed channels allocated to each set of Cj. From this figure we find that for load increases to 15% (5.84 Erlangs) above base load (5.08 Erlangs) the plot of (8:2, 16:4) system is very close to the other plot of (6:4, 12:8) system. Whereas beyond 15% to about 85% (9.4 Erlangs) above base load the (6:4, 12:8) system performs better. Again, the (8:2, 16:4) system starts to give better results beyond 85% increase in traffic.

7.6. PERFORMANCE OF SYSTEM WITH 30 CHANNELS IN C1 AND 20 CHANNELS IN EACH OF CJ

7.6.1 Performance in C1

The plots in Fig. 7.12 show directly the relationship between the traffic offered to the hexagonal cells and the blocking rate in C1. The parameters of different channel divisions are indicated on each plot in Fig. 7.10. This Figure shows that for less than 2% (22.3 Erlangs) load increases above base load (21.9 Erlangs), the channel partition (18:12, 12:8) gives the lowest probability of blocking. Beyond 2% the (28:2, 16:4) outperforms the others with 2% maximum blocking.

7.6.2 Performance in Cj

Figure 7.13 represents the percentage blocking in the middle nineteen cells. From this figure we found that for load increases to about 55% (20.5 Erlangs) above base load (13.2 Erlangs) the channel partition (22:8 ,16:4) gives the lowest probability of blocking. As the load is increased from 55% to about 100% (26.4 Erlangs) the (28:2, 20:0) system performs better.

7.7 PERFORMANCE OF SYSTEM WITH 34 CHANNELS IN C1 AND 18 CHANNELS IN EACH OF CJ

The simulated results of 34 channels in C1 and 18 channels in each cell Cj are shown in Figs. 7.14 and 7.15 respectively.

7.7.1 Performance in C1

In Figure 7.14 we find that for load increases of up to about 10% (28 Erlangs) above base load (25.5 Erlangs) the curves (except 34:0,18:0) for different channel partition are extremely close. When the load is increased beyond 10% to about 65% (42 Erlangs) the (26:8, 14:4) system yields better results. For load increases beyond 65% above base load the fixed system outperforms all other channel partition.

7.7.2 Performance in Cj

The performance of the different channel divisions used, with on the average of 18 fixed channels per cell Cj, is presented in Fig. 7.15. This Figure shows that for load increases up to about 30% (15 Erlangs) above base load (11.5 Erlangs) the (12:6, 22:12) system performs better. Beyond 85% (21.2 Erlangs) load increases the (16:2,30:4) system gives the lowest blocking probability.

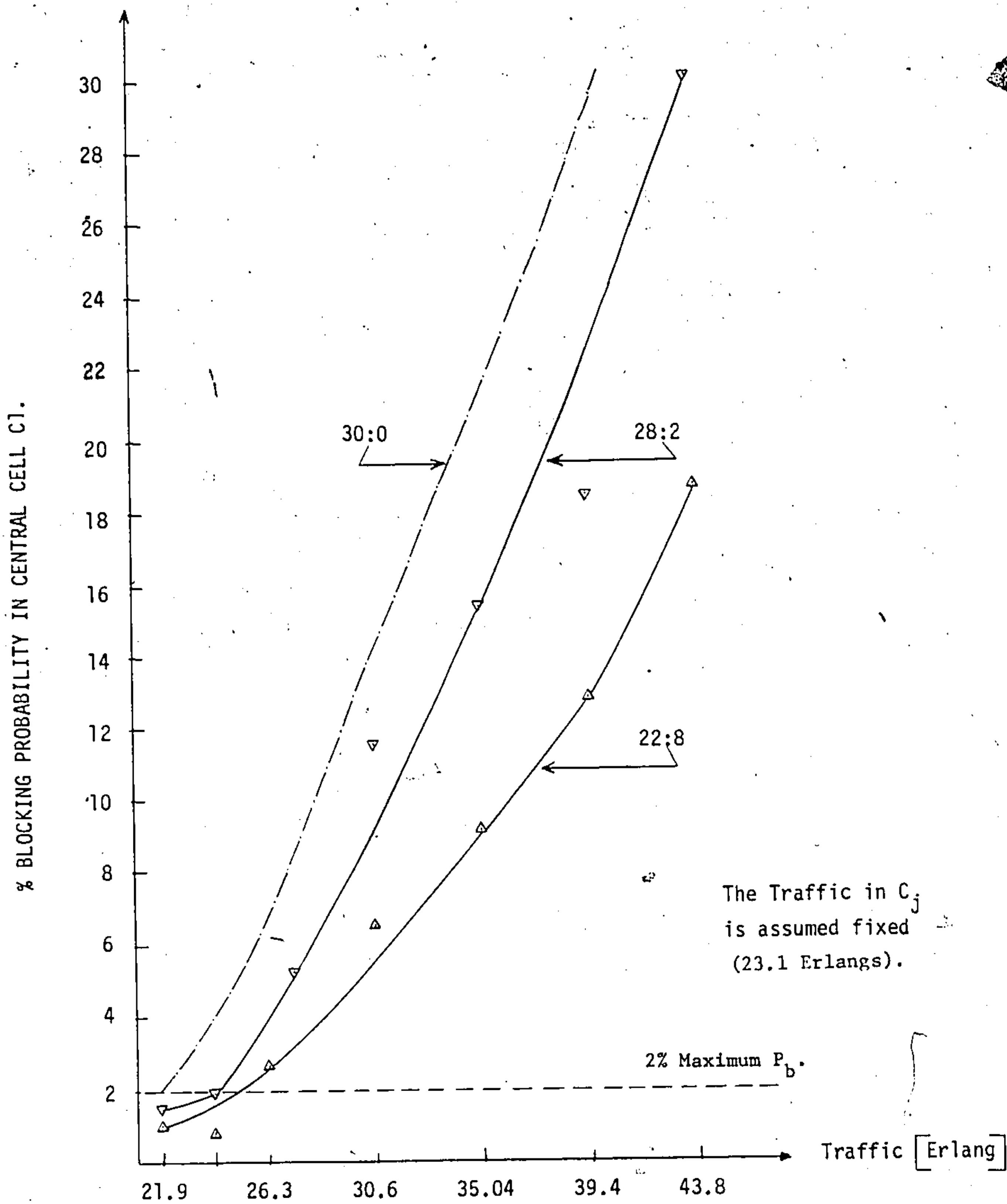


Fig. 7.5 - Performance of System with initially 30 Fixed Channels per Cell.

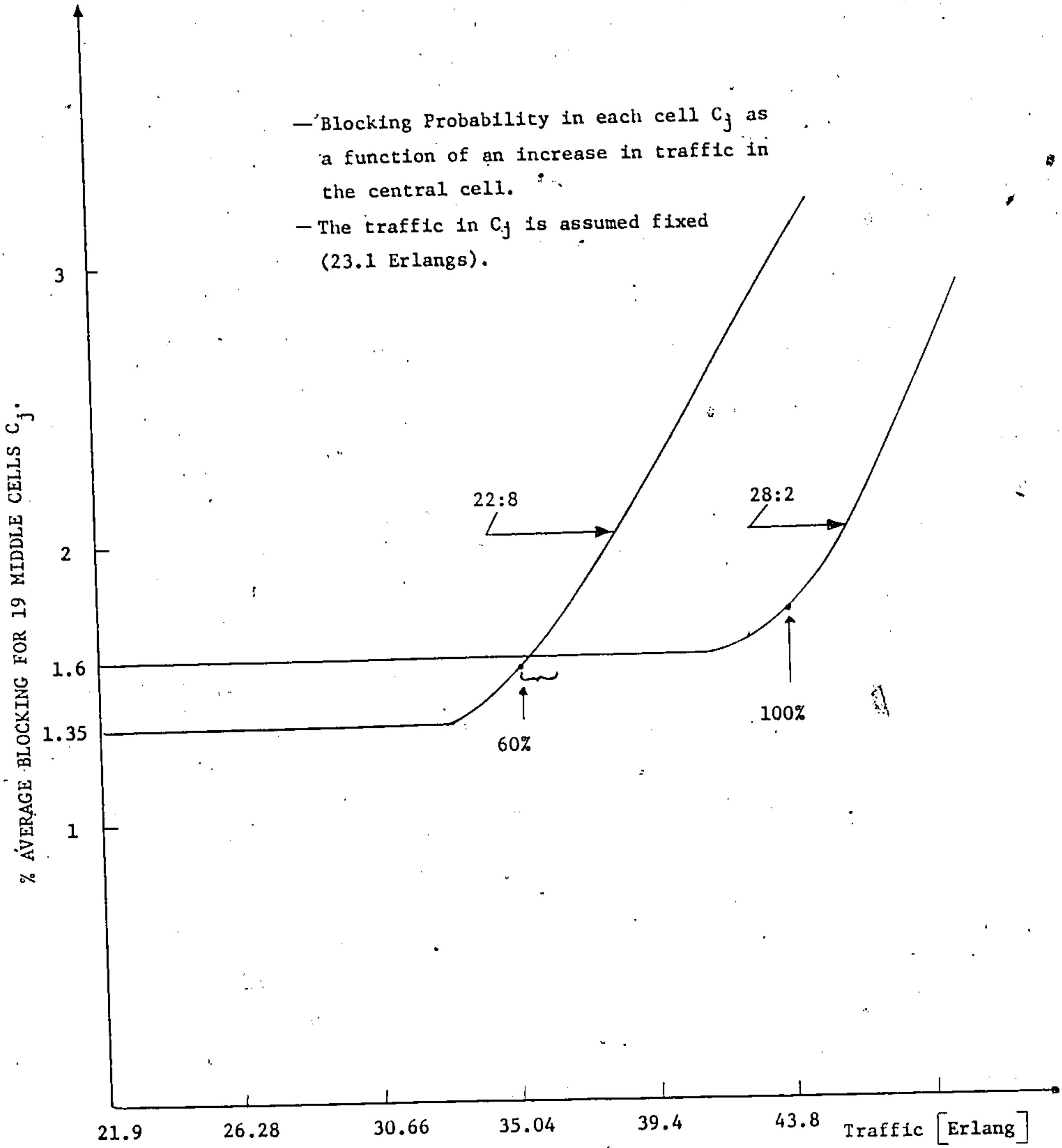


Fig. 7.6 - Blocking Probability for hybrid systems in the surrounding cells C_j. The traffic in C_j is assumed fixed.

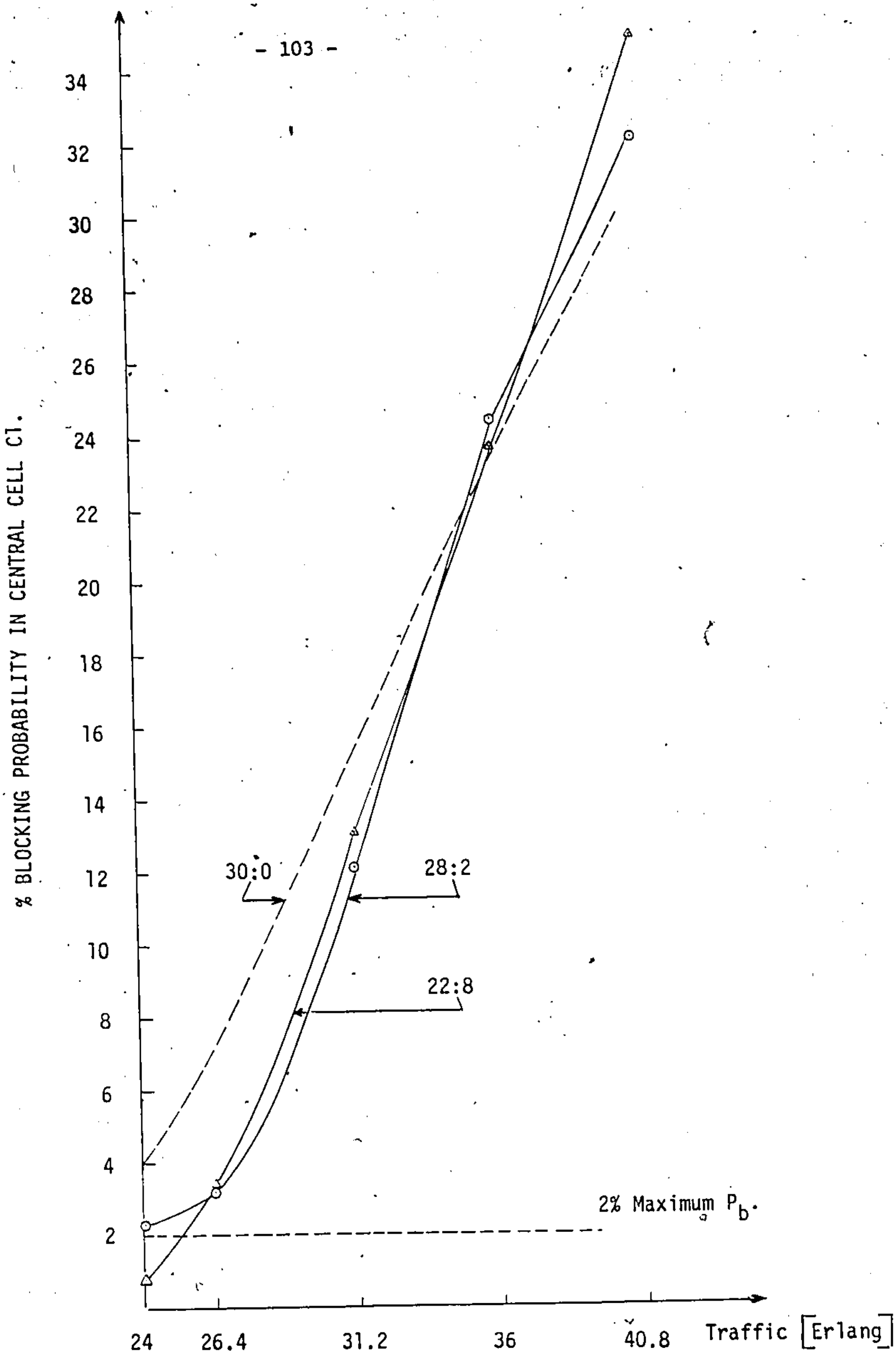


Fig. 7.7 — Performance of System with initially 30 Fixed Channels per Cell.

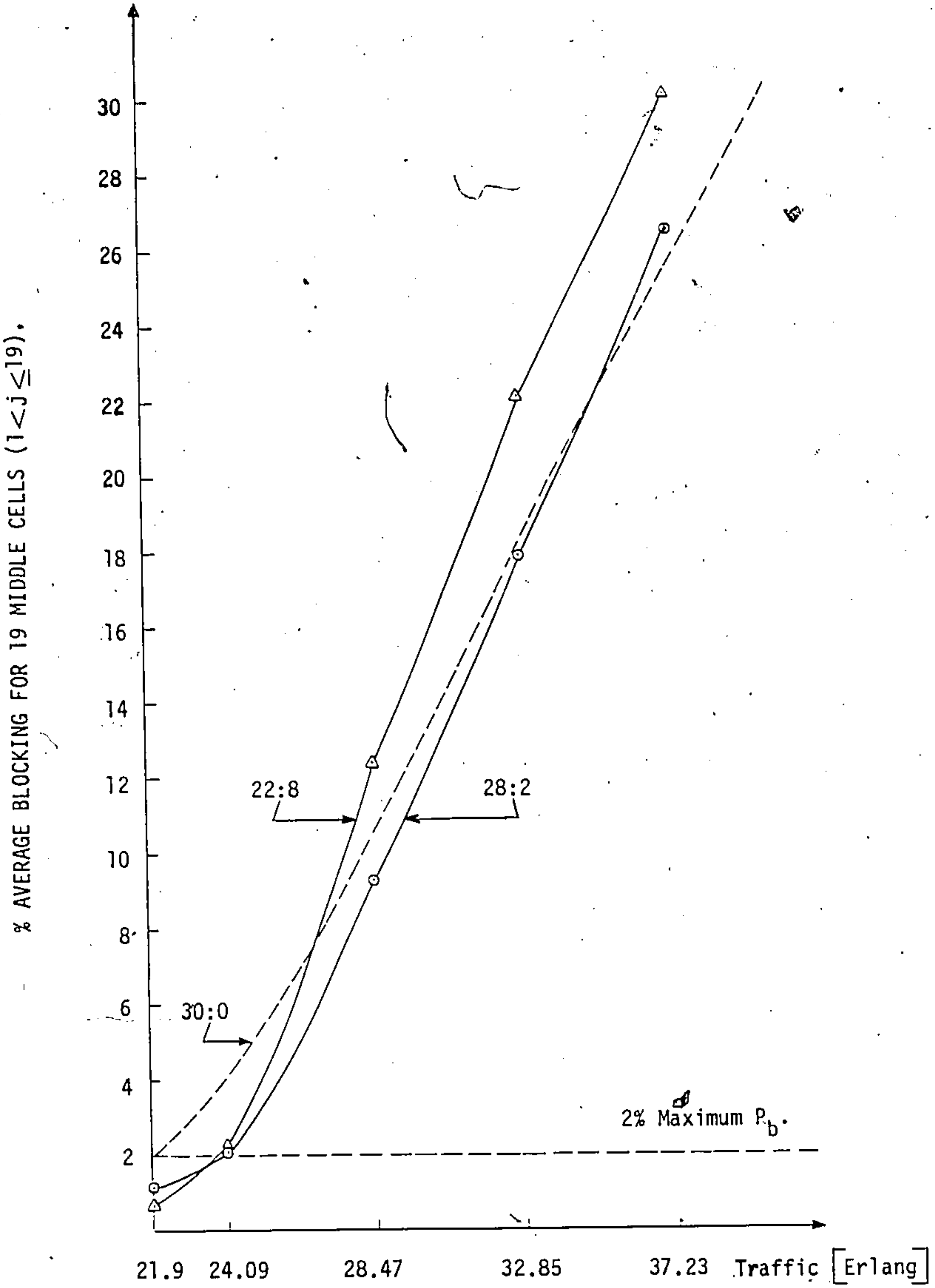


Fig. 7.8 — Performance of System with initially 30 Fixed Channels per each Cell of C_j.

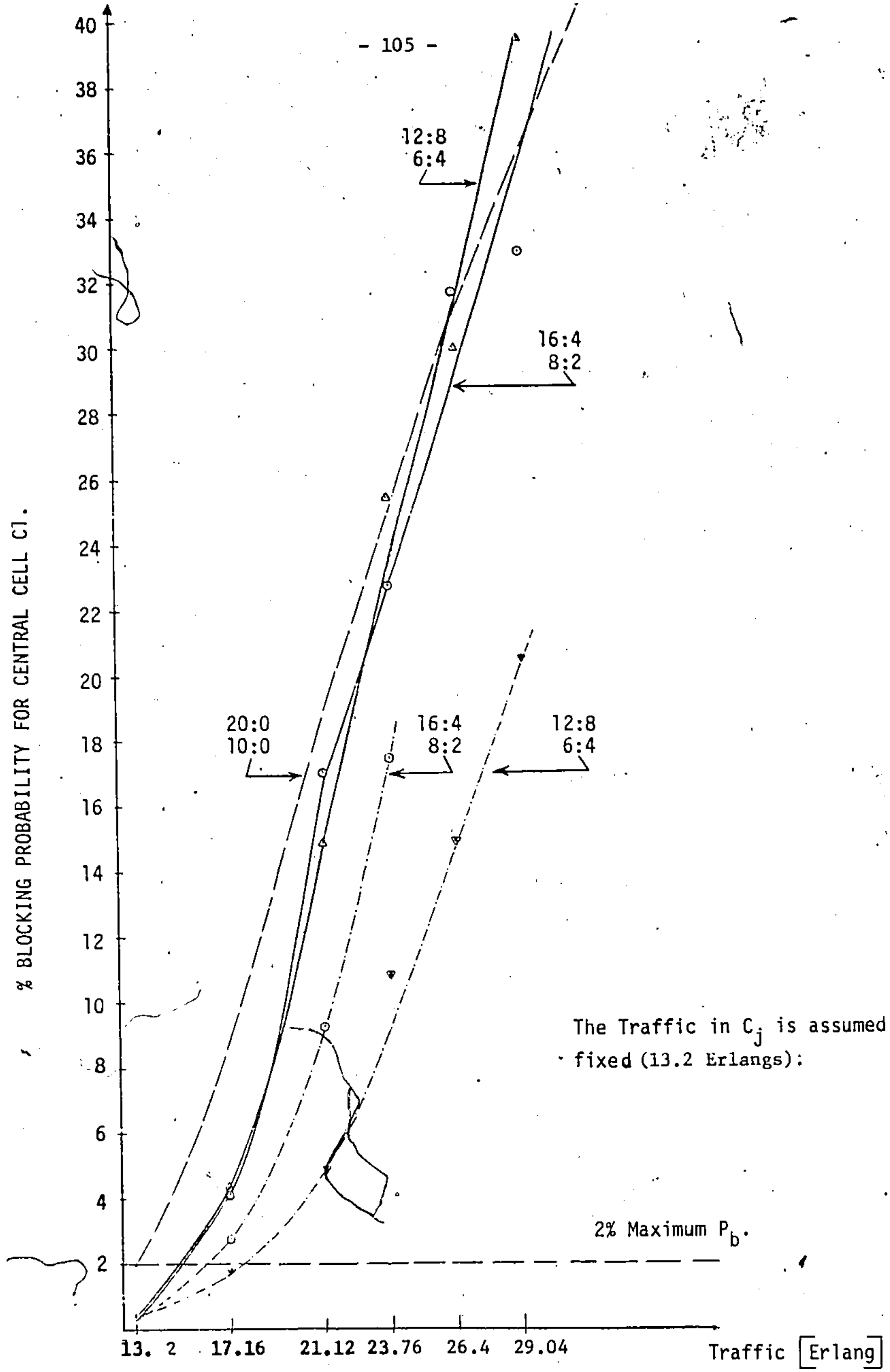


Fig. 7.9 — Performance of System with initially 20 Fixed Channels in C1 and 10 Fixed Chennels per each Cell of C_j.

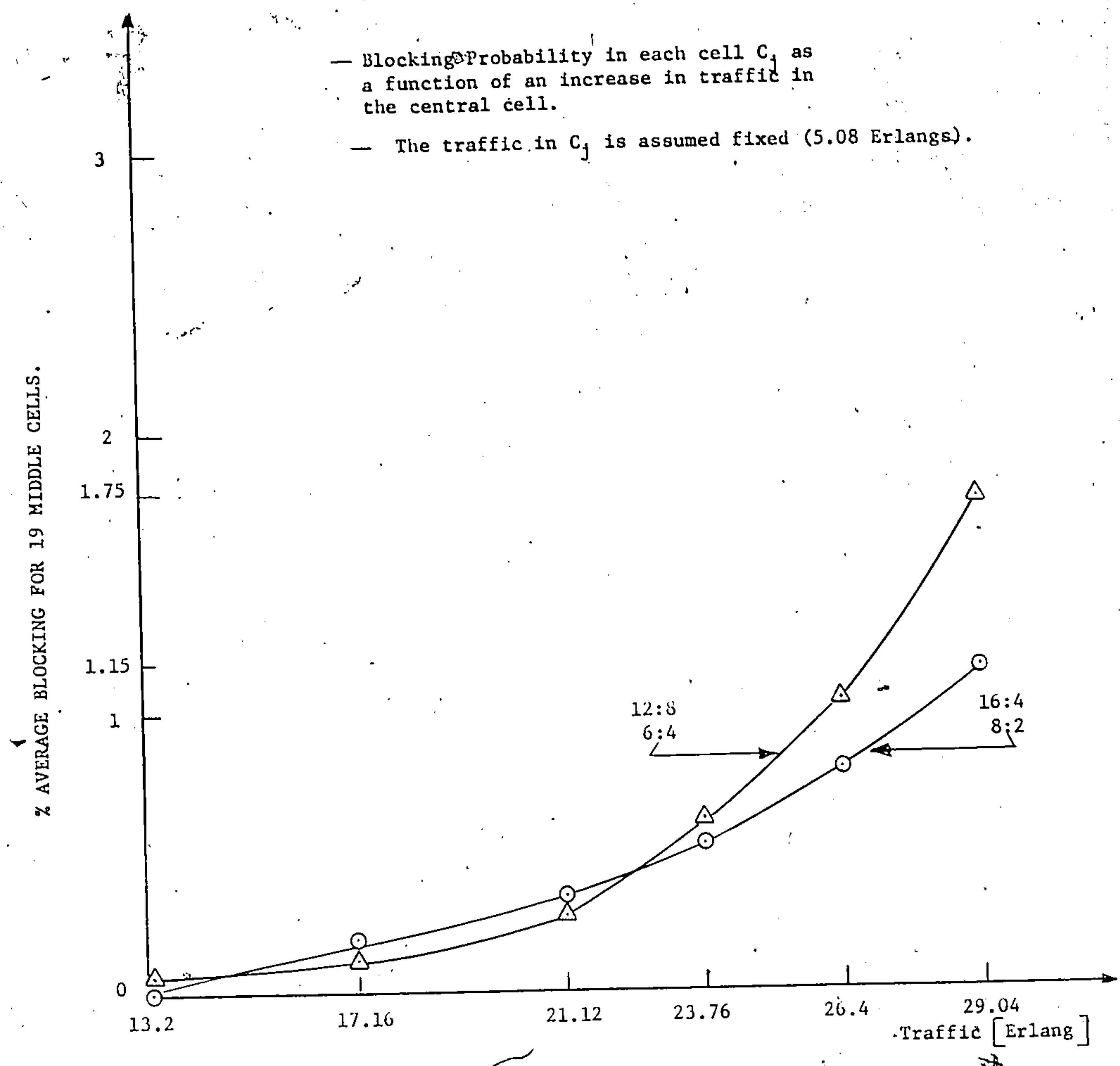


Fig. 7.10 - Blocking Probability for hybrid systems in the surrounding cells C_j. The traffic in C_j is assumed fixed.

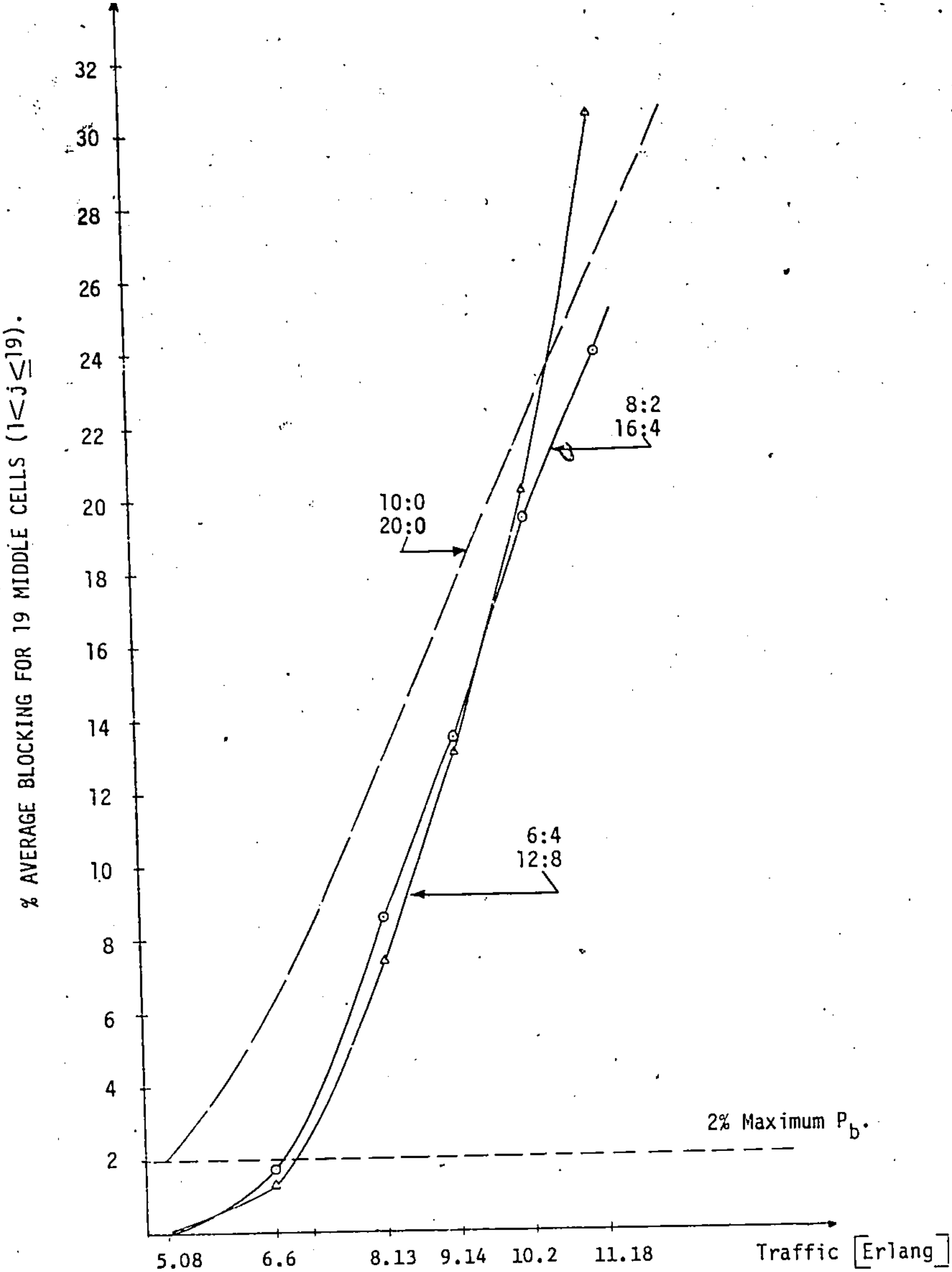


Fig. 7.11 – Performance of System with initially 10 Fixed Channels per each Cell of C_j and 20 Fixed Channels in C1.

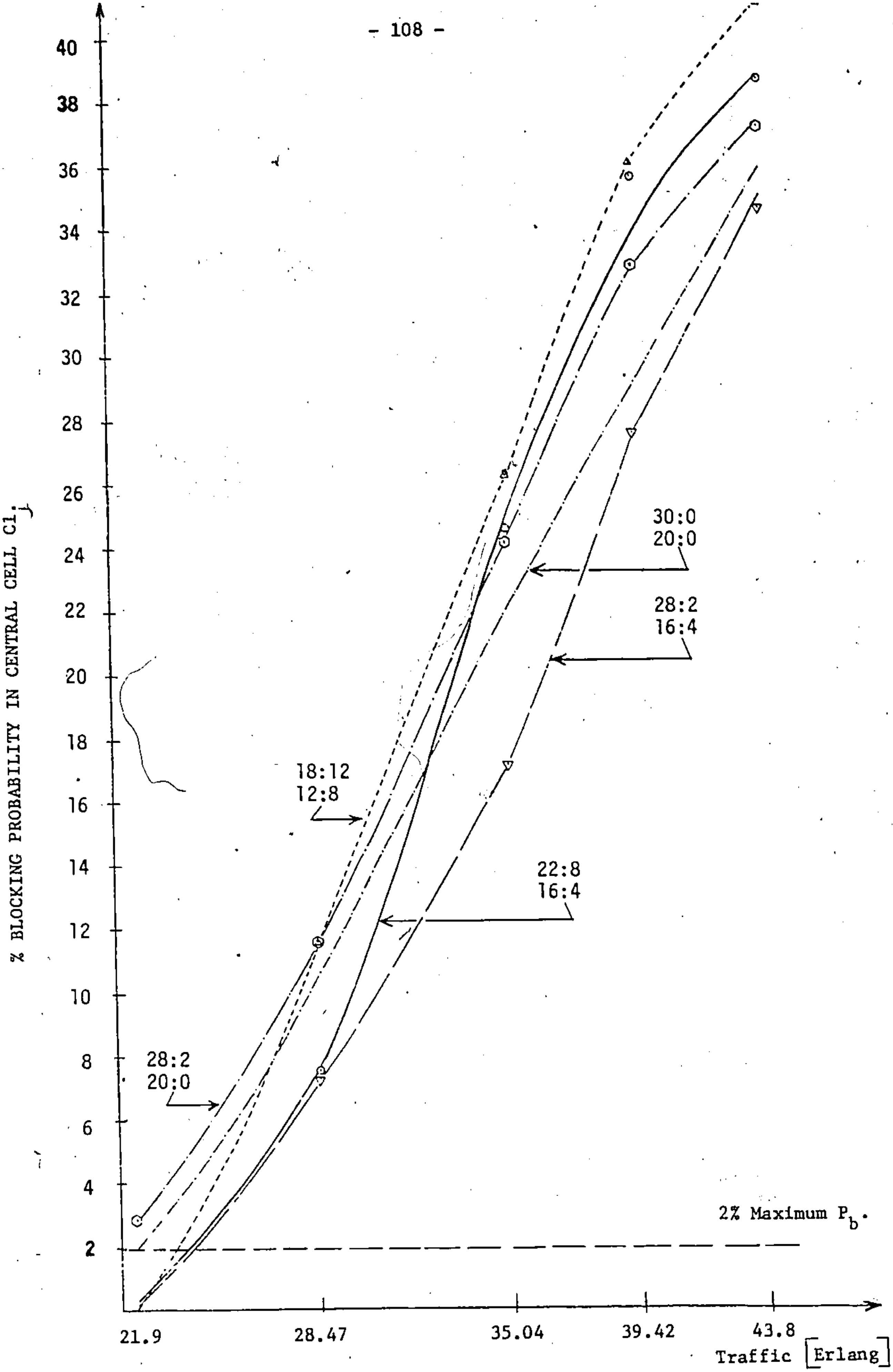


Fig. 7.12 — Performance of System with initially 30 Fixed Channels in C1 and 20 Fixed Channels per each Cell of C_j.

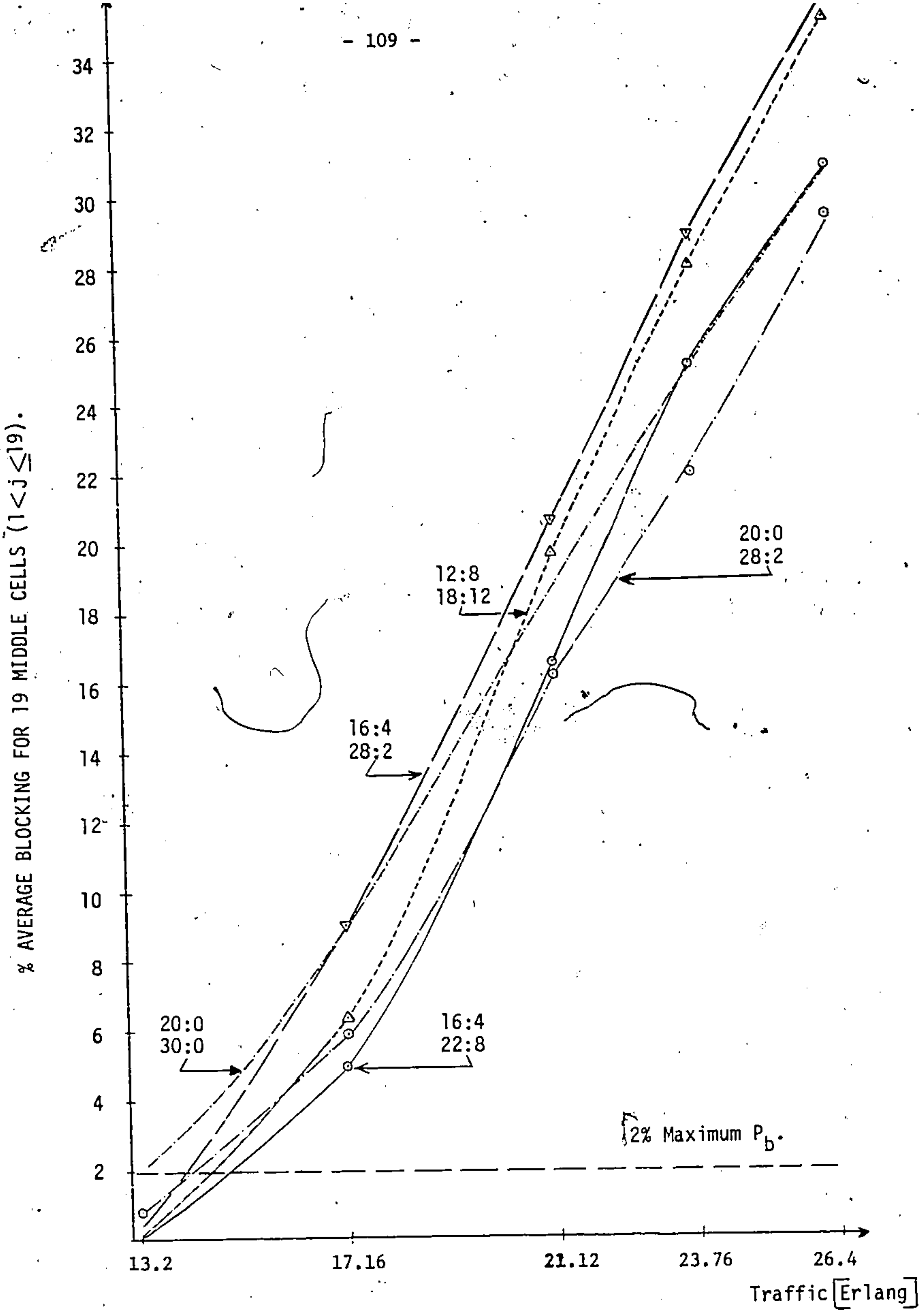


Fig. 7.13 – Performance of System with initially 20 Fixed Channels per each Cell of C_j and 30 Fixed Channels in Cl.

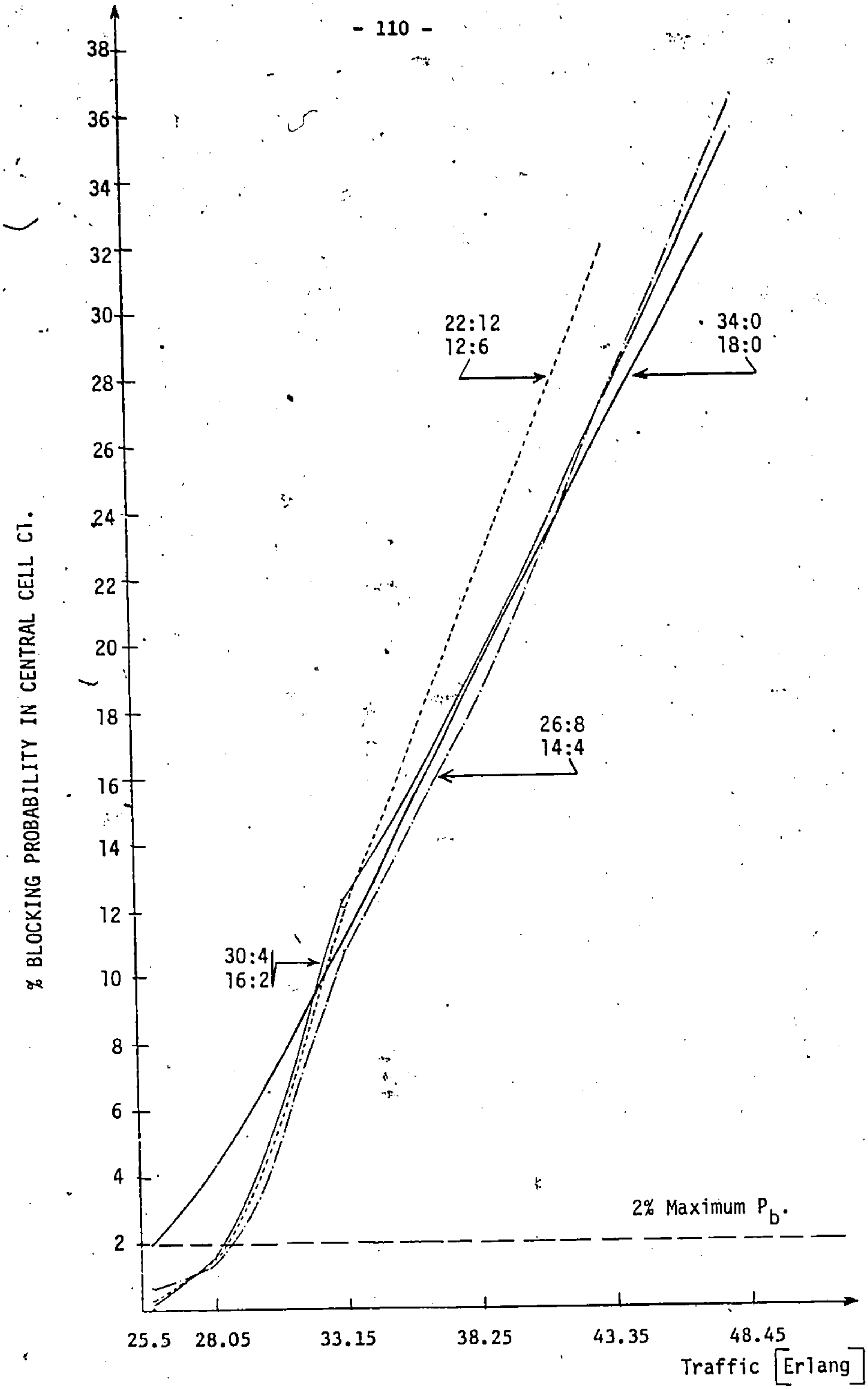


Fig. 7.14 – Performance of System with initially 34 Fixed Channels in C1 and 18 Fixed Channels per each Cell of C_j.

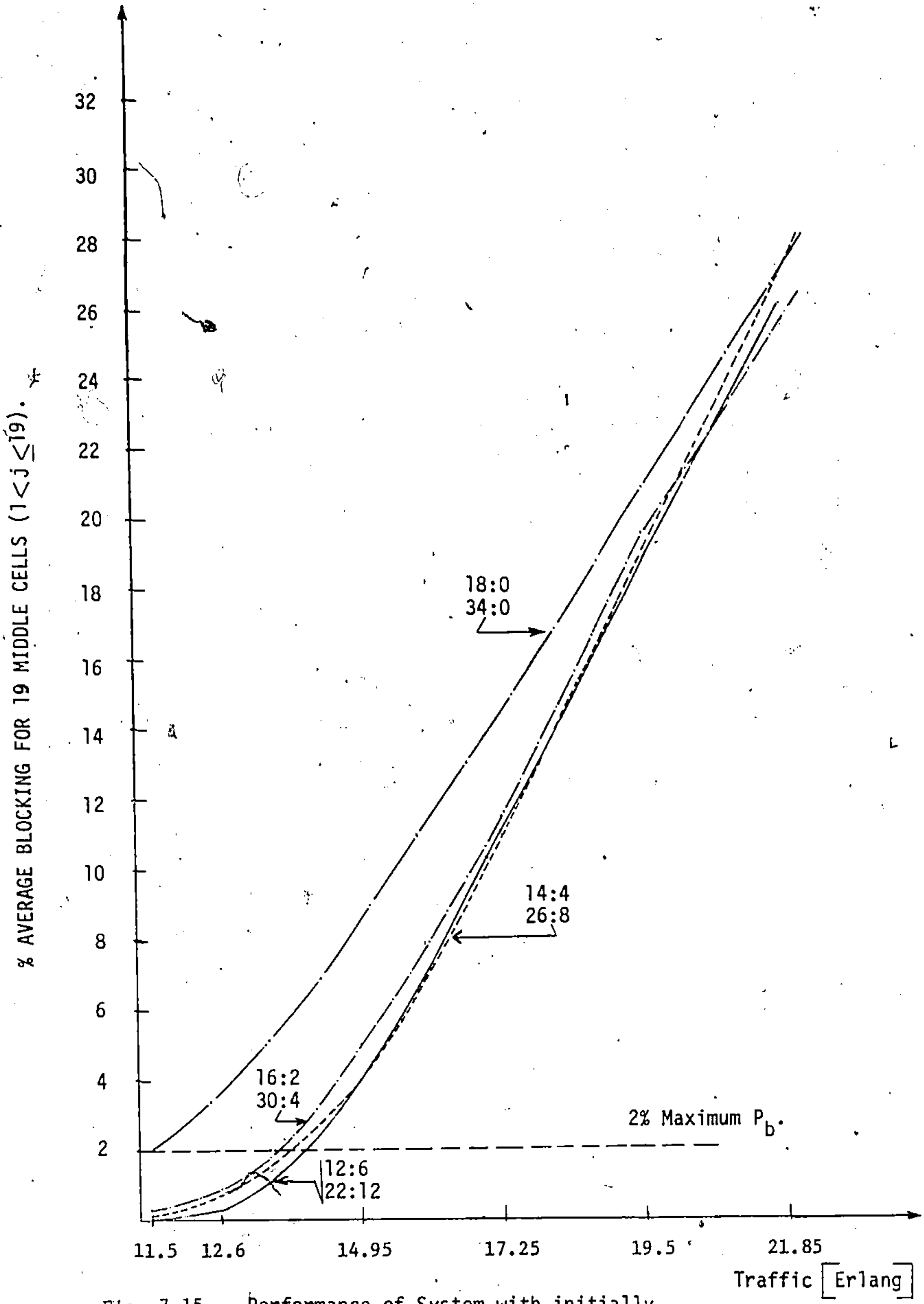


Fig. 7.15 — Performance of System with initially 18 Fixed Channels per each Cell of C_j and 34 Fixed Channels in C1.

7.8 SPECTRAL EFFICIENCY, HYBRID VS FIXED WITH THE SAME NUMBER OF CHANNELS IN EACH CELL.

The spectral efficiency is computed by simply finding the ratio between the net saving of channels, for hybrid systems as compared to the fixed systems, to the total number of channels in each cell.

TABLE 7.3

Number of channels in service area	Number of channels in C1	% of channels in C1	Number of channels in each Cj	% of channels in each Cj.
30	10	33.3%	10	33.3%
45	15	33.3%	15	33.3%
54	18	33.3%	18	33.3%
63	21	33.3%	21	33.3%
75	25	33.3%	25	33.3%
84	28	33.3%	28	33.3%
96	32	33.3%	32	33.3%
105	35	33.3%	35	33.3%

The table above shows different systems simulated in the service area and arranged to completely operate against a non-uniform spatial distribution of offered traffic. The traffic in C1 is 20% higher than that in each cell Cj.

The first column represents the number of channels in the service area. The same channels are divided into three channel sets. Hence, the percentage of channels in each cell is 33.3%. Consequently Pb in C1 is greater than Pb in each cell Cj.

7.8.1 Spectral efficiency: Hybrid vs Fixed in central cell.

In Figures 7.16 to 7.20, the Y-axis represents the percentage blocking in the central cell C1. The X-axis represents the increase in loading in Erlangs.

The simulated results for the Fixed Channels Assignment Schemes are plotted in Figure 7.20. As is mentionned above, 33.3% of fixed channels are assigned to each cell with 20% difference of traffic.

The results presented above give performance of the various system configurations simulated with respect to the maximum blocking 2%.

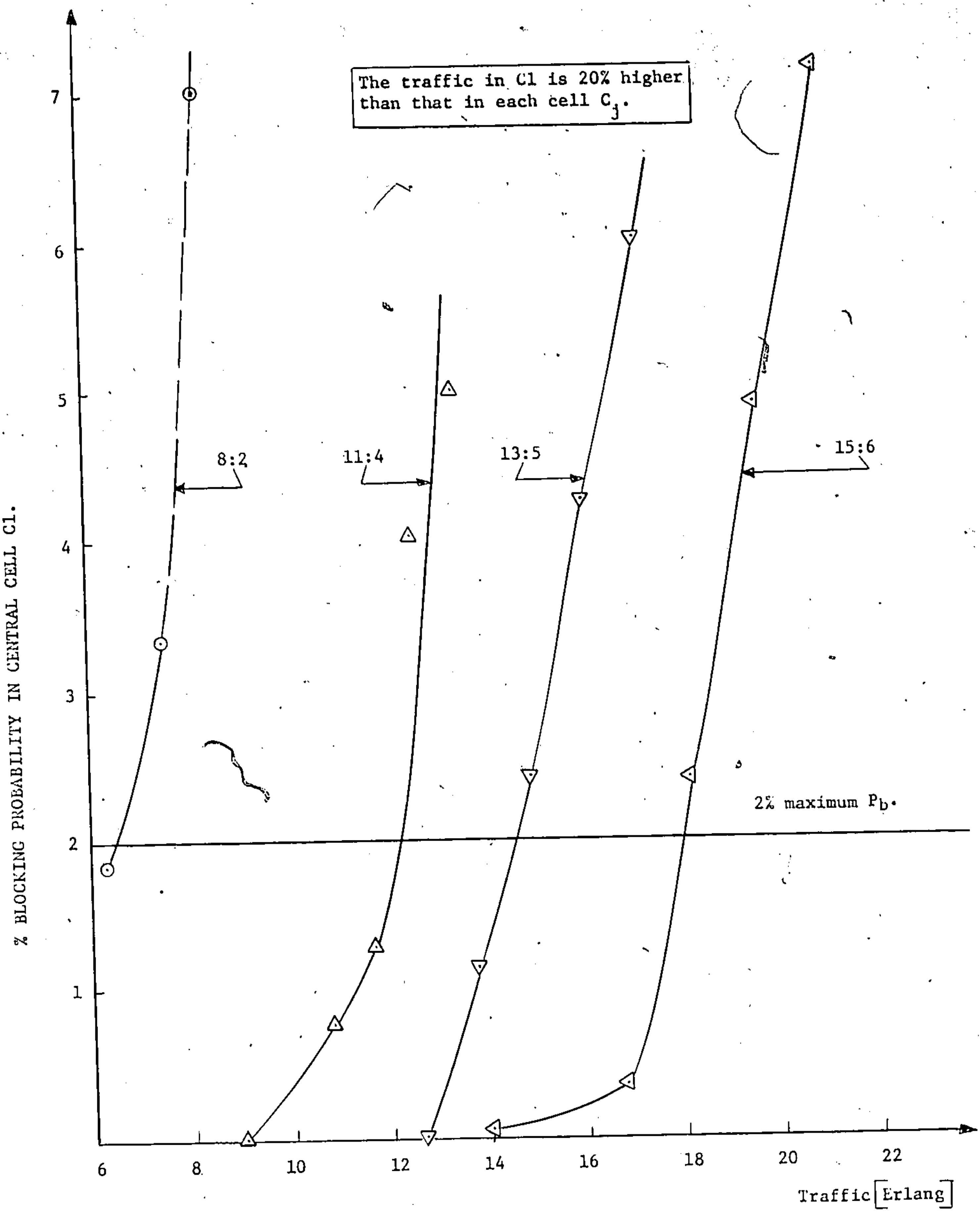


Fig. 7.16 — Blocking Probability for Hybrid Systems with 10, 15, 18, and 21 channels in central cell.

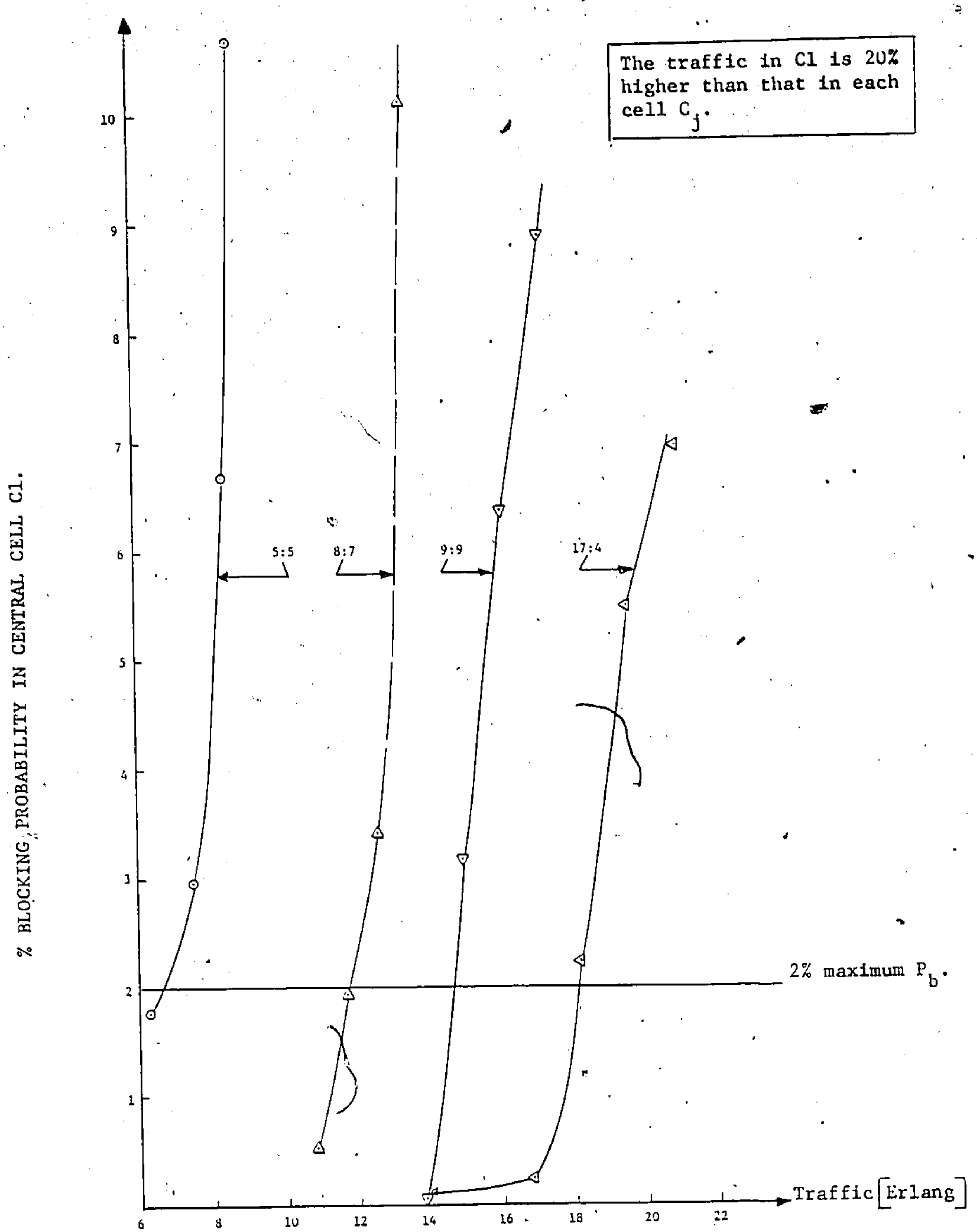


Fig. 7.17 — Blocking Probability for Hybrid Systems with 10, 15, 18, and 21 channels in central cell.

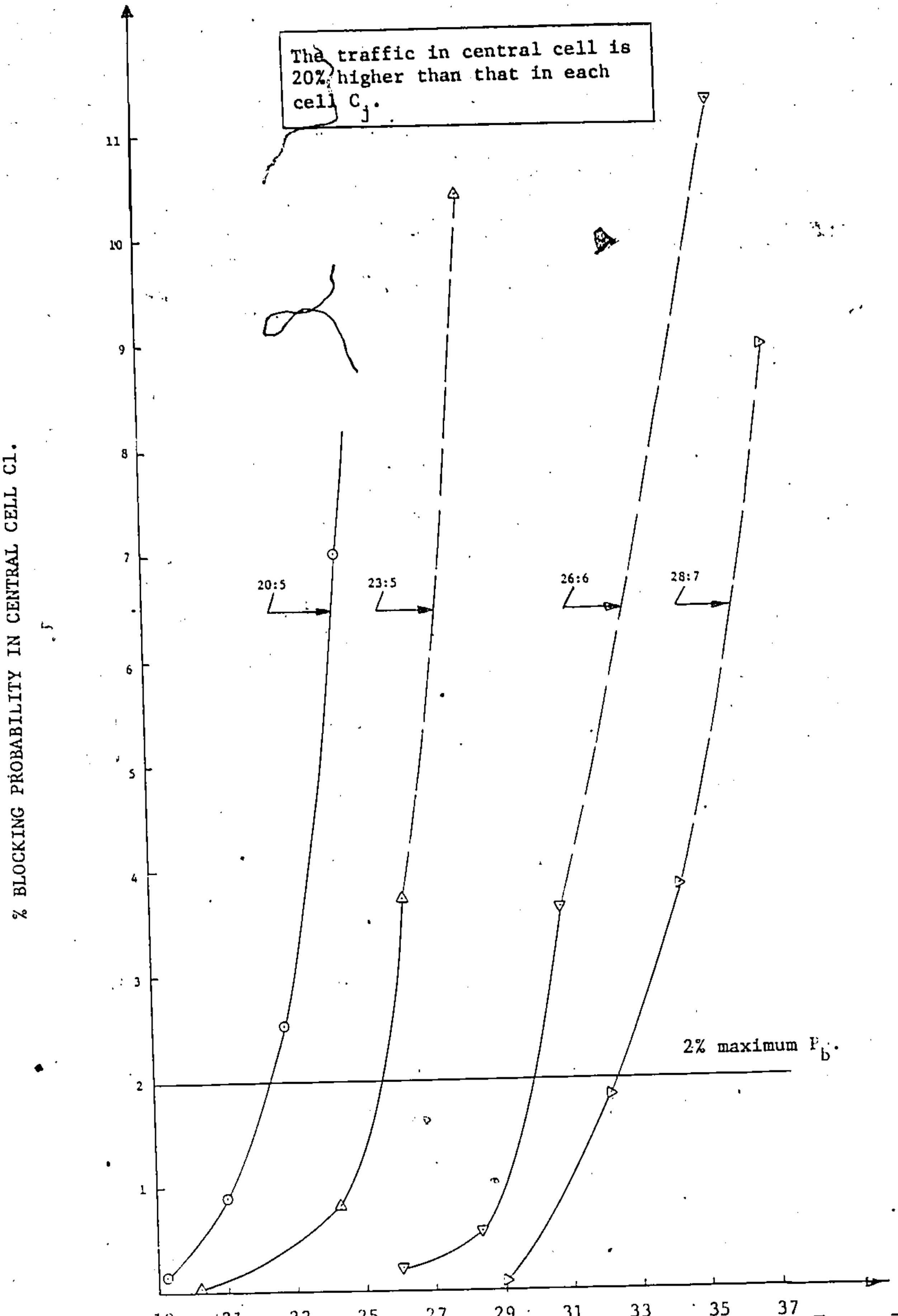


Fig. 7.18 — Blocking Probability for Hybrid Systems with 25, 28, 32 and 35 channels in central cell.

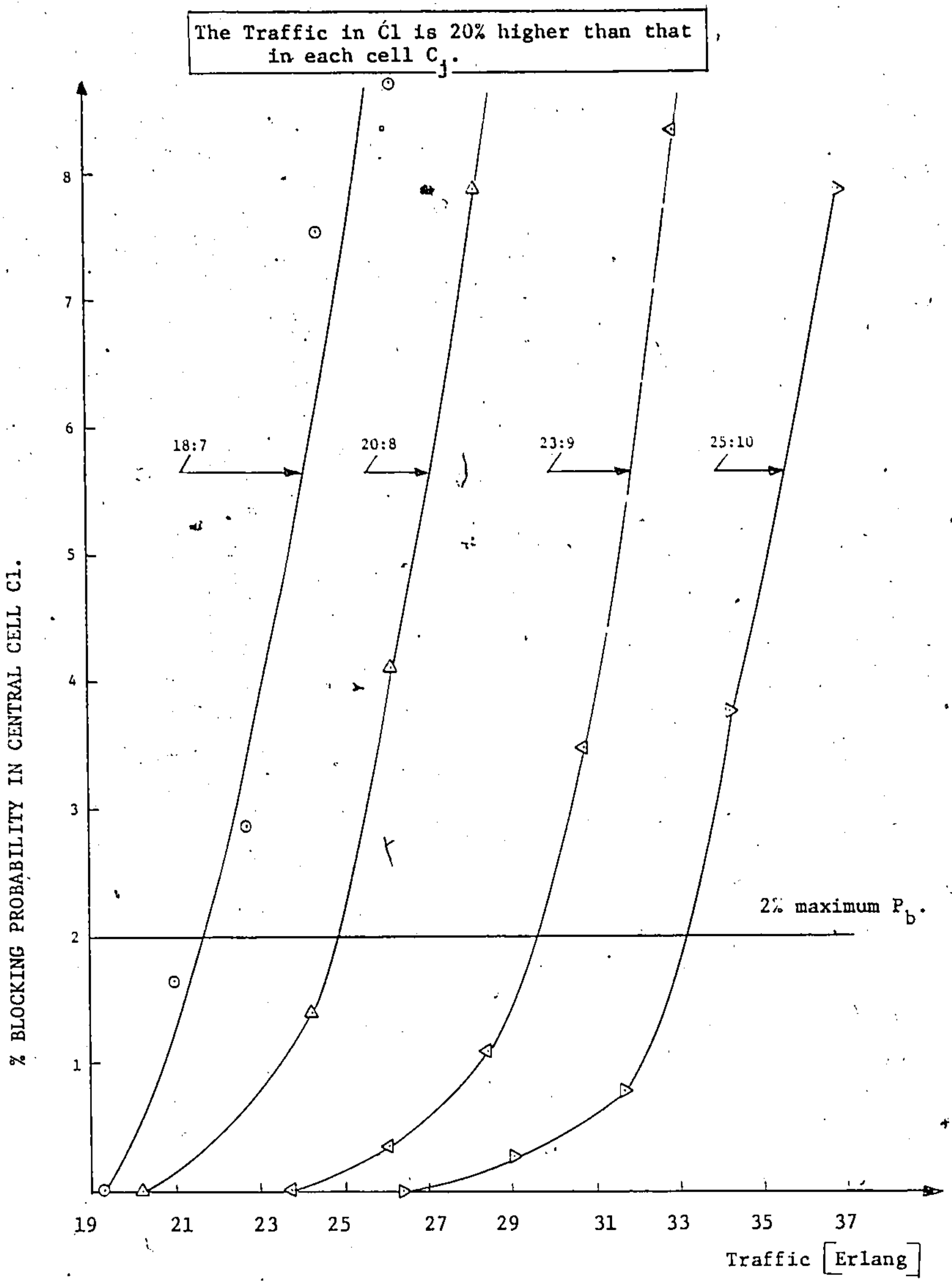


Fig. 7.19 — Blocking Probability for Hybrid Systems with 25, 28, 32 and 35 channels in central cell.

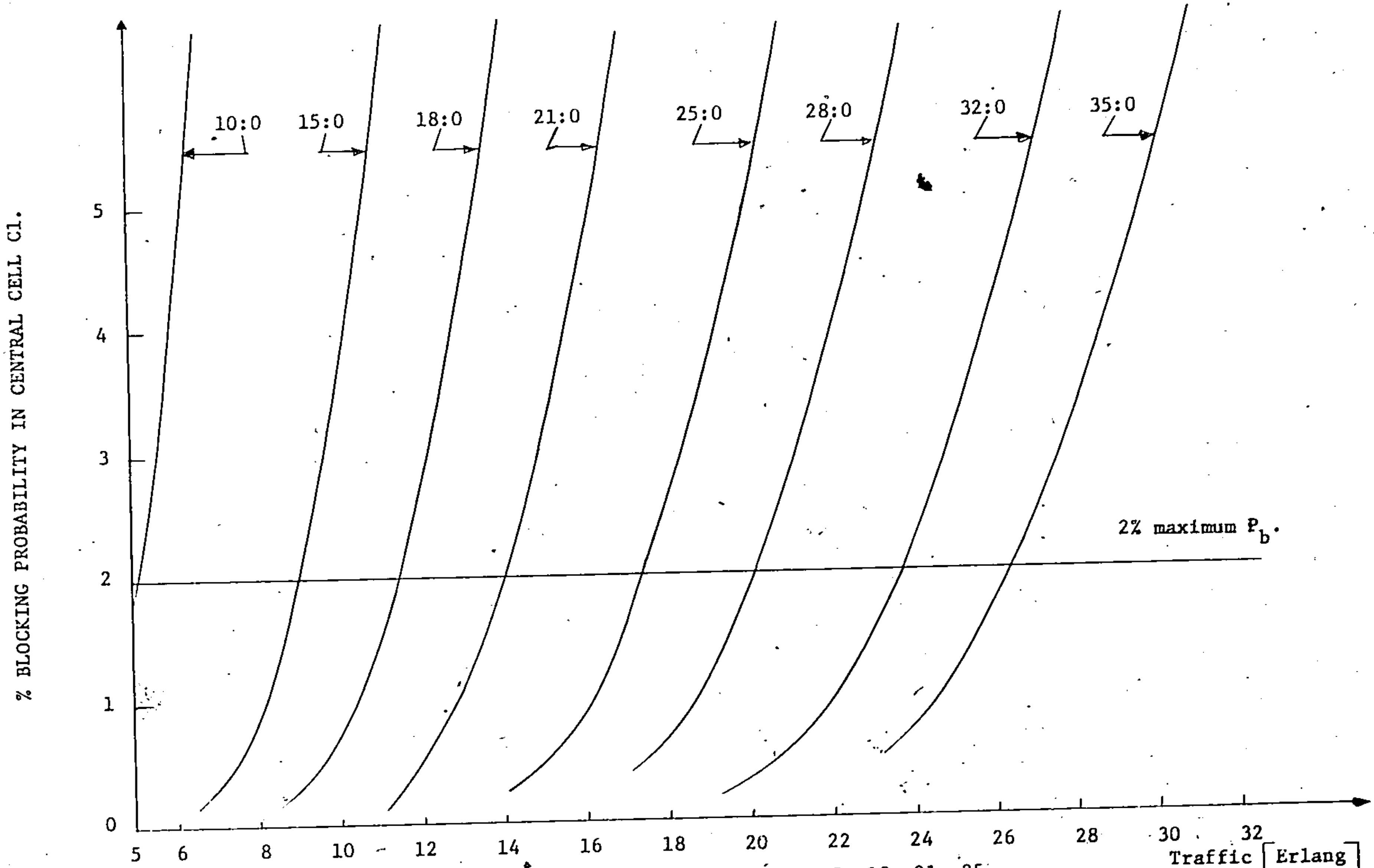


Fig. 7.20 — Blocking Probability for Fixed Systems with 10, 15, 18, 21, 25, 28, 32 and 35 channels in central cell C1.

The results being obtained due to the simulations for all system configurations with respect to the maximum traffic required and grade of service with a blocking rate of 2%, are displayed in Figure 7.21. This figure represents a comparison between the optimum hybrid systems with respect to the number of frequencies required in C1 in comparison with the fixed systems. For example, with a maximum traffic of 10 Erlangs, the 11:4 hybrid system gives a performance comparable to the 18:0 fixed system - a net saving of 3 channels in the central cell.. The spectrum efficiency in this case is 16.67%. We found again, that the hybrid systems are more spectrum efficient than the fixed systems, for the same offered load and maximum blocking rate 2%.

Similarly as we did in the case of uniform traffic (chapter 6), Figure 7.22 represents the spectral efficiency of Hybrid Systems with respect to the Fixed Systems in the central cell. From this figure, we conclude that 16.4% is the average spectral efficiency of hybrid systems in comparison with the fixed systems simulated.

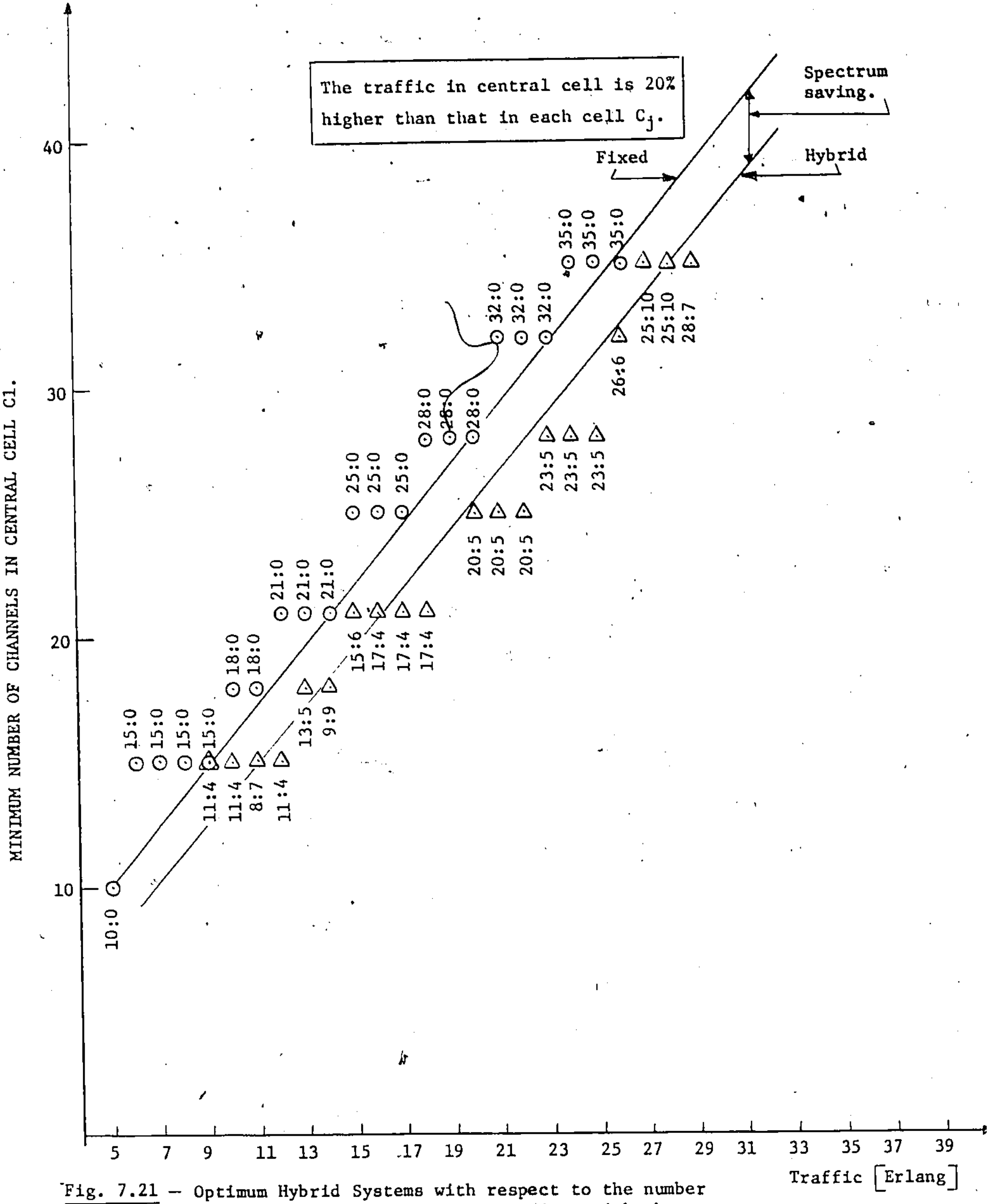


Fig. 7.21 – Optimum Hybrid Systems with respect to the number of Frequencies required in comparison with the Fixed Systems.

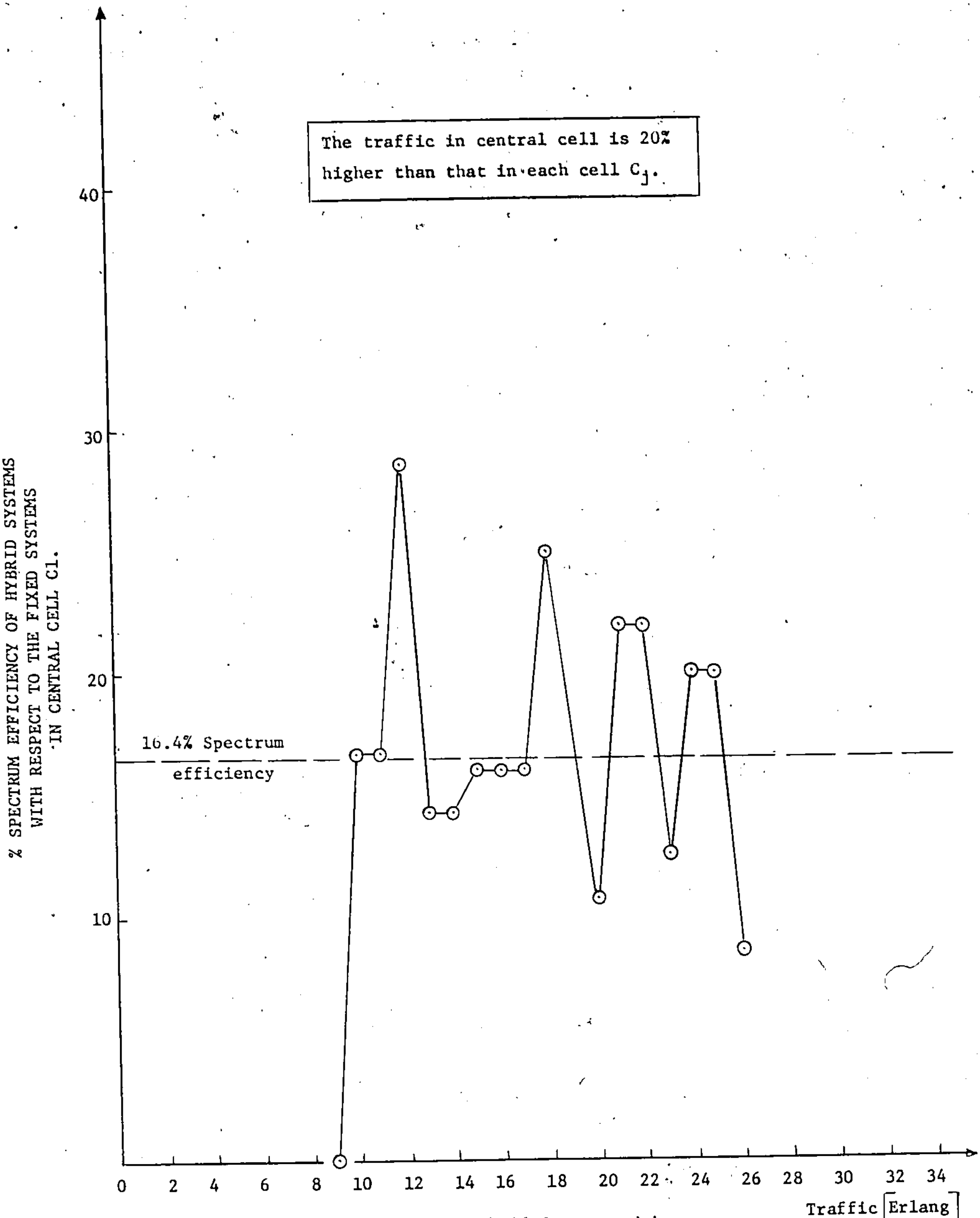


Fig. 7.22 – Spectrum efficiency of Hybrid Systems with respect to the Fixed Systems in central cell.

7.8.2 Spectral efficiency: Hybrid vs Fixed in each cell Cj.

Figures 7.23 to 7.26 represent the blocking probability for hybrid systems in the surrounding cells (#2 through #20) with different divisions. The X-axis represents the traffic in Erlangs. Same as in central cell; the results obtained, with 2% maximum blocking rate and same offered traffic, are compared with the Fixed Systems as shown in Figure 7.27.

Figure 7.27 represents a comparison between the optimum hybrid systems and the fixed systems in the surrounding cells. The traffic in each Cj is 20% lesser than that in C1. For example, with the same traffic (10 Erlangs) and 2% maximum Pb, the 11:4 hybrid system has a performance comparable to the 18:0 fixed system - a net saving of 3 channels in each cell Cj. The total saving in the system area is 9 channels (i.e. that of N1, N2 and N3).

Figure 7.28 gives the average spectral efficiency of the hybrid systems in each cell Cj as compared to the fixed systems. We notice, that 6.5% is the total average of this spectral efficiency.

7.8.3 Interpretation

Two assumptions were given with non-uniform traffic:

1. same percentage of fixed channels in each cell, and

2. the traffic in the central cell was 20% greater than that in each cell Cj.

The results obtained were:

1. The average spectral efficiency in the central cell of hybrid systems as compared to the fixed systems is found to be 16.4%.

2. the average spectral efficiency of hybrid systems as compared to the fixed systems in each of the surrounding cells was 6.6%.

This approach would indicate that, the spectral efficiency in the central cell is the highest as compared to the spectral efficiency in other cells.

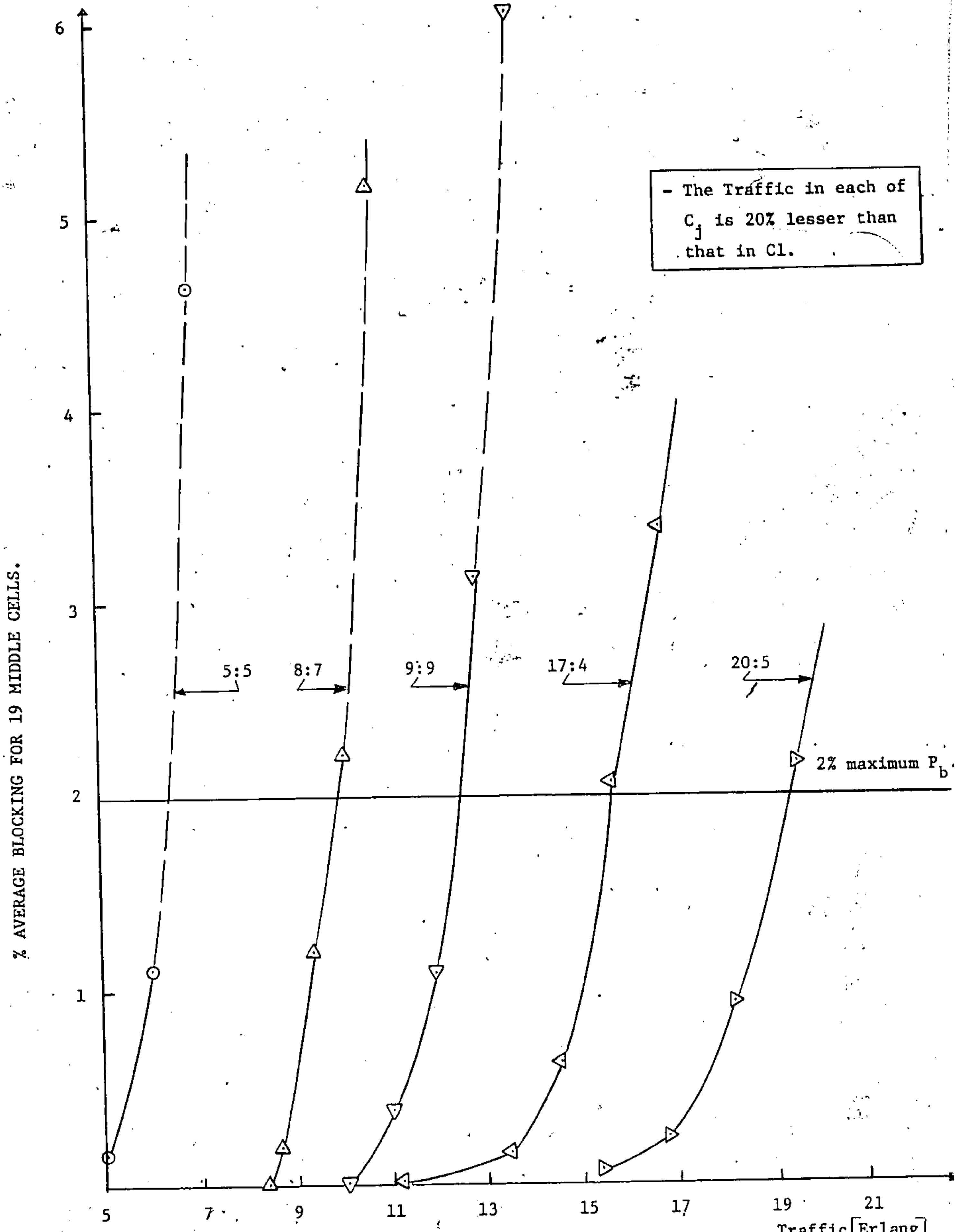


Fig. 7.23 — Blocking Probability for Hybrid Systems with 10, 15, 18, 21 and 25 channels per each cell C_j.

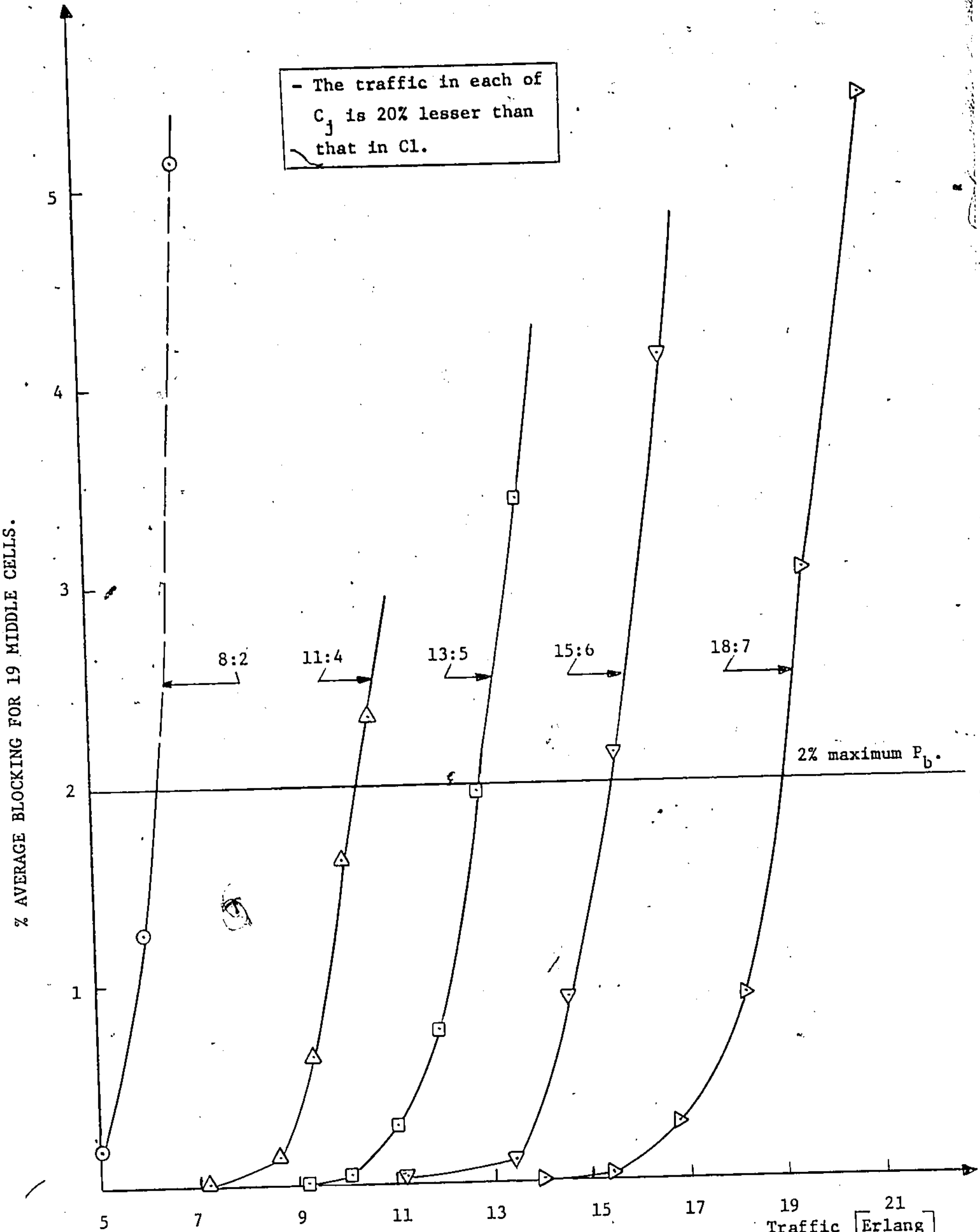


Fig. 7.24 – Blocking Probability for Hybrid Systems with 10, 15, 18, 21 and 25 channels per each cell C_j.

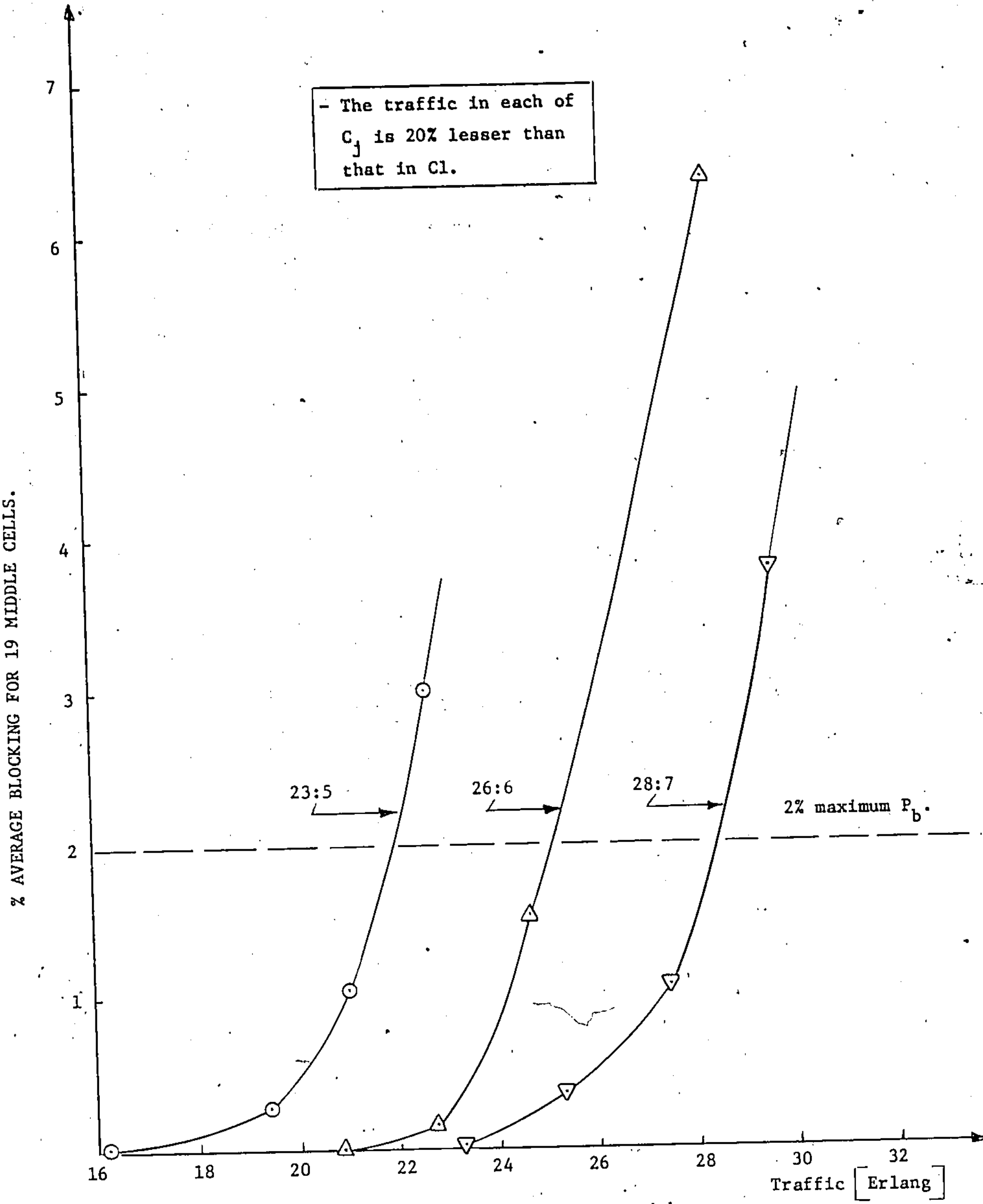


Fig. 7.25 – Blocking Probability for Hybrid Systems with 28, 32 and 35 channels per each cell C_j.

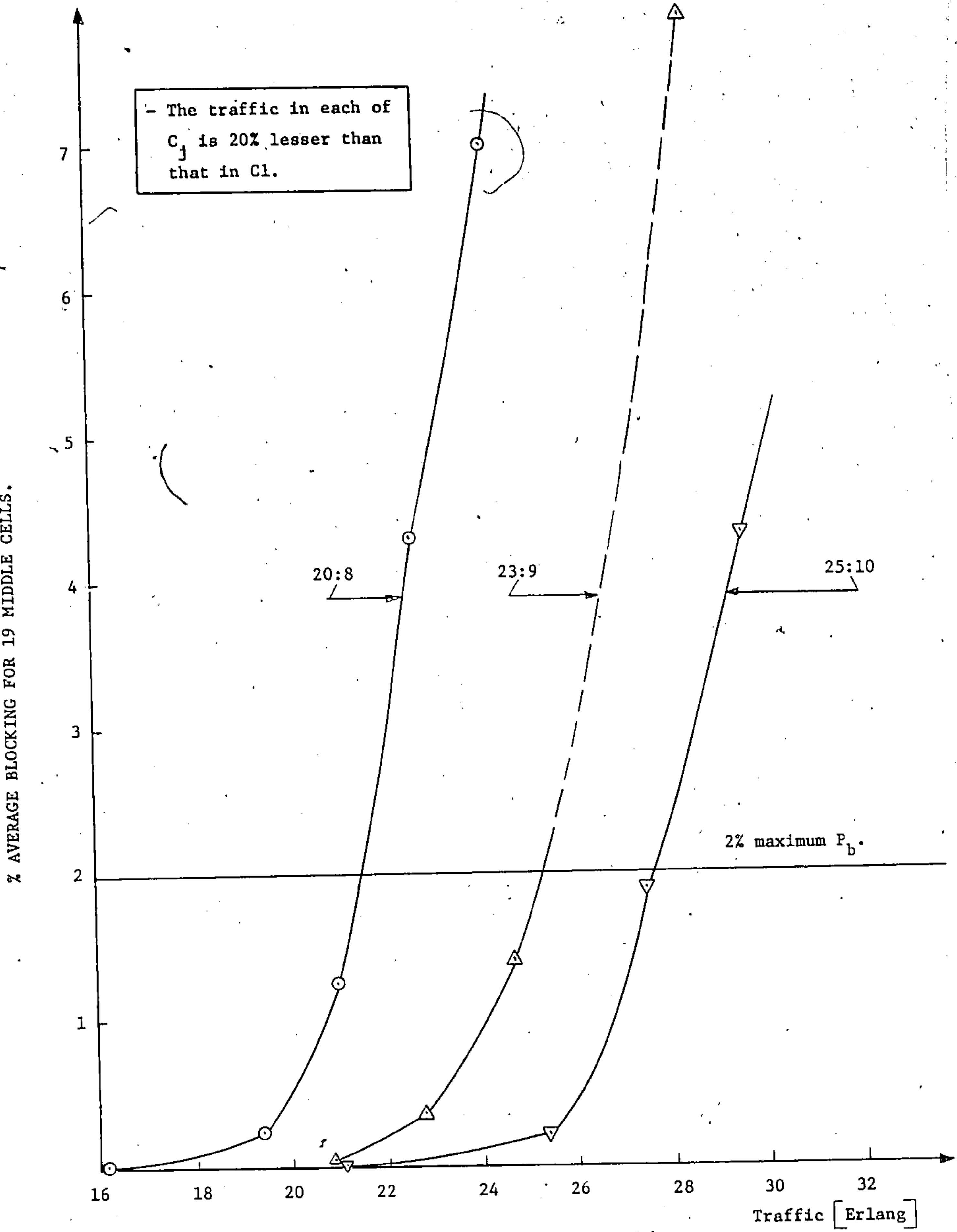


Fig. 7.26 – Blocking Probability for Hybrid Systems with 28, 32 and 35 channels per each cell C_j.

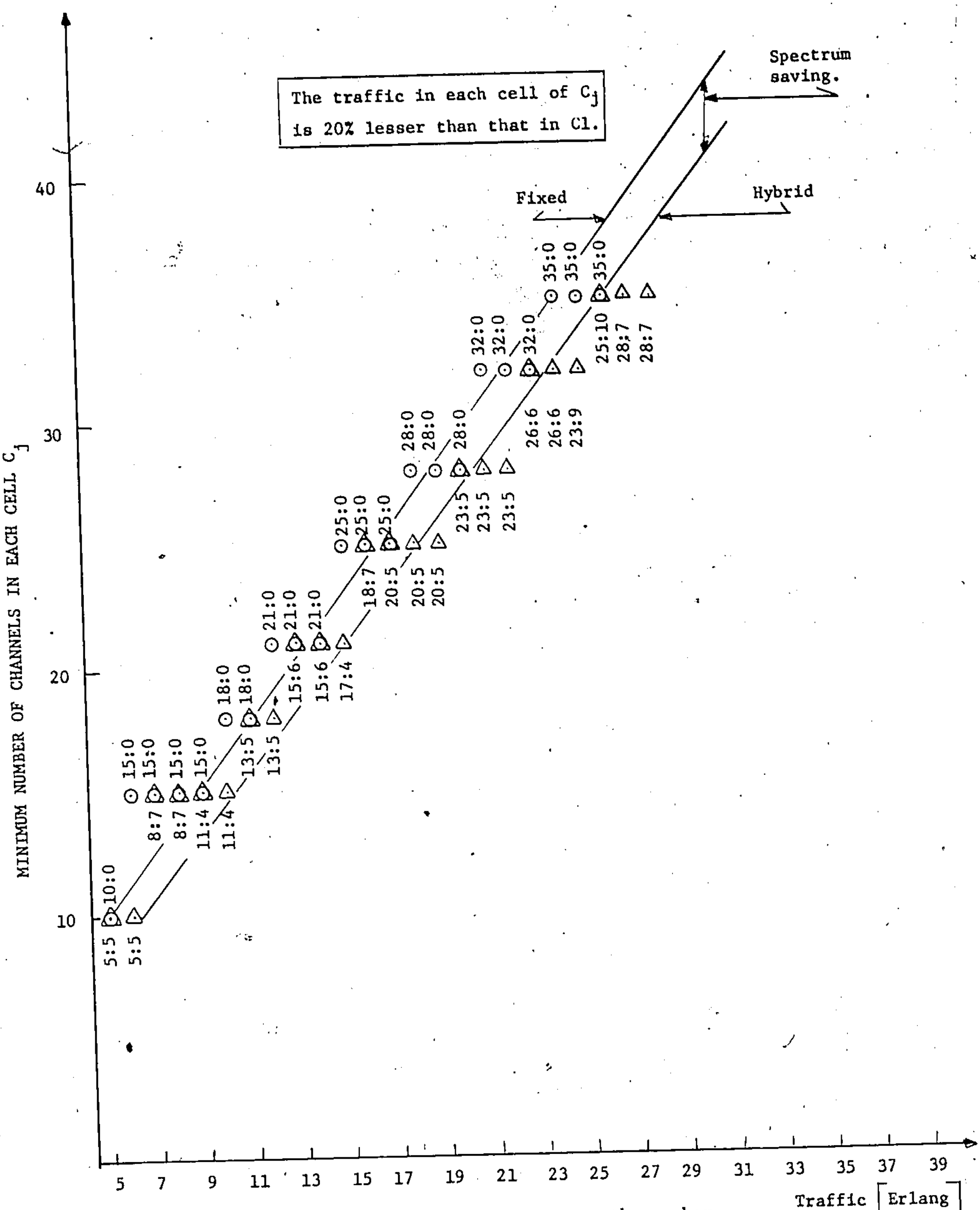


Fig. 7.27 — Optimum Hybrid Systems with respect to the number of Frequencies required in comparison with the Fixed Systems in each cell C_j.

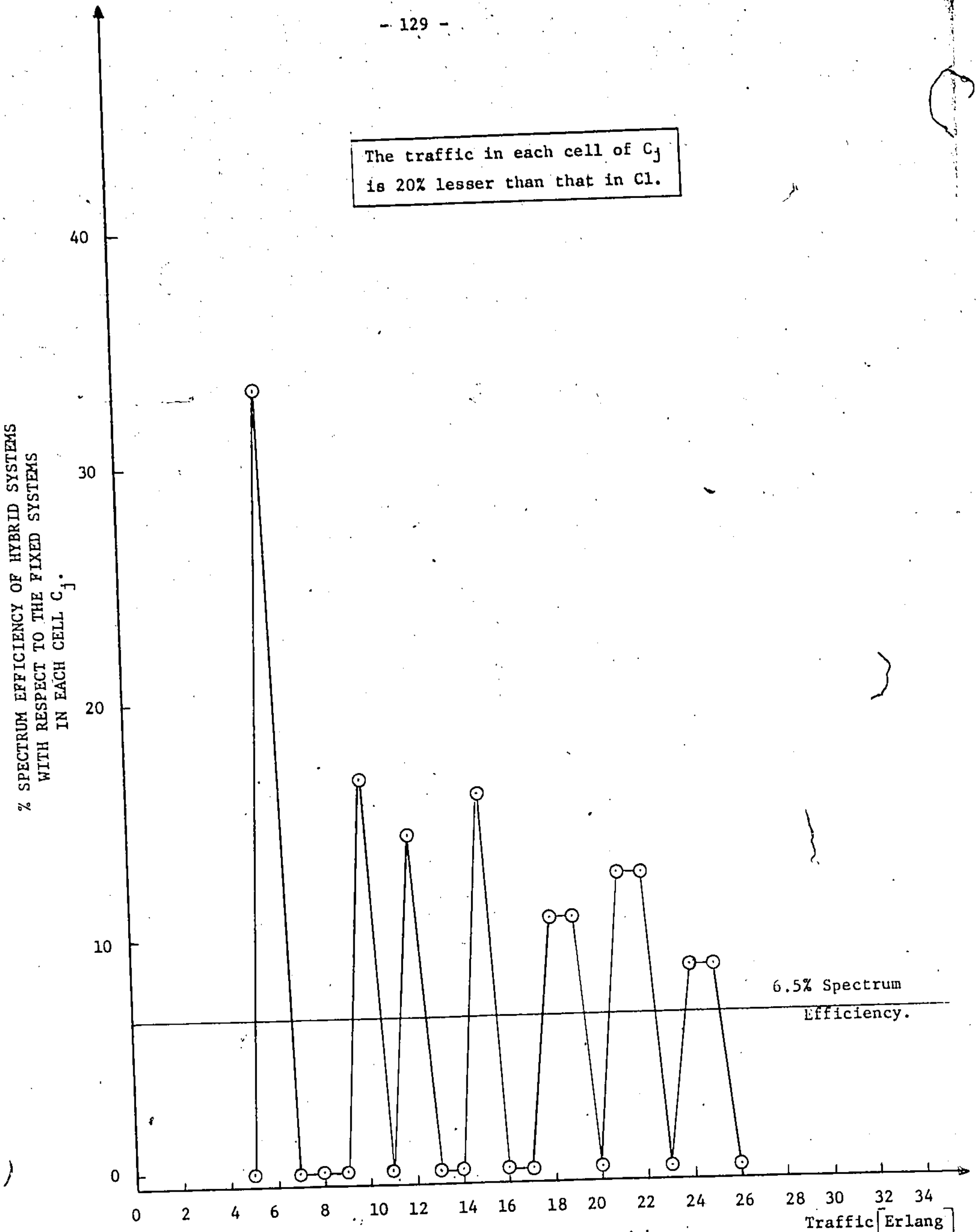


Fig. 7.28 — Spectrum efficiency of Hybrid Systems with respect to the Fixed Systems in each cell C_j.

7.9 SPECTRAL EFFICIENCY: HYBRID V.S FIXED, WITH 40% AND 30% OF FIXED CHANNELS IN C1 AND EACH CJ RESPECTIVELY.

TABLE 7.4

Number of channels in service area	Number of channels in C1	% of channels in C1	Number of channels in each cell Cj	% of channels in each cell Cj.
30	12	40%	9	30%
45	19	42%	13	29%
54	22	40%	16	30%
63	25	39.7%	19	30.3%
75	29	38.6%	23	30.7%
84	34	40.47%	25	29.8%
96	38	39.6%	29	30.2%

Same number of channels in the service area, as shown in table 7.3, are also indicated in table 7.4. In this table the second and third columns represent the number and percentage (40%) of fixed channels in the central cell. The remaining columns represent the number and percentage (30%) of channels in each of the surrounding cells. The traffic in C1 is also assumed to be 20% higher than that in each cell Cj.

7.9.1 Spectral efficiency: Hybrid vs Fixed in central cell.

Figures 7.29 and 7.30 represent the blocking probability in C1 for different hybrid systems simulated. The result obtained is with respect to the maximum traffic required and a grade of service 2%.

Figure 7.31 represents the blocking probability for Fixed systems in central cell. 40% of fixed channels are assigned in C1.

The results obtained from the three Figures described in the above section with 2% maximum blocking rate, are compared as shown in Figure 7.32. This figure represents a comparison between the optimum hybrid and fixed systems in the central cell with respect to the minimum number of frequencies required. For example, with a maximum traffic of 8 Erlangs, the 9:3 system has a performance (at 2% maximum Pb and same traffic handling capacity) comparable to the 19:0 fixed system and the net saving is 7 channels in central cell. This indicates that the hybrid systems are generally more spectrum efficient than the fixed systems for the same offered load and blocking rate.

Figure 7.33 shows the percentage spectrum efficiency of the hybrid systems with respect to the fixed systems in the central cell. This percentage is 6.6% on the average.

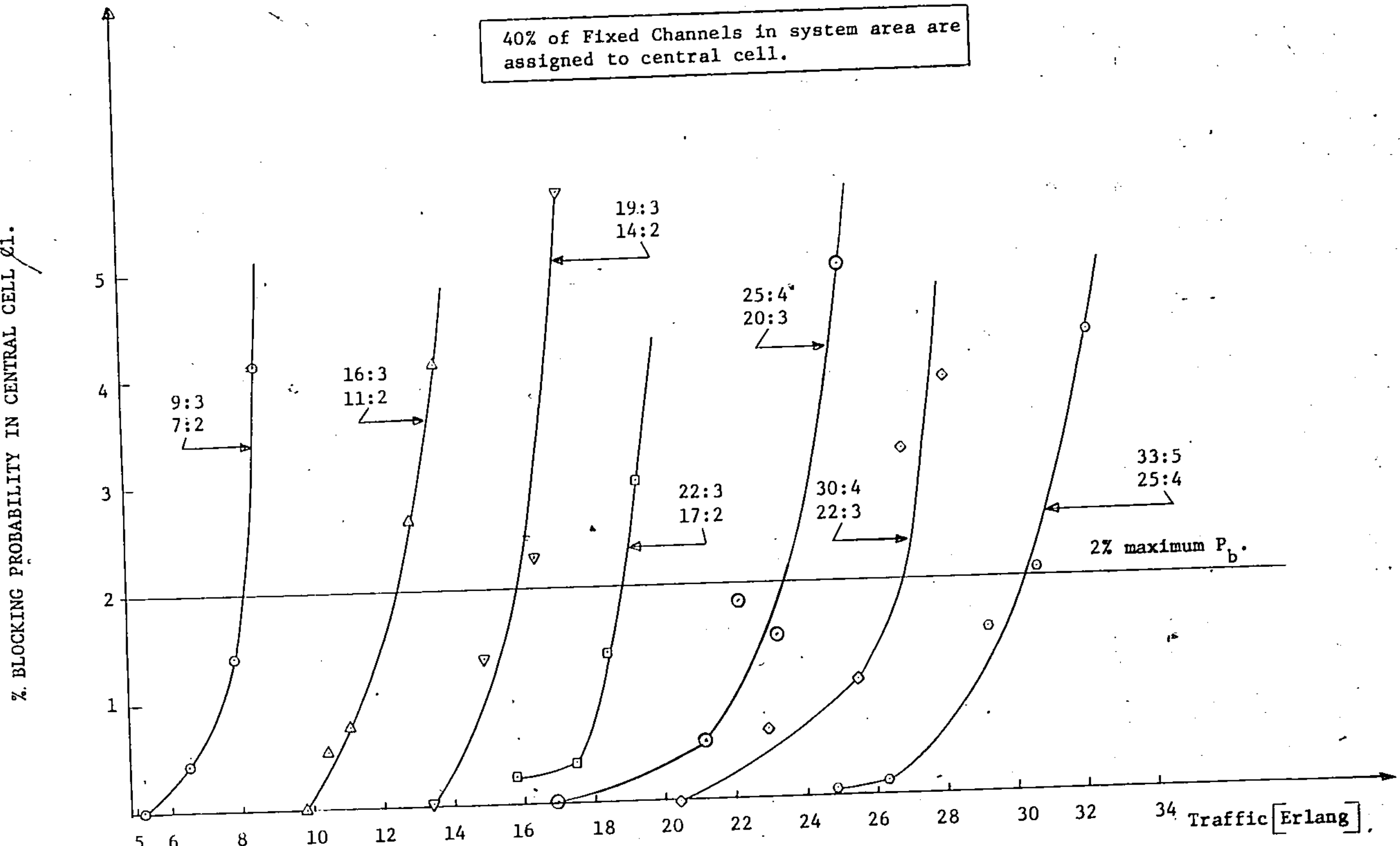


Fig. 7.29 — Blocking Probability for Hybrid Systems with 12, 19, 22, 25, 29, 34 and 38 channels in central cell C1.

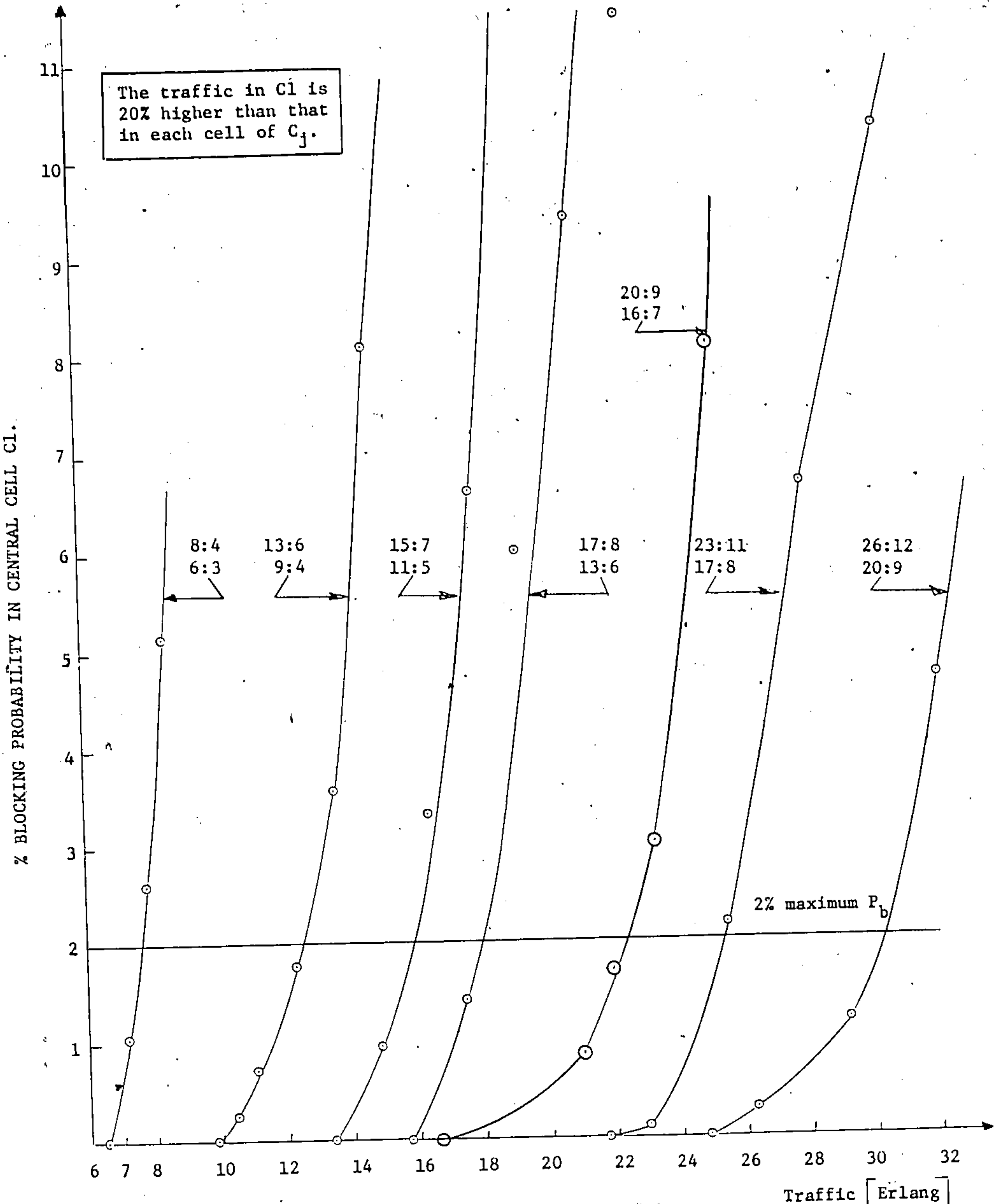


Fig. 7.30 — Blocking Probability for Hybrid Systems with 12, 19, 22, 25, 29, 34 and 38 channels in central cell Cl. 40% of Fixed Channels in central cell.

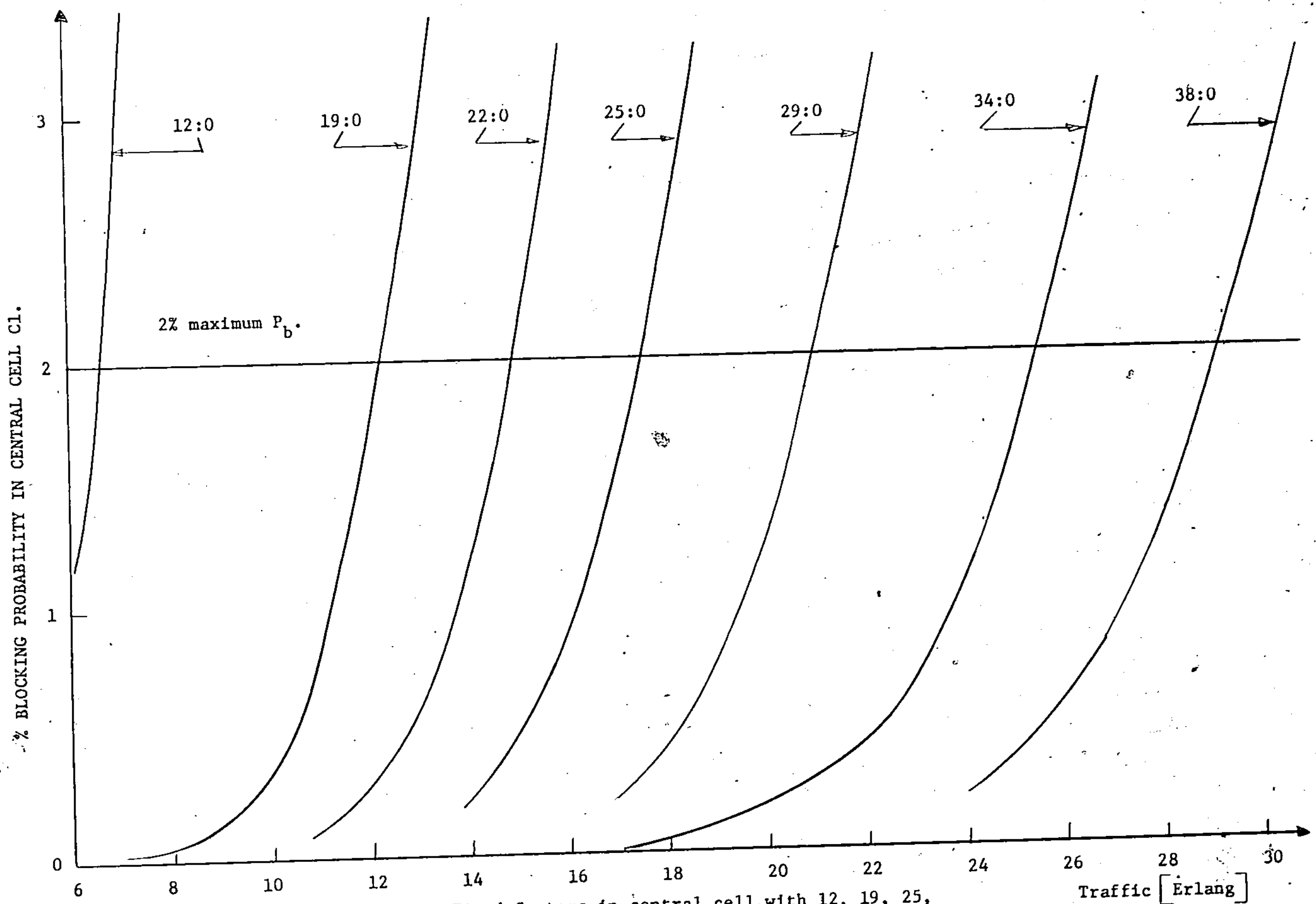


Fig. 7.31 — Blocking Probability for Fixed Systems in central cell, with 12, 19, 25, 29, 34 and 38 channels. 40% of Fixed Channels in Cl.

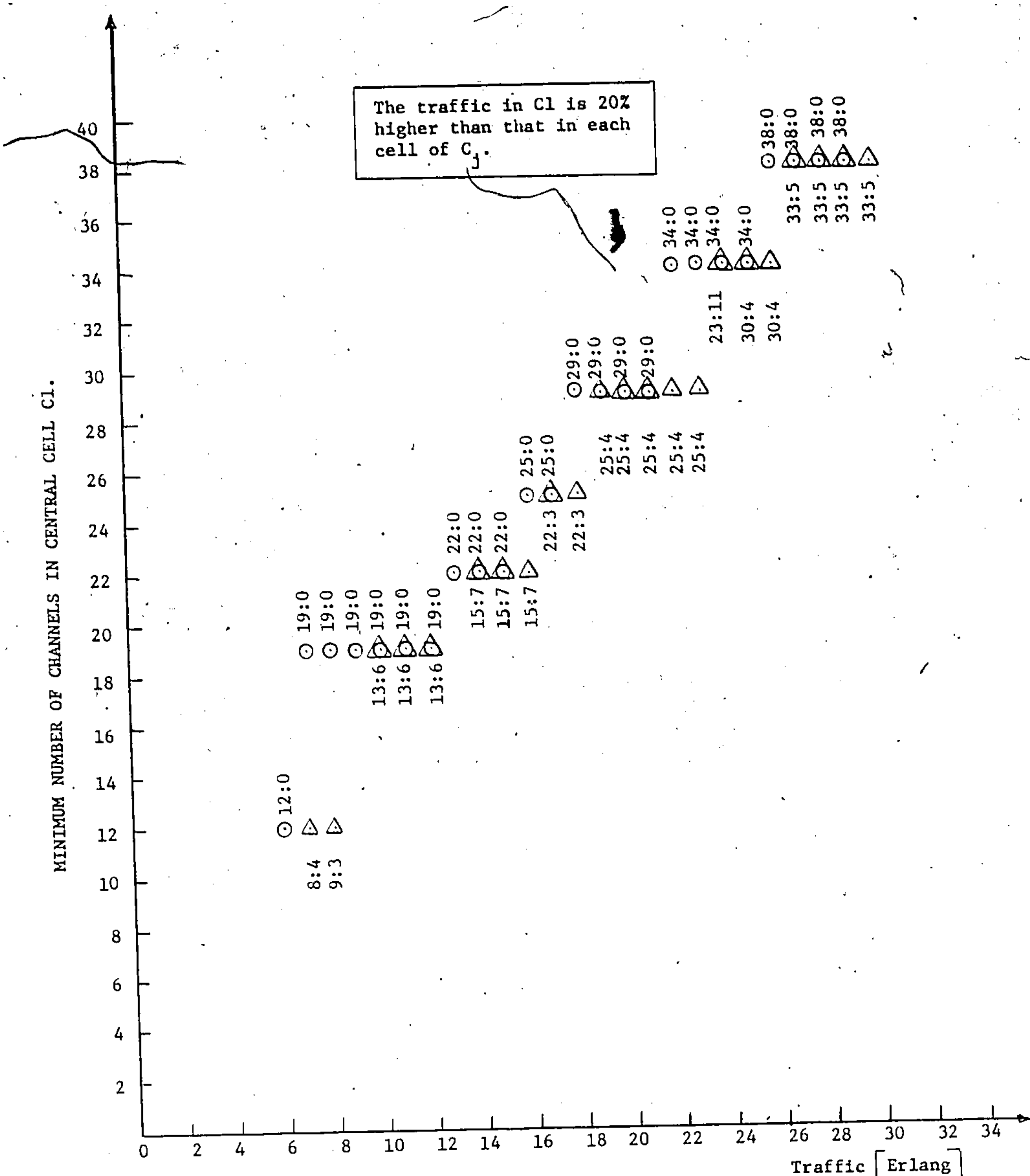


Fig. 7.32 — Optimum Hybrid Systems with respect to the number of Frequencies required in comparison with the Fixed Systems in central cell .

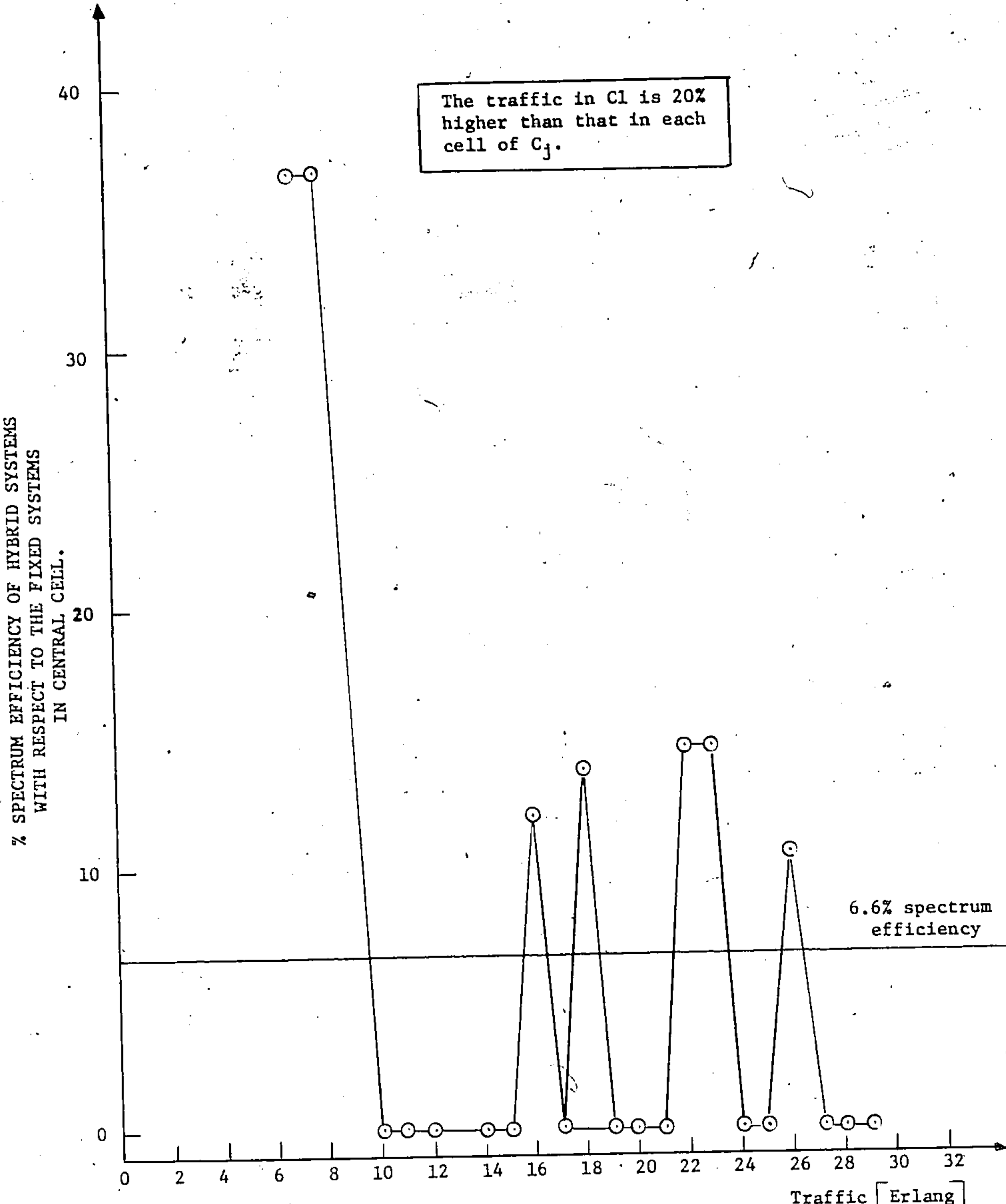


Fig. 7.33 — Spectrum efficiency of Hybrid Systems with respect to the Fixed Systems in central cell.

7.9.2 Spectral efficiency: Hybrid vs Fixed in each cell Cj.

Figures 7.34 and 7.35 represent the average percentage blocking in 19 middle cells for hybrid systems with 9, 13, 16, 19, 23, 25 and 29 channels in each cell Cj. Same as in central cell, the results obtained are compared to the results obtained from Figure 7.36 with 2% maximum blocking rate. This Figure represents the percentage blocking for Fixed Systems in the 19 middle cells.

The compared results between Fixed and Hybrid systems are shown in Figure 7.37. This figure represents the minimum number of channels in each cell Cj with the increase of traffic in Erlangs. For example, with a maximum traffic of 8 Erlangs, the 9:4 system has a performance comparable to the 16:0 fixed system - a net saving of 3 (18.75% spectrum efficiency) channels per channel set (i.e. N2 and N3).

The total saving in the system area is 13 channels (i.e. that of N1, N2 and N3).

Figure 7.38 represents the percentage spectral efficiency in each cell Cj for Hybrid Systems as compared to Fixed Systems. The average spectrum efficiency obtained is 14.2%.

7.9.3 Interpretation

Two assumptions were made:

1. 40% and 30% of Fixed channels, are assigned to the central cell and its surroundings, respectively.

2. The traffic in the central cell was 20% higher than that in each cell Cj.

The results obtained were:

1. the saving in frequencies in the central cell, for hybrid systems as compared to fixed systems, was on the average 6.6%; and

2. the saving in frequencies in other cells, for hybrid systems as compared to fixed systems, was on the average 14.2%.

From the two results obtained above, we can observe a general pattern for the spectrum efficiency of the hybrid systems as compared to the fixed systems. We have found that the spectral efficiency is decreased from 16.4% to 6.6% in the central cell. This decrease is expected as the percentage of fixed channels is being increased in the central cell from 33.3% to 40%.

The spectral efficiency of hybrid systems as compared to the fixed systems is increased from 6.5% to 14.2% in the surrounding cells. This increase is expected as the percentage of fixed channels is being dropped down from 33.3% to 30% in each cell Cj.

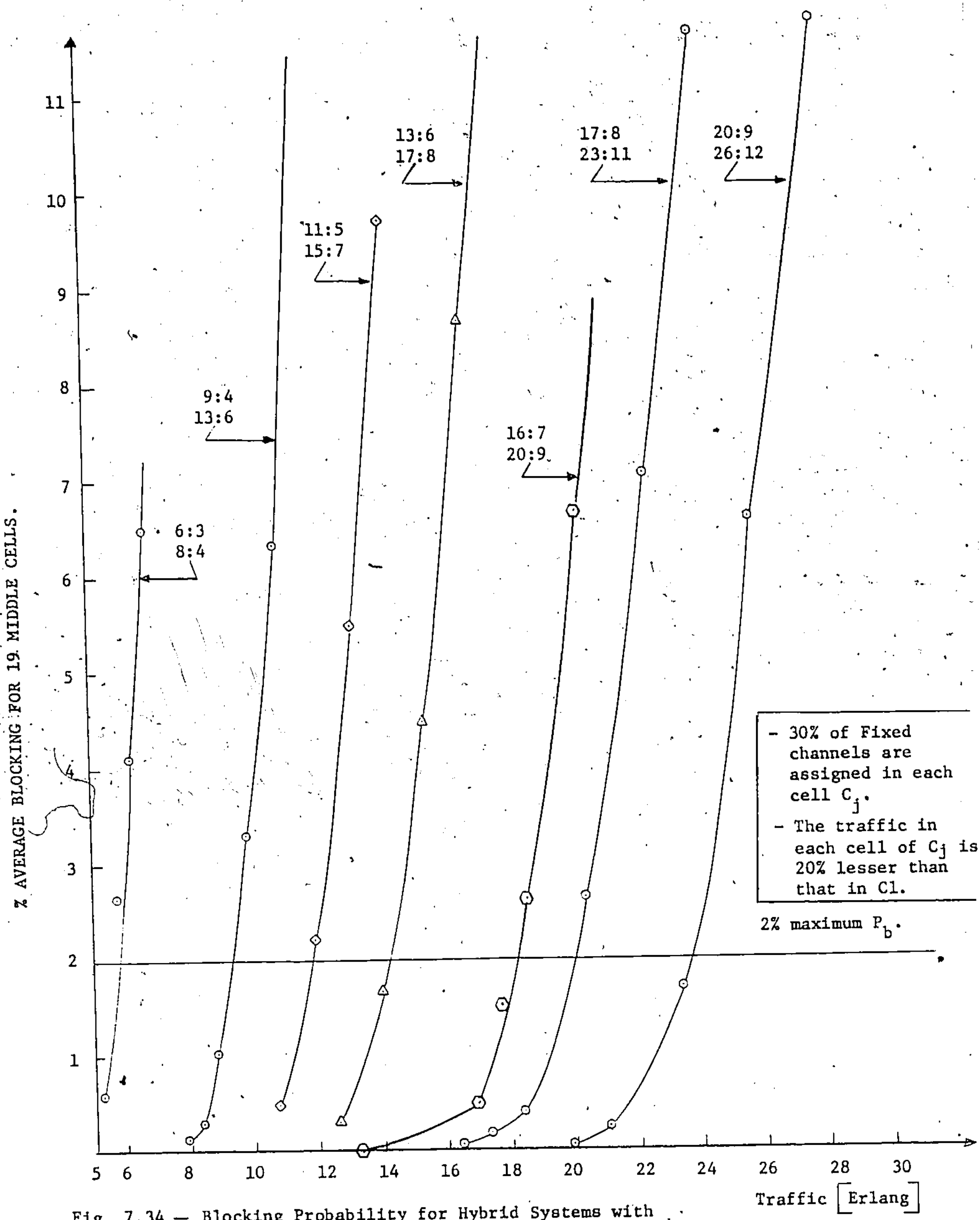


Fig. 7.34 — Blocking Probability for Hybrid Systems with 9, 13, 16, 19, 23, 25 and 29 channels in each cell C_j.

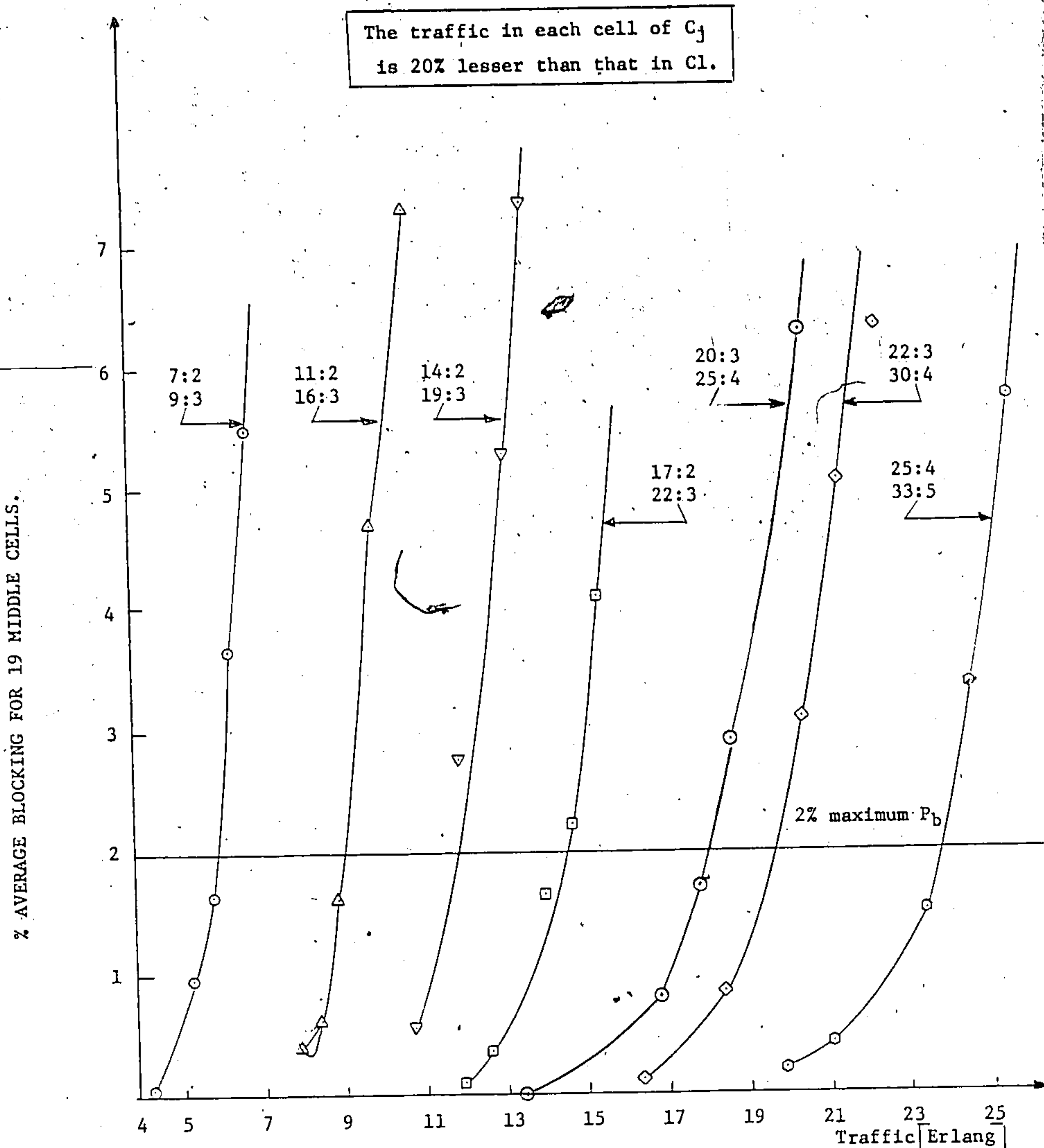


Fig. 7.35 — Blocking Probability for Hybrid Systems with 9, 13, 16, 19, 25 and 29 channels in each cell C_j.

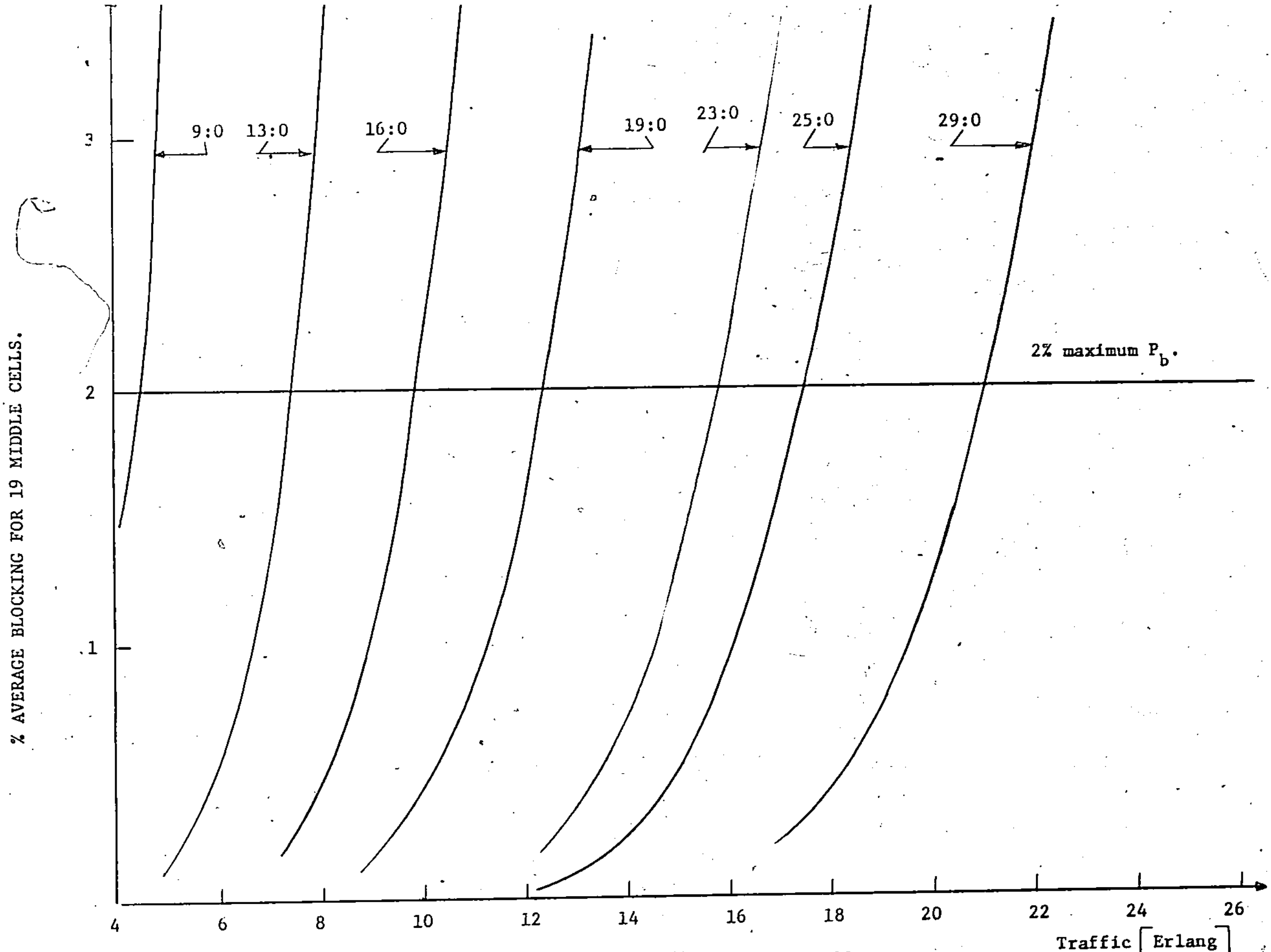


Fig. 7.36 — Blocking Probability for Fixed Systems with 9, 13, 16, 19, 23, 25 and 29 channels per each cell C_j.

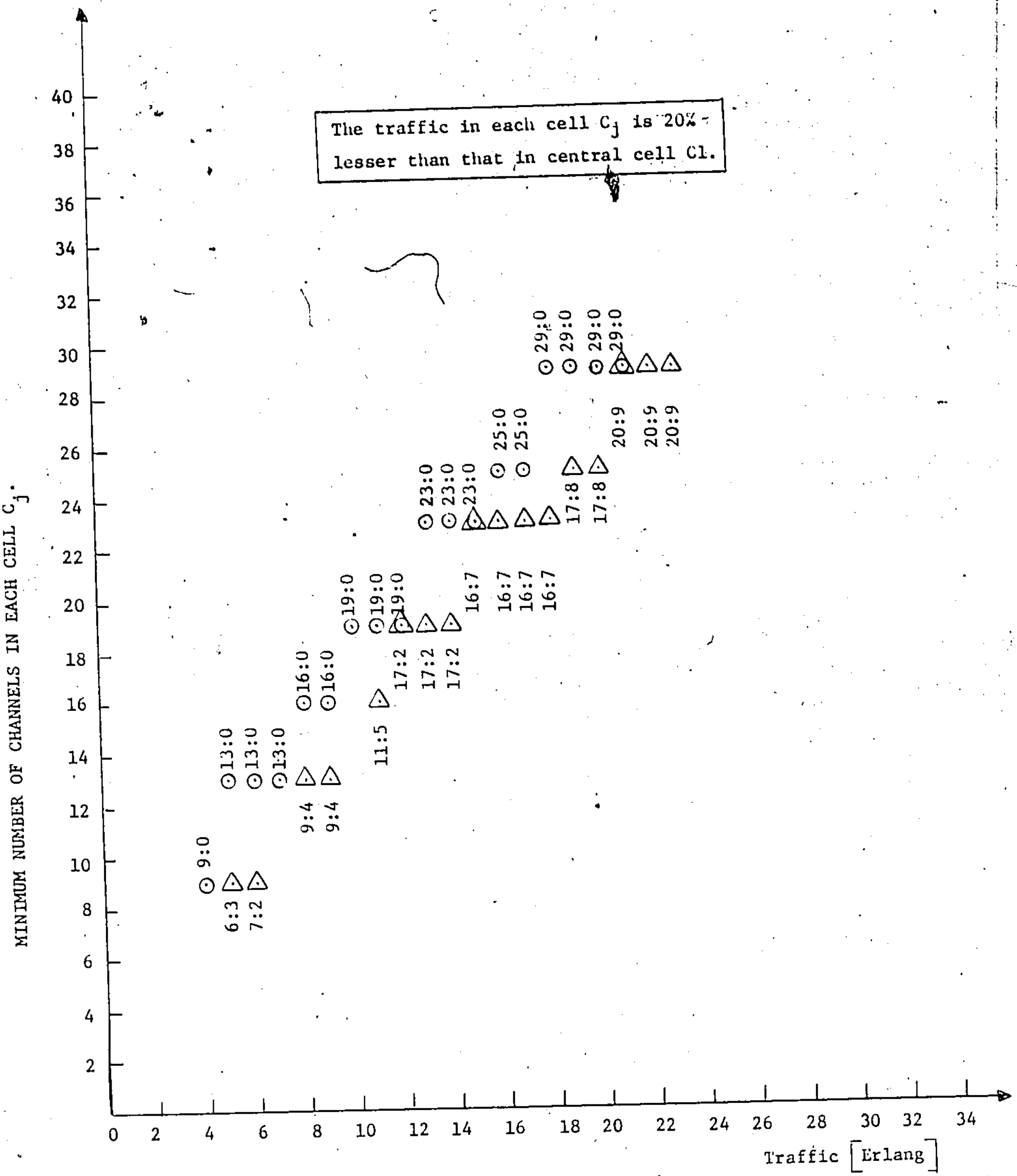


Fig. 7.37 – Optimum Hybrid Systems with respect to the number of Frequencies required in comparison with the Fixed Systems in each cell C_j.

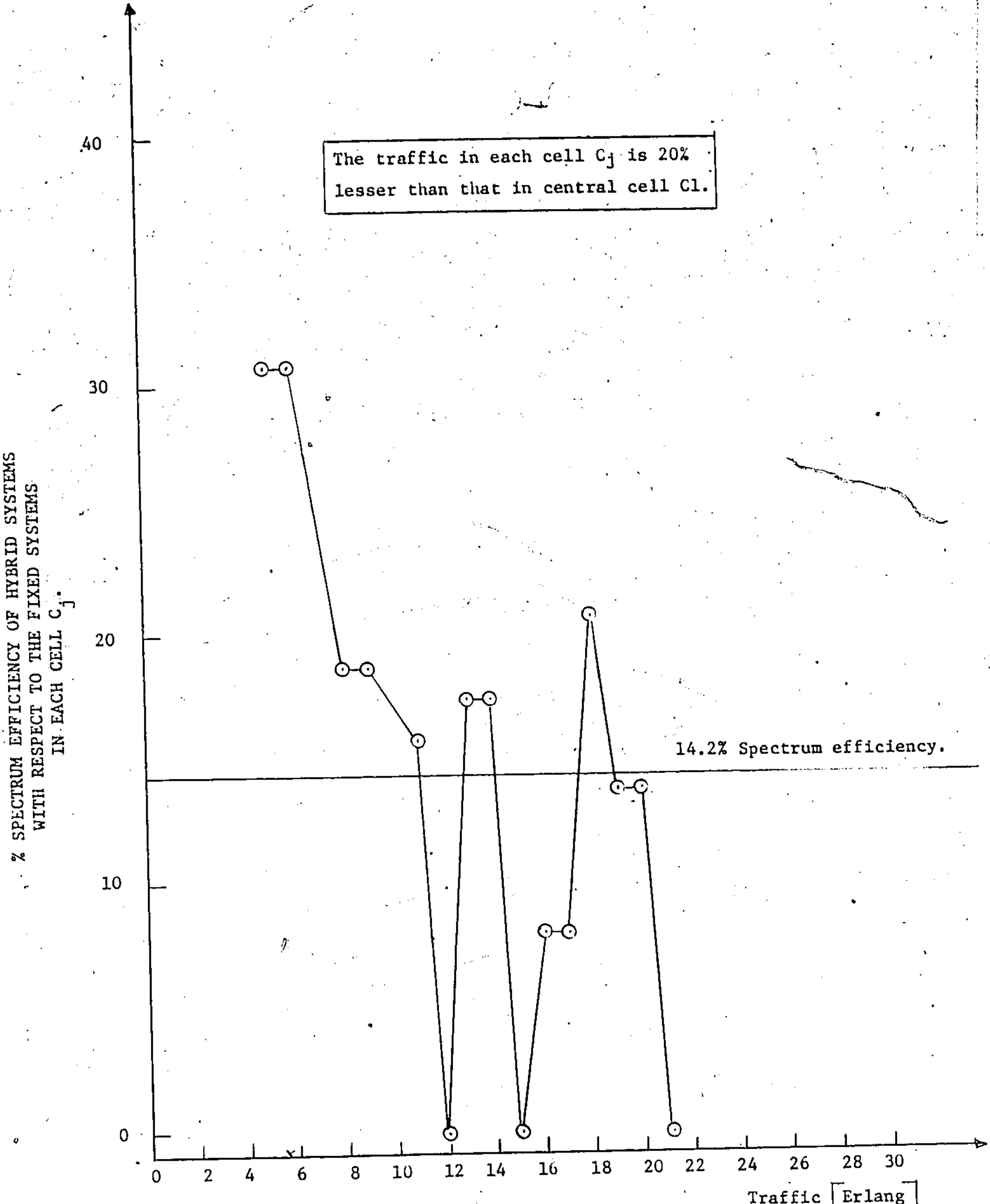


Fig. 7.38 – Spectrum efficiency of Hybrid Systems with respect to the Fixed Systems in each cell C_j.

Chapter VIII

CONCLUSIONS

In the simulation results obtained, of the cellular system employing the Hybrid Channel Assignment Scheme with Erlang-B service discipline, some observations and conclusions can be made. The principal result is that the Hybrid-Channel Assignment does provide an effective way of increasing traffic handling capacity in systems that are limited in the spectrum availability.

In chapter 6 we presented simulation results of a cellular land-mobile radio communications system and the traffic was uniformly distributed over the cells. We have found that the hybrid system (70% fixed, 30% dynamic) was very close to the best hybrid scheme in terms of maximum traffic carried and 2% grade of service. The saving in frequencies, when using the hybrid channel assignment scheme, was on the average 15% as compared to the fixed channel assignment scheme.

Chapter 7 reported the simulation results of the cellular system using the hybrid channel assignment scheme with Erlang-B service and non-uniform traffic. In this case:

i) We first considered the same number of channels to the central cell and others.

The results obtained (Figures 7.1 through 7.4) showed that if the traffic in the central cell C1 was 20% greater than that in each cell Cj, the systems with mostly dynamic channels in C1 and mostly fixed channels in Cj gave the lowest probability of blocking in the respective cells for traffic up to about 25% above base loads. Beyond that amount of traffic, the system with mostly fixed channels performed best, both in C1 and all Cj.

For this 20% difference of traffic between C1 and Cj we determined the spectral efficiency of the hybrid systems with respect to the fixed systems in C1 and each Cj.

ii) Next the traffic was assumed fixed in each cell Cj and was substantially increased in the central cell C1.

The simulated results indicated that the hybrid system with the most dynamic channels outperforms the others even at the highest traffic (>100% above a given base load).

iii) Next the traffic in C1 was assumed X% higher than that in each cell Cj and was increased by a constant ratio in each cell.

The following results were obtained:

- Systems with fixed channels only gave the best performance indices under high offered traffic (>70% on the average above a given base load). In this case the traffic was increased by a constant ratio within all cells.

iv) Systems with the most dynamic channels performed the best up to about a 120% increase of traffic in C1 with the traffic in the surrounding cells fixed, under consideration of different number of channels in the system area.

v) Two cases were then considered, where the total number of channels in the simulated area was fixed. The traffic in the central cell was assumed 20% greater than that in each cell Cj for both cases.

1. 33.3% of the available channels in the system, were allocated to each cell.

2. 40% and 30% of the fixed channels, in the service area, were assigned to the central cell C1 and each cell Cj, respectively.

The following results were found:

1. The two Channel Assignment Schemes, Fixed and Hybrid, were compared in C1 and in each cell Cj. We have determined the minimum number of channels needed in each cell Cj and in the central cell C1, in order to carry a given traffic and still maintain a maximum rejection rate of 2%.

2. The spectral efficiency of the Hybrid Systems as compared the Fixed Systems was obtained. The average saving in frequencies varied from 16.4% to 6.6%, in the central cell, as the number of fixed channels there increased from 33.3% to 40%. The average saving in frequencies in Cj varied from 6.5% to 14.2% as the number of channels, in Cj, was reduced from 33.3% to 30%.

The above results, for both uniform and non-uniform traffic in cellular land-mobile systems, show the superiority, in general, of the Hybrid Channel Assignment Scheme in terms of both traffic carried and spectral efficiency, as compared to the Fixed Scheme. The Hybrid Scheme could be used as an alternative to the "cell-splitting" option in areas of significant traffic increase, such as the center of a city. This Scheme however requires a computer at the MTSO, which implies higher costs than in the case of Fixed Channel Assignments. A cost analysis should be carried to determine the best tradeoffs.

APPENDICES

Appendix A

A.1 FAST RAYLEIGH FADING [4,5,8]

The radio transmission path characteristics between the mobile and base station change continuously as the mobile moves. Multiple reflections of waves transmitted from a single source may interfere destructively to varying degrees. This fading (interference) causes the received signal power r to vary as the vehicles moves a few signal wavelengths in accordance with the Rayleigh distribution $P_r(\alpha)$ as follows [8]:

$$P_r(\alpha) = \begin{cases} 0 & \alpha < 0 \\ \left(\frac{\alpha}{r_0}\right) e^{-\frac{\alpha^2}{2r}} & \alpha \geq 0 \end{cases}$$

the constant r_0 specifies mean of the distribution; where

$$\bar{r} = r_0\sqrt{\frac{\pi}{2}}$$

$\bar{r}$ denotes the expected value of r.

A.2 LOG-NORMAL FADING

The actual value of the mean received power

$$S = r_0\sqrt{\frac{\pi}{2}}$$

varies slowly with respect to the wavelength as the distance between the base station and mobile changes. This slow variation is approximated by a Log-Normal distribution. This r_0 varies as R^{-n} where R is the distance between the base station and the mobile. The probability density $P_s(\alpha)$ is

$$P_s(\alpha) = \frac{1}{\sqrt{2\pi}\,\sigma} \exp\left[-\frac{(\alpha - \alpha_0)^2}{2\sigma^2}\right]$$

the expected value (α_0) of "s" is

$$\alpha_0 = A - 10n \cdot \log_{10}\left(\frac{R}{R_0}\right)$$

where constant A depends on terrain and environment, antenna heights and gains, and carrier frequency; R_0 is a normalizing factor (the radius of the cell).

A.3 DIVERSITY CONSIDERATIONS

The objective of diversity is to provide one path for transmission of a radio signal between mobile and base station. In the limit, diversity can virtually eliminate the effects of both Rayleigh fading of the desired signal and the effect of random FM and frequency selective fading.

The technique which is most often used in mobile telephone systems is space diversity [5], in which different sites positions create a multiplicity of base-to-mobile paths, and in which the critical parameter is the degree of separation between paths that is necessary to achieve independence.

Appendix B

CHANNEL ASSIGNMENT STRATEGIES

The following channel assignment strategies have been investigated [13]:

1. First Available

This strategy assigns the first available radio channel encountered during a channel search; that is a channel is not being used in any cell which is also a member of the ICG for the particular cell in question. This strategy assigns available channels randomly and minimizes the amount of data processing necessary to set up a call.

2. Mean Square (MSQ)

The mean square assignment strategy minimizes the quantity :

$$\frac{1}{n}\sum_{j=1}^{n} D_j^2 \quad , \qquad D_R \leq 2 \cdot D_j \leq 2 \cdot D_R .$$

for the available channels. Channel activity is checked at cells in the interval (between D_R and

2Dr). Dj is the distance between the assigned coverage cell and the cell currently using the same channel within the specified interval and n is the number of cells using the channel within this interval. If n=0 for some channel, that is, if the channel is not in use in any cell between Dr and 2Dr, then the first such channel encountered is assigned to serve the call.

3. Nearest Neighbor (NN)

This strategy chooses for assignment that channel which is 'in-use' at a cell nearest to the assigned coverage cell, but still at least a reuse interval, Dr, away. By doing so the distance D, over the available channels, between the first cell using that channel and the assigned coverage cell is minimized. If more than one channel has the same minimum D then the first channel search will be assigned to the cell in question.

4. Nearest Neighbour + K (NN + K)

Borrow a channel using the same criterion as in (3) above, except using the minimum distance (D+K), where K=1,2,3... . This strategy tends to allow more calls to keep their assigned channels upon cell boundaries crossings. If no such channel exists at the time of borrowing, the channel with D=Dr will be assigned to the borrowing cell.

5. <u>Maximum Usage</u>

Borrow a channel that is being used most at a distance Dr cell radii away from the assigned cell. That is, a channel, which is currently in use in most cells just outside the interference cell group boundary of the cell in question is chosen. If there is more than one such candidate the first channel encountered will be assigned to the borrowing cell.

Appendix C

GPSS PROGRAM

TABLE OF DEFINITIONS

Time unit = 1 msec.

POISSON/EXPONENTIAL DISTRIBUTION

The arrival rates of phone calls to the cells was assumed to be poisson. Consequently, interarrival-time was assumed to be exponential, with a known mean. The poisson arrival rate can be shown to be given by the expression

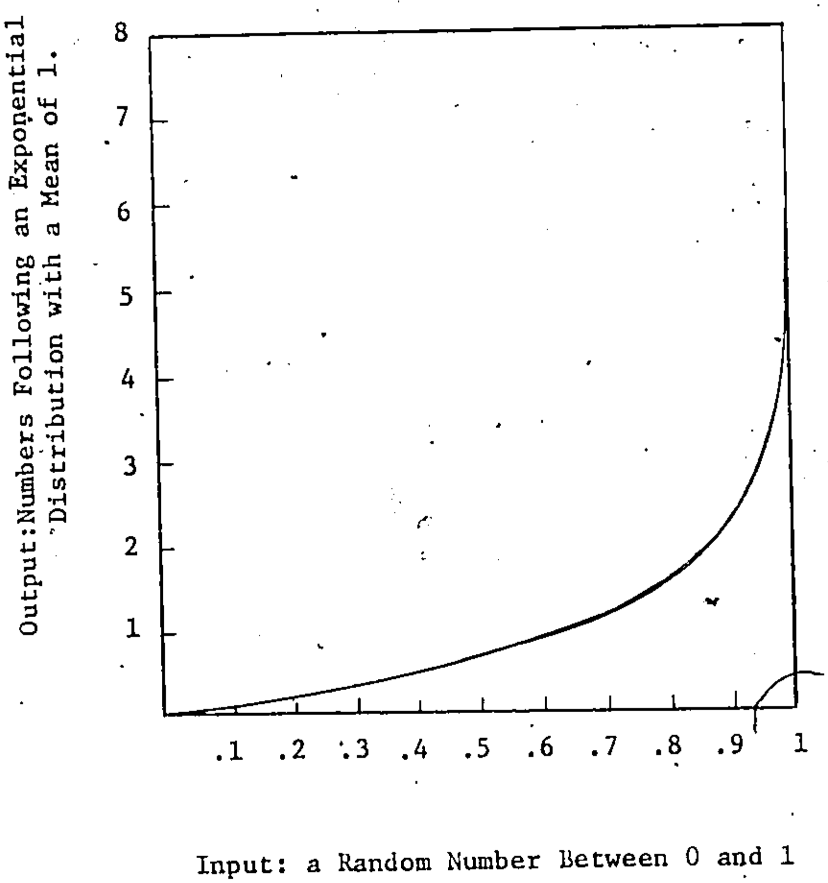
$$P_k(t) = \frac{e^{-\lambda \cdot t} (\lambda t)^k}{k!} \qquad k = 0, 1, 2, \ldots.$$

$P_k(t)$ is the probability that exactly K arrivals will occur in the time interval duration 't', and (λ) is the mean arrival rate of phone calls per unit time. Therefore, the evaluation of 't' involves getting first a random number (RNj) and then evaluating -log (1 - RNj). The j on RNj is used to represent any one of the 8 available random number generators in GPSS/360.

EXPON FUNCTION RN4,C24

It is defined as C24, continues with 24 points, which corresponds to -log (1 - RNj).

0.,0/0.1,0.104/0.2,0.222/0.3,0.355/0.4/0.509/0.5,0.69/
0.6,0.915/0.7,1.2/0.75,1.38/0.8,1.6/0.84,1.83/0.88,2.12/
0.9,2.3/0.92,2.52/0.94,2.81/0.95,2.99/0.96,3.2/0.97,3.5/
0.98,3.9/0.99,4.6/0.995,5.3/0.998,6.2/0.999,7.0/0.9997,8.0



MATRICES

The two control matrices for GPSS program are MH1 and MH2.

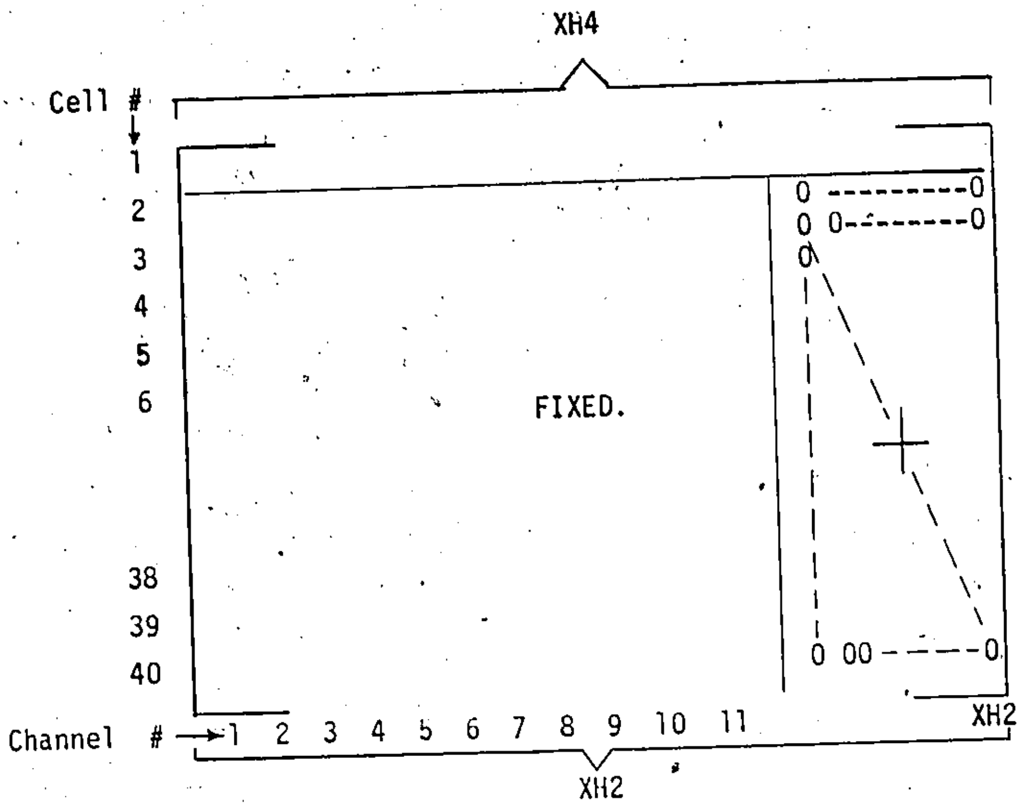
1. MH1 is used to keep track on the availability of the fixed channels in all cells related to the service area. MH1 has dimensions 40xXH2. The number of rows corresponds to the number of cells in the system. In our case the number of rows is 40.

2. MH2 is used to record the distribution of dynamic channel throughout the system. MH2 has dimensions 40 x XH3.

Entries in both matrices change in a dynamic fashion as the simulation progresses. We specify "x" as row number (cell number) and"y" the column number. Therefore, any positions (x,y) in MH1 can assume the logical values "0" and "1" indicating the availability or nonavailability respectively of Fixed Channels "y" in cell "x". same with Matrix MH2, any position (x,y) in MH2 can only assume the values "0" and "1" indicating the non-use or use of dynamic channels "y" in cell "x".

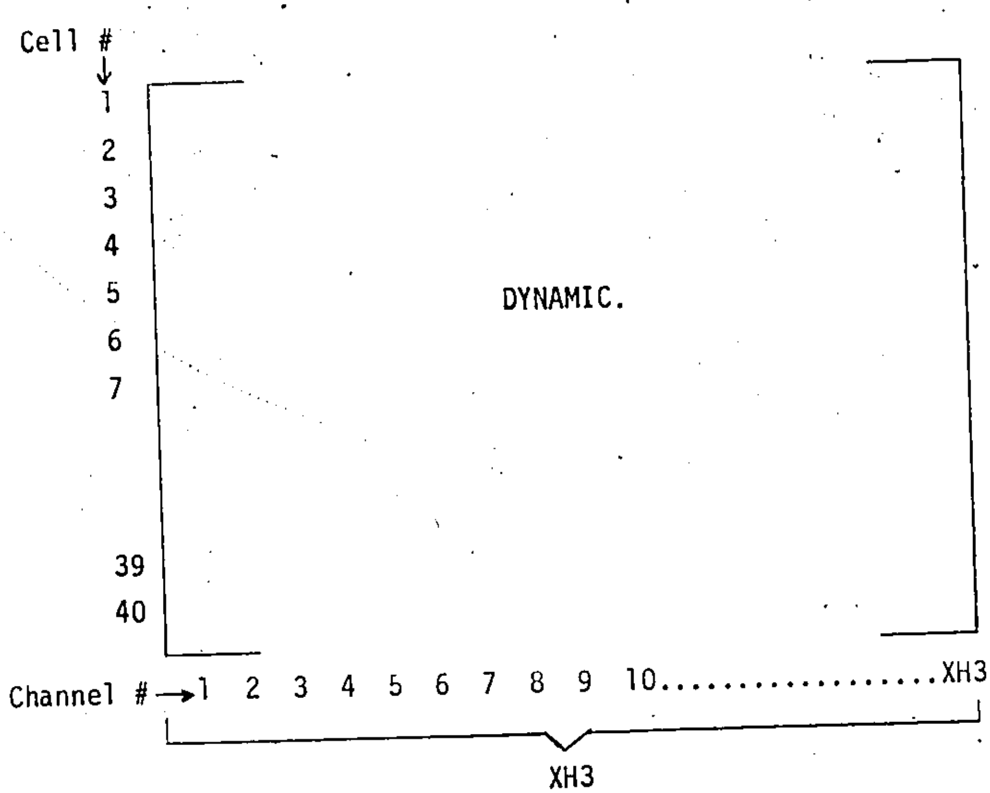
If "y1" Fixed Channels assigned to row #1 (cell #1) and "y2" Fixed Channels assigned to each of the remaining rows in MH1 then we would give to MH1 the value of "y1" if (y1 > y2), that is

Initial	XH3,# of fixed channels/cell (voice)	
Initial	XH3,# of dynamic channels in system	
Initial	XH4,# of fixed channels/cell#1 (voice)	
Matrix	H,40,# of columns =	maximum number of fixed channels
Matrix	H,40,# of columns =	number of dynamic channels in system area.



Entrys to the Matrix would be 1 or zero; a zero would indicate the channel is idle, a 1 would indicate the channel is busy.

+ would indicate: XH4 > XH2



A "1" in position (x,y) would indicate that channel y is currently being used in cell x .

PARAMETER OF EACH TRANSACTION

P1	contains the cell number (source) of each cell.
P3	number of fixed channels per cell if call served by fixed channel assignment.
P3	number of dynamic channels in system; if call served by dynamic channel assignment.
P6	indicates whether a call is currently using a fixed or a dynamic channel assignment.
P7	If call was not assigned P7=0 If call was assigned P7=1
P8	Parameter used in channel reassignment.

STORAGES

1-40	Storages 1 through 40 are assigned a capacity of 50 calls.
41	Entire system statistics.

TABLES

JOHNA	Tabulates the calls that have been served immediately upon arrival.

FAILA	Tabulates the calls that have been denied of service (BCC)
KARLA	Tabulate the calls that have been served by dynamic channels (assignment/reassignment)

VARIABLES

1-40	Variable "i" gives the cochannel interference criterion whether or not a given dynamic channels may be used in a given cell.
41-80	Same as above,they are the combinations of the expressions for variables 1 to 40.
81	The maximum simulation time.
82	The mean call holding time.
83	The mean call-interarrival-time for central cell
84	The mean call-interarrival-time for the surrounding cells (#2 through #40).

BOOLEAN VARIABLES

1	Controls the simulation run.

```
//GPSS.SYSIN DD *
        CREATE
        REALLOCATE BLO,500,BVR,2,CHA,1,COM,110000,FMS,1
        REALLOCATE FSV,1,FUN,2,GRP,41,HMS,7,HSV,10,LOG,41
        REALLOCATE QUE,42,STO,42,TAB,5,VAR,87,XAC,1500
        SIMULATE   16
*
*INITIALIZATION
*
        INITIAL    XH2,8        # OF FIXED CHANNELS/CELL (VOICE)
        INITIAL    XH3,6        # OF DYNAMIC CHANNELS IN SYSTEM
        INITIAL    XH4,8        # OF FIXED CHANNELS/CELL1 (VOICE)
 1      MATRIX     H,40,8       # OF COLUMNS = MAX NUM OF FIXD CHAS
 2      MATRIX     H,40,6       # OF COLUMNS = XH3
*
*STORAGE AND QUEUE DEFINITION
*
        STORAGE    S1-S40,50  STORAGES 1 THRU 40 ARE ASSIGNED A
 SYSTM EQU         41,S       CAPACITY OF 50 CALLS.  STORAGE
 SYSTM STORAGE                "SYSTM" HAS UNLIMITED CAPACITY.
*
*TABLE DEFINITION
*
 JOHNA TABLE       P1,1,1,41  "JOHNA/FAILA" TABULATE THE NUMBER OF
 FAILA TABLE       P1,1,1,41  CALLS WHICH OBTAIN THE VOICE CHANNEL
 DANI  TABLE       P1,1,1,41  TABLE OF CHANNELS REASSIGNMENT
 KARLA TABLE       P1,1,1,41  TABLE OF CALLS WHICH OBTAIN DYN CHANS
*
*FUNCTION DEFINITION(S)
*
 EXPON FUNCTION    RN4,C24      EXPONENTIAL DISTRIBUTION FON
0,0/.1,.104/.2,.222/.3,.355/.4,.509/.5,.69/.6,.915/.7,1.2/.75,1.38
.8,1.6/.84,1.83/.88,2.12/.9,2.3/.92,2.52/.94,2.81/.95,2.99/.96,3.2
.97,3.5/.98,3.9/.99,4.6/.995,5.3/.998,6.2/.999,7/.9998,8
*
*VARIABLE DEFINITION
*
 1      VARIABLE   MH2(1,P3)+MH2(2,P3)+MH2(3,P3)+MH2(4,P3)+V41
 2      VARIABLE   MH2(2,P3)+MH2(9,P3)+MH2(10,P3)+MH2(3,P3)+V42
 3      VARIABLE   MH2(3,P3)+MH2(10,P3)+MH2(11,P3)+MH2(12,P3)+V43
 4      VARIABLE   MH2(4,P3)+MH2(3,P3)+MH2(12,P3)+MH2(13,P3)+V44
 5      VARIABLE   MH2(5,P3)+MH2(1,P3)+MH2(4,P3)+MH2(14,P3)+V45
 6      VARIABLE   MH2(6,P3)+MH2(7,P3)+MH2(1,P3)+MH2(5,P3)+V46
 7      VARIABLE   MH2(7,P3)+MH2(8,P3)+MH2(2,P3)+MH2(1,P3)+V47
 8      VARIABLE   MH2(8,P3)+MH2(21,P3)+MH2(9,P3)+MH2(2,P3)+V48
 9      VARIABLE   MH2(9,P3)+MH2(22,P3)+MH2(23,P3)+MH2(10,P3)+V49
 10     VARIABLE   MH2(10,P3)+MH2(23,P3)+MH2(24,P3)+MH2(11,P3)+V50
 11     VARIABLE   MH2(11,P3)+MH2(24,P3)+MH2(25,P3)+MH2(26,P3)+V51
 12     VARIABLE   MH2(12,P3)+MH2(11,P3)+MH2(26,P3)+MH2(27,P3)+V52
 13     VARIABLE   MH2(13,P3)+MH2(12,P3)+MH2(27,P3)+MH2(28,P3)+V53
 14     VARIABLE   MH2(14,P3)+MH2(4,P3)+MH2(13,P3)+MH2(29,P3)+V54
 15     VARIABLE   MH2(15,P3)+MH2(5,P3)+MH2(14,P3)+MH2(30,P3)+V55
 16     VARIABLE   MH2(16,P3)+MH2(6,P3)+MH2(5,P3)+MH2(15,P3)+V56
 17     VARIABLE   MH2(17,P3)+MH2(18,P3)+MH2(6,P3)+MH2(16,P3)+V57
 18     VARIABLE   MH2(18,P3)+MH2(19,P3)+MH2(7,P3)+MH2(6,P3)+V58
 19     VARIABLE   MH2(19,P3)+MH2(20,P3)+MH2(8,P3)+MH2(7,P3)+V59
```

71.	20	VARIABLE	MH2(20,P3)+MH2(39,P3)+MH2(21,P3)+MH2(8,P3)+V60
72.	21	VARIABLE	MH2(21,P3)+MH2(40,P3)+MH2(22,P3)+MH2(9,P3)+V61
73.	22	VARIABLE	MH2(22,P3)+MH2(23,P3)+MH2(9,P3)+V62
74.	23	VARIABLE	MH2(23,P3)+MH2(24,P3)+MH2(10,P3)+V63
75.	24	VARIABLE	MH2(24,P3)+MH2(25,P3)+MH2(11,P3)+V64
76.	25	VARIABLE	MH2(25,P3)+MH2(26,P3)+V65
77.	26	VARIABLE	MH2(26,P3)+MH2(27,P3)+MH2(12,P3)+V66
78.	27	VARIABLE	MH2(27,P3)+MH2(28,P3)+MH2(13,P3)+V67
79.	28	VARIABLE	MH2(28,P3)+MH2(29,P3)+V68
80.	29	VARIABLE	MH2(29,P3)+MH2(30,P3)+MH2(14,P3)+V69
81.	30	VARIABLE	MH2(30,P3)+MH2(31,P3)+MH2(15,P3)+V70
82.	31	VARIABLE	MH2(31,P3)+MH2(32,P3)+V71
83.	32	VARIABLE	MH2(32,P3)+MH2(33,P3)+MH2(16,P3)+V72
84.	33	VARIABLE	MH2(33,P3)+MH2(34,P3)+MH2(17,P3)+V73
85.	34	VARIABLE	MH2(34,P3)+MH2(35,P3)+V74
86.	35	VARIABLE	MH2(35,P3)+MH2(36,P3)+MH2(18,P3)+V75
87.	36	VARIABLE	MH2(36,P3)+MH2(37,P3)+MH2(19,P3)+V76
88.	37	VARIABLE	MH2(37,P3)+MH2(38,P3)+MH2(20,P3)+V77
89.	38	VARIABLE	MH2(38,P3)+MH2(39,P3)+V78
90.	39	VARIABLE	MH2(39,P3)+MH2(40,P3)+V79
91.	40	VARIABLE	MH2(40,P3)+MH2(22,P3)+V80
92.	41	VARIABLE	MH2(5,P3)+MH2(6,P3)+MH2(7,P3)
93.	42	VARIABLE	MH2(1,P3)+MH2(7,P3)+MH2(8,P3)
94.	43	VARIABLE	MH2(4,P3)+MH2(1,P3)+MH2(2,P3)
95.	44	VARIABLE	MH2(14,P3)+MH2(5,P3)+MH2(1,P3)
96.	45	VARIABLE	MH2(15,P3)+MH2(16,P3)+MH2(6,P3)
97.	46	VARIABLE	MH2(16,P3)+MH2(17,P3)+MH2(18,P3)
98.	47	VARIABLE	MH2(6,P3)+MH2(18,P3)+MH2(19,P3)
99.	48	VARIABLE	MH2(7,P3)+MH2(19,P3)+MH2(20,P3)
100.	49	VARIABLE	MH2(2,P3)+MH2(8,P3)+MH2(21,P3)
101.	50	VARIABLE	MH2(3,P3)+MH2(2,P3)+MH2(9,P3)
102.	51	VARIABLE	MH2(12,P3)+MH2(3,P3)+MH2(10,P3)
103.	52	VARIABLE	MH2(13,P3)+MH2(4,P3)+MH2(3,P3)
104.	53	VARIABLE	MH2(29,P3)+MH2(14,P3)+MH2(4,P3)
105.	54	VARIABLE	MH2(30,P3)+MH2(15,P3)+MH2(5,P3)
106.	55	VARIABLE	MH2(31,P3)+MH2(32,P3)+MH2(16,P3)
107.	56	VARIABLE	MH2(32,P3)+MH2(33,P3)+MH2(17,P3)
108.	57	VARIABLE	MH2(33,P3)+MH2(34,P3)+MH2(35,P3)
109.	58	VARIABLE	MH2(17,P3)+MH2(35,P3)+MH2(36,P3)
110.	59	VARIABLE	MH2(18,P3)+MH2(36,P3)+MH2(37,P3)
111.	60	VARIABLE	MH2(19,P3)+MH2(37,P3)+MH2(38,P3)
112.	61	VARIABLE	MH2(8,P3)+MH2(20,P3)+MH2(39,P3)
113.	62	VARIABLE	MH2(21,P3)+MH2(40,P3)
114.	63	VARIABLE	MH2(9,P3)+MH2(22,P3)
115.	64	VARIABLE	MH2(10,P3)+MH2(23,P3)
116.	65	VARIABLE	MH2(11,P3)+MH2(24,P3)
117.	66	VARIABLE	MH2(11,P3)+MH2(25,P3)
118.	67	VARIABLE	MH2(12,P3)+MH2(26,P3)
119.	68	VARIABLE	MH2(13,P3)+MH2(27,P3)
120.	69	VARIABLE	MH2(13,P3)+MH2(28,P3)
121.	70	VARIABLE	MH2(14,P3)+MH2(29,P3)
122.	71	VARIABLE	MH2(15,P3)+MH2(30,P3)
123.	72	VARIABLE	MH2(15,P3)+MH2(31,P3)
124.	73	VARIABLE	MH2(16,P3)+MH2(32,P3)
125.	74	VARIABLE	MH2(17,P3)+MH2(33,P3)

```
 75     VARIABLE    MH2(17,P3)+MH2(34,P3)
 76     VARIABLE    MH2(18,P3)+MH2(35,P3)
 77     VARIABLE    MH2(19,P3)+MH2(36,P3)
 78     VARIABLE    MH2(20,P3)+MH2(37,P3)
 79     VARIABLE    MH2(21,P3)+MH2(20,P3)
 80     VARIABLE    MH2(21,P3)+MH2(39,P3)
 81     VARIABLE    9000000     MAXIMUM SIMULATION TIME
 82     VARIABLE    120000      MEAN CALL HOLDING TIME
 83     VARIABLE    24000       MEAN INTERARRIVAL TIME OF CALLS
 84     VARIABLE    24000       MEAN INTERARRIVAL TIME OF CALLS
 1      BVARIABLE   C1'LE'V81*N$CALLS'LE'130000
*
*CALL GENERATION
*
 CEL1   GENERATE    V83,FN$EXPON,,,10,F
        ASSIGN      1,1
        TRANSFER    ,JIMS
 CEL2   GENERATE    V84,FN$EXPON,,,10,F
        ASSIGN      1,2
        TRANSFER    ,JIMS
 CEL3   GENERATE    V84,FN$EXPON,,,10,F
        ASSIGN      1,3
        TRANSFER    ,JIMS
 CEL4   GENERATE    V84,FN$EXPON,,,10,F
        ASSIGN      1,4
        TRANSFER    ,JIMS
 CEL5   GENERATE    V84,FN$EXPON,,,10,F
        ASSIGN      1,5
        TRANSFER    ,JIMS
 CEL6   GENERATE    V84,FN$EXPON,,,10,F
        ASSIGN      1,6
        TRANSFER    ,JIMS
 CEL7   GENERATE    V84,FN$EXPON,,,10,F
        ASSIGN      1,7
        TRANSFER    ,JIMS
 CEL8   GENERATE    V84,FN$EXPON,,,10,F
        ASSIGN      1',8
        TRANSFER    ,JIMS
 CEL9   GENERATE    V84,FN$EXPON,,,10,F
        ASSIGN      1,9
        TRANSFER    ,JIMS
 CEL10  GENERATE    V84,FN$EXPON,,,10,F
        ASSIGN      1,10
        TRANSFER    ,JIMS
 CEL11  GENERATE    V84,FN$EXPON,,,10,F
        ASSIGN      1,11
        TRANSFER    ,JIMS
 CEL12  GENERATE    V84,FN$EXPON,,,10,F
        ASSIGN      1,12
        TRANSFER    ,JIMS
 CEL13  GENERATE    V84,FN$EXPON,,,10,F
        ASSIGN      1,13
        TRANSFER    ,JIMS
 CEL14  GENERATE    V84,FN$EXPON,,,10,F
        ASSIGN      1,14
```

```
              TRANSFER   ,JIMS
      CEL15   GENERATE   V84,FN$EXPON,,,,10,F
              ASSIGN     1,15
              TRANSFER   ,JIMS
      CEL16   GENERATE   V84,FN$EXPON,,,,10,F
              ASSIGN     1,16
              TRANSFER   ,JIMS
      CEL17   GENERATE   V84,FN$EXPON,,,,10,F
              ASSIGN     1,17
              TRANSFER   ,JIMS
      CEL18   GENERATE   V84,FN$EXPON,,,,10,F
              ASSIGN     1,18
              TRANSFER   ,JIMS
      CEL19   GENERATE   V84,FN$EXPON,,,,10,F
              ASSIGN     1,19
              TRANSFER   ,JIMS
      CEL20   GENERATE   V84,FN$EXPON,,,,10,F
              ASSIGN     1,20
              TRANSFER   ,JIMS
      CEL21   GENERATE   V84,FN$EXPON,,,,10,F
              ASSIGN     1,21
              TRANSFER   ,JIMS
      CEL22   GENERATE   V84,FN$EXPON,,,,10,F
              ASSIGN     1,22
              TRANSFER   ,JIMS
      CEL23   GENERATE   V84,FN$EXPON,,,,10,F
              ASSIGN     1,23
              TRANSFER   ,JIMS
      CEL24   GENERATE   V84,FN$EXPON,,,,10,F
              ASSIGN     1,24
              TRANSFER   ,JIMS
      CEL25   GENERATE   V84,FN$EXPON,,,,10,F
              ASSIGN     1,25
              TRANSFER   ,JIMS
      CEL26   GENERATE   V84,FN$EXPON,,,,10,F
              ASSIGN     1,25
              TRANSFER   ,JIMS
      CEL27   GENERATE   V84,FN$EXPON,,,,10,F
              ASSIGN     1,27
              TRANSFER   ,JIMS
      CEL28   GENERATE   V84,FN$EXPON,,,,10,F
              ASSIGN     1,28
              TRANSFER   ,JIMS
      CEL29   GENERATE   V84,FN$EXPON,,,,10,F
              ASSIGN     1,29
              TRANSFER   ,JIMS
      CEL30   GENERATE   V84,FN$EXPON,,,,10,F
              ASSIGN     1,30
              TRANSFER   ,JIMS
      CEL31   GENERATE   V84,FN$EXPON,,,,10,F
              ASSIGN     1,31
              TRANSFER   ,JIMS
      CEL32   GENERATE   V84,FN$EXPON,,,,10,F
              ASSIGN     1,32
              TRANSFER   ,JIMS
```

```
       CEL33 GENERATE    V84,FN$EXPON,,,,10,F
             ASSIGN      1,33
             TRANSFER    ,JIMS
       CEL34 GENERATE    V84,FN$EXPON,,,,10,F
             ASSIGN      1,34
             TRANSFER    ,JIMS
       CEL35 GENERATE    V84,FN$EXPON,,,,10,F
             ASSIGN      1,35
             TRANSFER    ,JIMS
       CEL36 GENERATE    V84,FN$EXPON,,,,10,F
             ASSIGN      1,36
             TRANSFER    ,JIMS
       CEL37 GENERATE    V84,FN$EXPON,,,,10,F
             ASSIGN      1,37
             TRANSFER    ,JIMS
       CEL38 GENERATE    V84,FN$EXPON,,,,10,F
             ASSIGN      1,38
             TRANSFER    ,JIMS
       CEL39 GENERATE    V84,FN$EXPON,,,,10,F
             ASSIGN      1,39
             TRANSFER    ,JIMS
       CEL40 GENERATE    V84,FN$EXPON,,,,10,F
             ASSIGN      1,40
             TRANSFER    ,JIMS
       JIMS  TEST E      *1,1,CELLI
             ASSIGN      3,XH4
             TRANSFER    ,CALLS
      *
       CELLI ASSIGN      3,XH2
             TRANSFER    ,CALLS
       CALLS ENTER       SYSTM
             GATE LR     *1,DYNO1
      *
      *FIXED CHANNEL ASSIGNMENT
      *
             TEST NE     XH2,0,DYNO1
             TEST NE     XH4,0,DYNO1
       FIXED TEST E      MH1(P1,P3),0,SERCH
             MSAVEVALUE  1,P1,P3,1,H
             TABULATE    JOHNA
             ENTER       P1
             PRIORITY    2
             ADVANCE     V82,FN$EXPON
             TEST E      G*1,0,FREE
             MSAVEVALUE  1,P1,P3,0,H
       RESET LOGIC R     P1
             TRANSFER    ,EXIT
      *
      *SEARCH FOR A FIXED CHANNEL
      *
       SERCH LOOP        3,FIXED
             LOGIC S     P1
             TRANSFER    ,DYNO1
       FAILA TABULATE    FAILA
             LEAVE       SYSTM
```

```
        TERMINATE
*
*DYNAMIC CHANNEL ASSIGNMENT
*
 DYN01  ASSIGN      3,XH3
 DYN2   TEST E      V*1,0,LOOK
        MSAVEVALUE  2,P1,P3,1,H
        TABULATE    KARLA
        ASSIGN      6,1
        JOIN        P1
        ENTER       P1
        PRIORITY    2
        ADVANCE     V82,FN$EXPON
        TEST E      P7,0,MORE
        REMOVE      P1
        MSAVEVALUE  2,P1,P3,0,H
        TRANSFER    ,EXIT
*
 LOOK   LOOP        3,DYN2
        TRANSFER    ,FAILA
        LEAVE       SYSTM
        TERMINATE
*
 MORE   TEST E      G*1,0,FREE
        MSAVEVALUE  1,P1,P3,0,H
        LOGIC R     P1
        TRANSFER    ,EXIT
*
*CHANNEL REASSIGNMENT
*
 FREE   SCAN        P1,6,1,3,8,RESET
        ALTER       P1,1,7,1,3,P8
        ALTER       P1,1,3,P3,3,P8
        MSAVEVALUE  2,P1,P8,0,H
        REMOVE      P1,1,,3,P3
        TABULATE    DANI
        TRANSFER    ,EXIT
*
*CALLS LEAVE SYSTM
*
 EXIT   LEAVE       P1
        LEAVE       SYSTM
        TERMINATE
*
*AUXILIARY CLOCK
*
        GENERATE    355000
        TEST E      BV1,1,STOP
        TERMINATE   1
 STOP   TERMINATE   24
        START       1,NP
        RESET       S41
        START       25,,,
        END
/*
```

REFERENCES

1. Bernard T. O'connor, "Developments in Mobile Telephone Systems", Telecommunications. Vol. 15, No. 2, February 1981, PP. 31-32.

2. James Martin, Systems Analysis for Data Transmission, Prentice-Hall, Englewood Cliffs, New Jersey, 1972.

3. Martin Nesenbergs, "A Hybrid of Erlang B and C Formulas and its Applications", IEEE Tran. on Comm. Vol. COM. 27, No. 1, January 1979, PP. 59-68.

4. William C.Jakes Jr, Microwave Mobile Communications, John Wiley & Sons, New York, 1974.

5. "Technical Report of the American Telegraph & Telephone Company on High Capacity Mobile Radio Communications Systems", Dec. 1971.

6. T.J.Kahwa and N.D.Georganas, "A Hybrid Channel Assignment Scheme in Large-Scale Cellular -Structured Mobile Communication System", IEEE Tran.Comm. Vol. COM. 26, No. 4, April 1978, pp. 432-438.

7. Richard H. Frenkiel, "A High-Capacity Mobile Radiotelephone System Model Using a Coordinated Small-Zone Approach", IEEE Trans. on Veh. Tech., Vol. VT-19, May 1970, pp. 173-177.

8. Robert W. Donaldson, "Analysis and Design of Mobile Radio Cellular Systems with Fixed Channel Assignments", Report for the Dept. of Communications, Ottawa, Canada, Jan. 1978.

9. J.Sin, "A Hybrid Channel Assignment Scheme for Cellular, High-Capacity, Land-Mobile Radio Communications Systems with Erlang-C Service", M.A.Sc Thesis, University of Ottawa, Canada, April 1979.

10. Lewis G. Anderson, "A Simulation Study of Some Dynamic Channel Assignment Algorithms in a High Capacity Mobile Telecommunications Systems", IEEE Trans. on Veh. Tech., Vol. VT-22, No. 4, Nov. 1973, pp. 210-217.

11. Joel S. Engel and Martin M. Peritsky, "Statistically Optimum Dynamic Server Assignment in Systems with Interfering Servers", IEEE Trans. on Veh. Tech., VT-22, No. 4, Nov. 197, pp. 203-209.

12. D.C. Cox and D.O. Reudink, "Increasing Channel Occupancy in Large Scale Mobile Radio System: Dynamic Channel Reassignment", IEEE Trans. on Veh. Tech., November 1973, pp. 218-222.

13. D.C. Cox and R.O. Reudink, "Dynamic Channel Assignment in two-Dimensional Large-Scale Mobile Radio Systems", BSTJ, Vol. 51, No. 7, 1972, pp. 1611-1629.

14. IBM General Purpose Simulation System User's Manual, SH20-0851-1, Second Edition, IBM, White Plains, N.Y., 1971.

15. Thomas J. Schriber, Simulation Using GPSS, John Wiley & Sons, New York, N.Y., 1974.

16. P.A. Robillier, B.C. Kahan, A.R. Probst, Simulation with GPSS and GPSS V, Prentice-Hall, INC., Englewood Cliffs, New Jersey, 1976.

17. Richard N. Lane, "Spectral and Economic Efficiencies of Land Mobile Radio Systems", IEEE Trans. on Veh. Tech., VT-22, No. 4, Nov. 1973, pp. 93-103.

18. G.A. Arredondo, J.C. Feggler, and J.A. Smith, "AMPS:Voice and Data Transmission", Vol. 58, No. 1, January 1979.

19. "Advanced Mobile Phone Service", BSTJ, Vol. 58, No. 1, January 1979.

20. S. Elnoubi, R. Singh and S.C. Gupta, "A New Channel Assignment Scheme in Land Mobile Radio Communications", E.E, Dept., Southern Methodist University, Dallas, Texas, N.T.C Conference, 1979.

21. Harold Staras and Leonard Schiff, "A Dynamic Space Division Multiplex Mobile Radio System", IEEE Trans. Veh. on Tech., Vol. 20, No. 3, August 1979, pp. 206-213.

22. Leonard Schiff, "Traffic Capacity of Three Types of Commun User Mobile Radio Communication Systems", IEEE Trans. on Comm. Tech., Vol. COM-18, No. 1, February 1970, pp. 12-21.

23. George R. Cooper and Raymond W. Nettleton, "A Spread-Spectrum Technique for High-Capacity Mobile Communications", IEEE Trans. on Veh. Tech., Vol.VT-27, No. 4, November 1978, pp. 264-275.

24. Philip T. Porter, "Supervision and Control Features of a Small-Zone Radiotelephone System", IEEE Trans. on Veh. Tech., Vol.20, No.3, August 1970, pp. 75-79.

25. D.C. Cox and D.O. Reudink, "Effects of Some Nonuniform Spatial Demand Profiles on Mobile Radio System Performance", IEEE Trans. on Veh. Tech., Vol.VT-21, No. 2, May 1972, pp. 62-67.

26. D.C. Cox and D.O. Reudink, "Dynamic Channel Assignment in High-Capacity Mobile Communications Systems", B.S.T.J, Vol.50, No.60, July-August, 1971, pp. 1833-857.

27. D.C. Cox and D.O. Reudink, "Some Effects on Channel Occupancy of Limiting the Number of Available Servers in Small Cell Mobile Radio Systems Using Dynamic Channel Assignment", IEEE Trans. on Comm. Vol. COM-27, No. 8, August 1979, pp. 1224-1226.

28. Zachary C. Fluht and Eric Nussbaum, "Switching Plan for a Cellular Mobile Telephone System", IEEE Trans. on Veh. Tech., Vol.VT-22, No. 4, November 1973, pp. 197-202.

29. J.K. Sin and N.D. Georganas, "A Simulation Study of a Hybrid Channel Assignment Scheme for Cellular, Land-Mobile Radio Systems with Erlang-C Service", IEEE Trans. on Comm. Vol. COM-29, No. 2, February 1981, PP. 143-147.

30. N.D. Georganas, "Etude de Methodes de la Gestion du Spectre des Frequences pour les Systemes de Communications Mobiles", Research Contract Report, Phase II, Federal Dept. of Communications, Ottawa, March 1980.

31. N.D. Georganas, "Etude de Methodes de la Gestion du spectre des Frequences pour les Systemes de Communications Mobiles", Research Contract Report, Phase III, Federal Dept. of Communications, Ottawa, March 1981.

32. G. Nehme, G. Mousseau, A. Michaud and N.D. Georganas, "A Simulation Study of High-Capacity Cellular Land-Mobile Radio-Communication Systems", Canadian Communications & Power Conference, October 1980, PP. 421-424.

V I T A E

NAME	:	George Hanna Nehmé
DATE AND PLACE OF BIRTH	:	ZAHLE, LEBANON, 1954
EDUCATION	:	B.A.Sc. (Electrical Engineering)
		April 1979
		University of Ottawa,
		Ottawa, Ontario