Problem 4:
A digital signaling system is required to operate at 9.6 kbps. If a signal element encodes a 4-bit word, what is the minimum bandwidth of the channel?

Solution:
Channel capacity (C) = 9.6 kbps = 9600 bps.
A signal element encodes a 4-bit word.
That means \( \log_2 M = 4 \).
Bandwidth (B) = ?
Then by Nyquist’s formula,
\[ C = 2B \log_2 (M) \]
Hence,
\[ 9600 = 2B \times 4 = 8B \]
i.e. \( B = 9600/8 = 1200 \text{ Hz.} = 1.2 \text{ KHz} \).
Hence the minimum bandwidth of the channel = 1.2 KHz.

Problem 5:
Given a channel with intended capacity of 20 Mbps, the bandwidth of the channel is 3 MHz. What signal-to-noise ratio is required to achieve this capacity?

Solution:
Capacity (C) = 20 Mbps = 20\times10^6 bps.
Bandwidth (B) = 3 MHz = 3\times10^6 Hz.
Signal-to noise ratio (SNR) = ?
By Shannon’s capacity formula,
\[ C = B \log_2 (1+SNR) \]
i.e. \( 20\times10^6 = 3\times10^6 \times \log_2 (1+SNR) \)
Therefore \( \log_2 (1+SNR) = 20/3 \)
i.e. \( \frac{\log (1+SNR)}{\log 2} = 20/3 \)
i.e. \( \log (1+SNR) = \frac{20\log 2}{3} = 2.01 \)
Hence $1 + \text{SNR} = 101.59 \approx 102$

Therefore $\text{SNR} = 101$

Hence the required signal-to-noise ratio is 101.

**Problem 6:**

The receiver in a communication system has a received signal power of -134 dBm, a received noise power spectral density of -174 dBm/Hz, and a bandwidth of 2000 Hz. What is the maximum rate of error-free information for the system?

**Solution:**

Received signal power = -134 dBm

Received noise power spectral density = -174 dBm/Hz

$\text{SNR(dBm)} = \text{signal power} - \text{noise power} = -134 - (-174) = 40 \text{ dBm}$

i.e. $\text{SNR} = 10 \text{ dB}$

By Shannon’s capacity formula,

$C = B \log_2 (1 + \text{SNR})$

i.e $C = 2000 * \log_2 (1 + 10) = 2000 * 3.46 = 6918.86 \text{ bps} = 6.76 \text{ kbps}$.

Hence the maximum rate of error-free information = 6.76 kbps.
Summary

Chapter 2: Teletraffic Engineering

2.1 Introduction:
When we are taking about teletraffic engineering, the call capacity of a MSC is a major factor to study. We use Erlang and Poisson blocking formulas to calculate GoS.

2.2 Service Level:
Service level in telegraphic engineering is divided into two parts.

1. The delay in receiving a dial tone
2. Service denial: due to less availability of trunks

2.3 Traffic Usage:
It is defined by two parameters:

1. Calling rate
2. Call holding time

The carried traffic is the volume of traffic actually carried by a switch, offered traffic is the volume of traffic is the volume of traffic offered to a switch and overflow traffic is the one which cannot be handled by the switch.

Offered load = carried load + overflow.

2.4 Traffic Measurement Units:
Traffic is measured in Erlangs, percentage of occupancy, centrum call seconds (CCS) or peg count.

\[
\text{Traffic Intensity} = \frac{\text{the sum of circuit holding time}}{\text{the duration of monitoring period}}
\]

\[
I = \frac{\sum_{i=1}^{N_C} t_i}{T} = \frac{N_C \bar{t}}{T} = n_s \bar{t}
\]

Where:
I = traffic intensity
T = duration of monitoring period
\( t_i = \) the holding time of the \( i^{th} \) individual call

\( N_c = \) the total number of calls in monitoring period

\( \bar{t} = \) average holding time

\( n_c = \) number of calls per unit time

2.5 Call Capacity:

It is defined with respect to a view of MSC. There are two ways to view the system.

1 Global view: The entire MSC is considered to be a single unit. In this, the call volume of interest is expressed as the sum of the originating and incoming (\( O + I \)) calls.

   a) Originating call (\( O \)) includes:
      → Partial dialed calls
      → Intra-office calls
      → Outgoing calls

   b) Incoming call (\( I \)) includes:
      → Incoming-terminating calls
      → Tandem calls
      → Direct inward dialing (DID)

2 Component view: The component of interest is considered a subsystem. Each request to the component for service is counted as an attempt. In this, the call volume of interest is expressed as the sum of the originating and terminating (\( O + T \)) half-calls.

   a) Originating half-calls: One originating half-call is for each originating call, because two peripheral equipment connections are required for a complete call. If the component serves both lines and trunks, incoming and outgoing half-calls are added to the total half-call volume.

   b) Terminating half-call: One terminating half call is for each incoming-terminating call and each interoffice call.

2.6 Definitions of Terms:

The following terms are used for mobile systems:

1. Number of calls attempted: it is the best measure of unconstrained customer demand.
2. Number of calls completed: the number of calls completed in a network sense, when compared with number of calls attempted, provides a measure of the state of network congestion.
3. Grade of Service (GoS): \( \frac{\text{No. of busy hour call attempts}}{\text{No. of busy hour call completed}} - \frac{\text{No. of busy hour call completed}}{\text{No. of busy hour call attempts}} \)
4. Quality of Service (QoS): It is an important factor in many areas of the telecommunications business. Several factors affect QoS. These are:
→ Transmission quality (level, crosstalk, echo etc.)
→ Dial tone delay and post dial delay
→ Grade of service
→ False incident and service deficiency
→ Adaptation of the system to the subscribers

2.7 Data collection:
The following data is collected on an MSC:
1. Page Count: one page count for each of the following categories – call attempt, trunk-group seizure attempt, test made for dial tone speed, call queued.
2. Overflow: overflow for each attempt collected for universal tone decoders, trunk groups, etc.
3. Traffic Usage: measured for trunks, decoders, etc.

2.8 Office engineering considerations:
The following steps are often taken in typical office engineering of a wireline or wireless office.
1. MSCs are engineered and administered based on the traffic load during the average busy hour of the busy season.
2. The busy hour is used for the overall administration, engineering, and maintenance of an office.
3. The component busy hour is used to establish trends, make projections, set capacities, and derive future requirements.
4. Dial-tone speed delay is recorded whenever a test call does not receive a dial tone within 3 seconds.
5. Terminating blockage is recorded whenever a terminating call is unable to complete because of a lack of an available path to the called line.
6. Trunk-group busy hour is the time-consistent hour during which maximum trunk-group load occurs. Trunk-group busy hour data is used to provide an adequate trunk base to meet service requirements.
7. Traffic data is collected for one or two weeks by half-hour during all parts of the day that may produce high loads (e.g., 8 A.M. to 11 P.M.).
8. Five days of the week with the heaviest load are determined; this is the business week of the office.
9. The hour (on the clock hour or on the half-hour) with the highest total load for the business week is determined; this is the office busy hour.
10. Traffic data collected for the busy hour for the months likely to be parts of the year that may produce high loads.
11. The three months, not necessarily consecutive, having the highest busy hour load are determined; this is the busy season.
12. The average load for the busy hour for the busy season’s business day is (Average Busy Season per Busy Hour) (ABS/BH)
13. The following approximate relations can be used to estimate the design traffic:
   \[(O + T) \text{ call: } (HD)/(ABS) = 1.4 - 1.5\]
   \[(O + I) \text{ call: } (HD)/(ABS) = 1.6 - 1.7\]
   High day (HD) origination attempts per call = 1.45

2.9 Traffic Types:
There are two traffic sources:
1. Infinite traffic source: the probability of call arrival is constant and does not depend on the occupancy of the system.
2. Finite traffic sources: the number of sources offering traffic to a group of trunks or circuits is comparatively small in comparison to the number of circuits.

2.10 Blocking formulas:
In conventional teletraffic engineering, three models are used for handling or dispensing lost calls:
   → Block Call Held (BCH): The BCH concept assumes that the user will immediately reatempt the call on receipt of a congestion signal and will continue to redial. The user hopes to seize connection equipment or a trunk as soon as equipment is available. In the BCH concept, lost calls are held or waiting at the calling user’s telephone.
   → Block Call Cleared (BCC): The BCC concept is primarily used in Europe, Asia, and Africa. In this case, the user hangs up and waits for some interval before reatempting the call if the user hears the congestion tone on the first attempt.
   → Block Call Delayed (BCD): The BCD concept assumes that the user is automatically put in a queue and is served when the connection equipment becomes available. The method by which a waiting call is selected from the pool of waiting calls is based on the queue discipline (such as first-come-first-served, first-come-last-served etc.). In the queuing system, the GoS is defined as the probability of delay.
   The assumptions in the Erlang B formula are:
   → Traffic originates from an infinite number of traffic sources independently.
   → Lost calls are cleared assuming a zero holding time.
   → Number of trunks or service channels is limited.
   → Full availability exists.
   → Inter-arrival times of call requests are independent of each other.
   → The probability of a user occupying a channel (called service time) is based on an exponential distribution.
   → Traffic requests are represented by a Poisson distribution implying exponentially distributed call inter-arrival times.

   \[ G_b = B(N,A) = \frac{A^N/A!}{\sum_{i=0}^{N} (A^i / i!)} \]

   Where:
   \( N \) = number of serving channels
   \( A \) = offered load
   \( B(N,A) \) = blocking probability

2. Poisson’s formula: The Poisson formula is used for designing trunks on a route for a given GoS.
   The assumptions in Poisson’s formula are:
   → Traffic originates from an infinite number of independent sources.
   → Traffic density per traffic source is equal.
   → Lost calls are held.
   → A limited number of trunks or service channels exist.

   \[ p_b = e^{-A \sum_{i=N}^{\infty} (A^i / i!)} \]

   Where:
   \( p_b \) = probability of blocking
   \( A \) = offered load
   \( N \) = number of serving channels

3. Erlang C formula: The Erlang C formula assumes that a queue is formed to hold all requested calls that cannot be served immediately.
   The assumptions in the Erlang C formula are:
   → Traffic originates from an infinite number of traffic sources independently.
   → Lost calls are delayed.
   → Number of trunks or service channels is limited.
   → The probability of a user occupying a channel (called service time) is based on an exponential distribution.
   → Calls are served in the order of arrival.
\[ C(N,A) = \frac{A^N}{\left[ N \left( 1 - \frac{A}{N} \right) \right]} \sum_{i=0}^{N-1} \frac{A^i}{i!} N\left( 1 - \frac{A}{N} \right) \]

Where:
N = number of serving channels
A = offered load
C(N,A) = blocking probability

4. Comparison of Erlang B and Poisson’s formulas: A comparison between the Erlang B and Poisson’s blocking formulas shows that Poisson’s formula results in higher blocking than that obtained by the Erlang B formula for a given traffic load.

5. Binomial formula: The binomial formula is also used in teletraffic engineering occasionally.
The assumptions used in the binomial formula are:
→ Traffic originates from a finite number of traffic sources independently.
→ Traffic density per traffic source is equal.
→ Lost calls are held in the system in a queue.

\[ p_b = \left[ \frac{s-D}{s} \right] s \sum_{i=0}^{s-1} \left( s-1 \right) / N \left[ \frac{D}{s-D} \right]^i \]

Where:
D = expected traffic density
p_b = blocking probability
N = number of channels in a group of channels
s = number of sources in group sources