Telecommunication Networks
Preface

• Intended audience for this course includes 4th year undergraduate Electrical and Telecommunication Engineering.
• Mathematics: 1st year University level.
• Rudimentary knowledge of modulation, and understand such terms as bandwidth, bit error rate, and line of sight.
Text Book


Introduction

• The industry reflects a drastic increase in the use of data communications and the digital network, whereas conventional telephony is taking a backseat.

• The internet has become ubiquitous much like the telephone did in the 1920s.

• Hence, data communications act as functional part of telecommunications, in other words, the overwhelming function of telecommunication is data communication.
Continue…

• There was, and still is, a philosophical difference between voice telephony and data communications in two arenas:
  1) Signaling.
  2) Error performance.

• Voice over IP (VoIP): This aptly joins the data and voice worlds.

• Wireless or Radio Systems: Such as broadband / ultrabroadband, line-of-sight microwave, satellite, cellular/PCS, and WLAN.

• Bulk delivery of information and the principle of bottleneck such as CATV.

• Network management or how we may keep the network operating at peak efficiency
Public Communication Networks
1) **Signaling:** in general, provides an exchange of information specifically concerned with the establishment and control of communication circuits whether connection-oriented or connectionless *(Alerting the second party).*

**Example:** In public switched telephony, signaling sets up a circuit in a *connection-oriented* fashion that is held in that condition until the call is terminated.
Example: In the data communications world, a message is broken down into packets, or frames, each of which has a header. The header directs the frame, or packet, to its destination. This is called connectionless service.

2) Error performance: In data communication we should expect better than 1 bit error in over 1000 million bits, while we can let error performance degrade on circuits carrying voice telephony to 1 bit error in 100 bits. Why? To be explained.
Chapter 1

Introduction to Basic Telephony
1.1 Definition and Concept

• Telecommunication deals with the service of providing electrical communication at a distance.
• The service is supported by an industry that depends on a large body of increasingly specialized scientists, engineers, and skilled people.
• The service may be private or open to public correspondence (i.e. access).
• Examples of the latter are government-owned telephone companies, often called administrations or private corporations, that sell their services publicly.
General block diagram of Telecommunication Network
Private Telecommunication Network
Simplified Telecommunication Network
1.2 Telecommunication Networks

Two major types of Telecom Networks:

• Public Switched Telephone Network (PSTN).
• Enterprise Networks

The primary concern of this subject is to:

• Describe the development of the PSTN and enterprise network.
• Discuss why they are built the way they are and how they are evolving.
1) PSTN

- It consists of hundreds of smaller networks interconnected.
- There are “fixed” and “mobile” counterparts.
- They may or may not have common ownership.
- Traditionally been based on speech operations.
Continue…

2) Enterprise Networks

• supports the business and government enterprise as a private business.
• Its most common configuration is the Local Area Network (LAN) and is optimized for data communications.
• Wide Area Network (WAN) is its long distance example developed by the US Department of Defense having been opened to the public worldwide. It is the internet.
1.3 Telecommunication Engineering

• Telecommunication engineering has traditionally been broken down into two basic segments:
  1) **Transmission**.
  Deals with the delivery of a quality electrical signal from point X to point Y.
  2) **Switching**.
  Connects X to Y, rather than to Z?
Continue…

• Transmission and switching were two very distinct disciplines.

• Today, that distinction has disappeared, particularly in the enterprise network.

• As we proceed through the development of this subject, we must deal with both disciplines and show in later chapters how the dividing line separating them has completely disappeared.
Chapter 2

Introduction To The Telephone Set
2.1 The Simple Telephone Connection

- For two persons A and B at a distance $D$ to communicate telephonically, each of them should be equipped by a microphone, a speaker, and a dc supply.
- The arrangements of the speakers is shown in the figure above.
Continue…

- Following the same scenario, for 8 users, each user should be equipped with 7 handsets.
- This type of connection is known as mesh connection.
- To provide service for \( n \) parties, the number of interconnection lines required to establish the network is

\[
NIL = \frac{n(n-1)}{2}
\]
The disadvantages of mesh network are

- The NIL increases nonlinearly with \( n \) that is impractical for large number of users.
- It has no selectivity method. With this telephone system, it is impossible to interconnect subscribers A and B without disturbing C.
- It has no alerting method for a party at a distance from the handset.
Continue…

To overcome these disadvantages:

1. A more powerful calling device with advanced features should be invented, this device is now known as **Telephone Set**.

2. A **signaling** standard must be introduced to set up the selectivity and alerting issues.
3. A **Central Office (CO)** is required to be established to perform signaling and switching.

- **Switch is defined as** a device that connects **inlets** to **outlets**.
- The inlet may be a calling subscriber line, and the outlet may be the line of a called subscriber.
2.2 Telephone Set

Is a device connected to the outside world by a pair of wires called *subscriber loop*. It serves the following basic functions:

1. Notify the user of an incoming call through an audible tone such as ring or bell.

2. The handset is made up of two electroacoustic transducers, the earpiece (Speaker) or receiver and the mouthpiece (Microphone) or transmitter.
3. Dialing subscribers number through a keypad.

4. It regulates the speech amplitude of the calling party by compensating for the varying distance to the central office.
5. It gain the attention of the central office when a user requests service by lifting the handset.

6. There is also a side-tone circuit that allows some of the transmitted energy to be fed back to the receiver. It is the sound of the talker’s voice heard in his (or her) own receiver.
7. It provides an open circuit dc path to the central office at idle condition.
8. In addition to receiving voice, it is also capable of receiving call progress tones such as busy, ringing, and so on from the central office.
Block diagram of telephone set
Continue…

• The dialing circuit is used for destination ID dialing through a keypad.
• The dc power supplied to the set from central office through the subscriber loop.
• Hybrid circuit is used to transform two wire system into four wire, hence, full-duplex operation is made possible.
• The equalizer is used to compensate for the varying lengths of wire between the central office and the subscriber.
2.2.1 Handset

Cross-sectional view of the telephone transmitter
Continue…

- Converts acoustic energy into electric energy by means of a carbon granule transmitter.
- Requires a dc potential called talk battery, usually on the order of 3 – 5 V, across its electrodes, which is supplied by the central battery from the switching center over the line and has been standardized at – 48 V dc, where –ve voltage is used to minimize electrolytic corrosion of the subscriber loop wires.
- Current from the battery flows through the carbon granules or grains when the handset is lifted from its cradle or goes “off hook”, otherwise, the phone is said to be “on hook”.

Continue…
Cross-sectional view of the telephone receiver
2.2.2 Telephone Ringer

Telephone ringer

90 V_{rms}
20 Hz
Continue…

• Its main function is to alert the party of an incoming call.
• Activated by a \(90 \text{ V}_{\text{rms}}\) at \(20 \text{ Hz}\) signal sent by the central office shown in next slide.
• The ring signal is superimposed on the existing \(-48 \text{ V dc}\) signal.
• The two coils are wound in a manner that causes the pivoting hammer to strike each bell on alternate parts of the cycle.
• The capacitor is used to block the dc current and pass the ac ringing current.
Telephone ring voltage: $90 \ V_{rms}$ at $20 \ Hz$

Ringing voltage for the telephone set
2.2.3 Telephone Hybrid and Side-tone

- Telephone **hybrid** is used to interface the transmitter and receiver’s individually paired wires to a single pair for the subscriber loop.
- It comprises of multiple winding transformers and additional electronic elements shown in next slide.
- It permits **full-duplex** operation.
Continue…

• **Side-tone** is a small amount of signal is fed back from a telephone’s mic to its speaker that allows the callers to hear themselves while speaking.

• Its level helps a person to determine how loudly to speak

• This feedback signal is generated through the balancing network shown in next slide.
Continue…

Schematic diagram of the Bell 500 telephone set.

Rotary dialing switch

Off-hook scenario
$S_1$ and $S_2$ closed

$S_1$ and $S_2$ separates the Ringer circuit from the Telephone system
2.3 Operation of the Telephone Set

- $S_1$ and $S_2$ are the on-hook/off-hook switches that open and close when the handset is engaged from its cradle.

- When the set is on-hook $S_1$ and $S_2$ are open, $D_1$ is close, and the -48 V dc supplied by the telephone company through the subscriber line has no current path to the set.

- When the set goes off-hook, $S_1$ and $S_2$ close and $S_3$ open, the -48 V dc droops to approximately -5 to -8 V dc due to the impedance the set presents to the line and the current flows through the set.
Continue…

DC connection from the central office
• This current flow is detected by the telephone company, which in turn, sends a dial tone to the caller indicating that service is available and a number may be dialed.

• In **Rotary Dialing (Dial Pulses)**, pulses are generated by making and breaking contact the line with switch $D_1$.

• Initially, $D_1$ is closed.

• $D_2$ shorts the receiver when dialing.
Continue…

Dial pulses generated for the number 6.

This time is limited to 10 sec, in which the next digit must be dialed, otherwise the dialing process will be terminated by the telephone company.
2.4 Telephone Gain Control

- Virtually every telephone set connected to the central office has different subscriber loop length.
- As a result, a large variation in the line resistance exists between each customer.
- Then the current supplied by the central office to subscriber loop will vary as a function of loop length.
Continue…

• The telephone set will compensate for this variation through **gain control circuit** comprising of varistors VR1 through VR3 used to maintain constant transmit and receive amplitudes.

• **Varistor** is a semiconductor device, whose resistance varies inversely with current.
2.5 Electronic Pulse Dialing Telephone

- In modern telephone sets, all the circuits discussed so far are replaced by ICs.
- Single-chip ICs are now available that perform dialing and ringing functions and more.
- Memory and control circuits are included for storing and automatically dialing telephone numbers.
- Piezoelectric transducers are used to perform ringing function, etc…
2.6 Dual-Tone Multi-frequency

- Another dialing standard that is much efficient than Rotary Dialing (Dial Pulses).
- DTMF is also known as Touch Tone.
- Central offices are equipped to handle both Touch Tone and Dial Pulses.
- Dialing is accomplished through a push-button keypad consisting of 12 keys corresponding to the numbers 0 through 9 and the characters Star (*) and Hash (#).
- Some keypads include four additional keys A through D, for special control functions.
DTMF frequency and keypad layout.
Continue…

• Four rows and four columns of keys form a frequency matrix consisting of a low band and a high band of frequencies.

• When dialing a key, two tones are generated and the electrical sum of these two tones is sent to the telephone company for processing: one from the low band and second from high band.

• An example is shown in next slide.
DTMF waveforms: (a) 770-Hz, low-band frequency; (b) 1336-Hz, high-band frequency; (c) electrical sum of the low- and high-band frequency producing the DTMF tone for the digit 5.
Chapter 3

Introduction To Local Feeder Network
3.1 A Need for Centralized Switching

• As was shown in chapter 2 (S# 20-23), for large number of subscribers, the mesh network becomes impractical.

• Clearly, an alternative method for providing telephone service is needed.

• Since we are equipped with a telephone set of tremendous features, it makes sense to device a centralized form of switching.
Continue…

• We know that, the telephone set requires a dc supply for biasing.
• This dc supply can be made available in two different ways:
  1) **Local battery**: each telephone set has a built in battery set.
  2) **Common battery**: the telephone company is responsible to provide the dc supply.
• Accordingly, there are two types of **Telephone Systems**:
  1) **Local Battery Telephone System (OLD SYSTEM)**
  2) **Common Battery System (NEW SYSTEM)**
3.2 Local Battery Telephone System (LBTS)

- Each telephone subscriber is connected to a **central office** (CO) through a **twisted pair** of wires used as the transmission medium.

- This type of connection is known as **Star Connection**.
Subscribers connected in a star arrangement.
Continue…

• This pair of wires is referred to as **Subscriber Loop** or **Local Loop** as shown in the figure.
The pairs in old telephones were terminated by Tip and Ring plug.

Today, the pairs are terminated by BT and RJ11 Plugs.
Continue…

• The central office provide a temporary connection between parties.

• A switchboard is used to terminate local loops.
Switching was performed at switchboard by a telephone operator who manually connects two subscriber loops together.
3.2.1 Operation of Local Battery Telephone System

- Telephones were individually powered with batteries and were part of the system.
- The calling party signaled the operator for service by cranking a magneto (a hand generator) located within the telephone set.
- The resulting AC signal activated a lamp at the switchboard notifying the operator that a connection was desired.
- The operator then determined from the caller which party to connect.
- A patch cord was used to interconnect the two party’s subscriber loops.
Continue…

Telephone company
Crank telephone sets
3.2.2 Drawbacks of LBTS

• Phone sets were bulky.
• Battery maintenance: Phone calls could not be made on weak and dead batteries.
• Lack of Privacy.
• It requires to staff the switchboard 24 hours a day.
3.3 Common Battery Telephone System (CBTS)

- Is today’s telephone system.
- The CO or the telephone exchange provides power to the telephone set through the two wire local loop.
- Switching is performed automatically.

Battery banks at the central office
3.4 The Local Feeder Network

• It consists of thousands of twisted-pair wires that are brought out to the community in bundled cable and are fanned out to a number of servicing areas.

• The number of local loop pairs is planned ahead of time to exceed the number of subscribers in a service area.

• Feeder Network cables are manufactured in a bundled increment of 25 pairs of twisted-pair cooper wires.
Continue…

Feeder Network Cable
Continue…

25 pair Shielded Feeder Network Cable
Continue…

1500 pair Shielded Feeder Network Cable
Feeder network distributing service to a community: (a) local distribution area; (b) detail of a serving area.
Continue…

• The feeder network cables are combined in **Cable Vault** in the basement of the central office where cables are **pressurized** in order to prevent moisture from penetrating the cables.

• Then, the feeder network cable is connected at the central office’s **main distribution frame (MDF)** or **demarcation point**, the point at which all outside-plant cable pairs are terminated and fused for over-voltage and current protection.

• MDF is a junction of local loop pairs and line card connections.
Local loop pairs, T-carriers and fiber optic cables all converge in the cable vault in the basement of the central office
Continue…

The air dryer unit
Continue…

Main distribution frame (MDF)
Continue…

- At the opposite end of the feeder network cable, subscriber loop pairs ultimately end up at the demarcation point between the central office and the customer.

- For residential customers, demarcation is the point where outside telephone lines terminate and connect with the inside wiring of the home.

- A demarcation box, called a network interface device (NID), is typically mounted on the outside of the home. It includes over-voltage and current protection.
Area demarcation point
Chapter 4

Introduction To The Telephone Network
4.1 Telephone Network

• It is a systematic development of interconnecting transmission media arranged so that one telephone user can talk to any other within that network.

• In this network, subscribers share common transmission facilities; switches (exchanges) permit this sharing by concentration.
Continue…

• The PSTN is the **dial-up** telephone network.
• It consists of hundreds of independent telephone companies (**Exchanges, Switching Centers**) that are interconnected through **Trunk Circuits** or **Junctions** such as Interoffice Trunks, Tandem Trunks, Toll Trunks, and Intertoll Trunks.
Continue…

• **Trunk Circuit**: Is set of telephone lines connecting one telephone switch or exchange with another. It is the feeder cable, such as twisted pairs, coaxial, and fiber optic.

• **Concentration**: is a line-to-trunk ratio
There are five types of exchanges:

1. Tandem Office (TO) or Regional Center.
2. Sectional Center.
3. Primary Center.
4. Toll Center (TC).
5. Central Office (CO) or End Office.

<table>
<thead>
<tr>
<th>Class 1</th>
<th>Regional center</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 2</td>
<td>Sectional center</td>
</tr>
<tr>
<td>Class 3</td>
<td>Primary center</td>
</tr>
<tr>
<td>Class 4</td>
<td>Toll center</td>
</tr>
<tr>
<td>Class 5</td>
<td>End office</td>
</tr>
</tbody>
</table>

Hierarchy of switching exchanges in North America
Interconnection of switching exchanges in North America
Continue…

• **Central Office**: A class 5 switching center, is the local telephone company that connects your telephone lines, also know as **End Office**. A large metropolis may require several COs for service, whereas in rural area a single CO is sufficient.

• **Tandem Office**: A class 1 switching center, it is used to interconnects COs in a largely populated areas to minimize the number of trunks that a call must be routed through to reach its destination.

• **CO** and **TO** are **Local Area** switching centers.
Continue…

- **Toll Center**: A switching center located in adjacent cities outside the local area.
- **Interoffice Trunk**: A trunk circuit that connects Central Offices.
- **Tandem Trunk**: A trunk circuit that connects a Tandem Office with CO.
- **Toll Trunk**: A trunk circuit that connects a CO to a Toll Center.
- **Intertoll Trunk**: A trunk circuit that connects toll centers together to achieve longer distance coverage.
- **Long-Haul Network**: A trunk circuit that spans long distance by interconnecting Toll Centers. Calls placed on a long-haul network is subject to toll fees.
Long-distance switching hierarchy within the PSTN depicting possible routes to complete a call between parties A and B.
• **Local Area**: is that geographical area containing a number of local exchanges and inside which any subscriber can call any other subscriber without incurring tolls (extra charges for a call).

• There are specialized versions of a local network and are the **Rural Network (Rural Area)** and the **Metropolitan Network (Metropolitan Area)**.
Continue…

• **Toll Area** as opposed to Local Area is that geographical area containing Toll Offices.
• Calls placed on Toll Area (long-Haul Network) are subject to extra charges.
• Toll calls and long-distance calls are synonymous.
• Local Calls and short-distance calls synonymous.
4.2 Basis of Network Configuration

• **Network** in telecommunication is defined as a method of connecting exchanges so that any one subscriber in the network can communicate with any other subscriber.

• Thus the problem is essentially how to connect exchanges efficiently.

• The nodal points or nodes or the interconnection points in a network are the switches or the switching centers.
Continue…

Examples of mesh, star, and double-star configurations.

- Types of connection:
  1. Mesh.
  2. Star.
  3. Double and higher-order star.
Continue…

• **A mesh connection** is one in which each and every exchange is connected by trunks (or junctions) to each and every other exchange.

• **A star connection** utilizes an intervening exchange, called a tandem exchange, such that each and every exchange is interconnected via a single tandem exchange.

• **A double-star configuration** is one where sets of pure star sub-networks are connected via higher-order tandem exchanges.

• This trend can be carried still further, as we see have seen in North American hierarchical networks.
Continue…

• Mesh connections are used when there are comparatively high **traffic**? *(will be explained)* levels between exchanges, such as in metropolitan networks.

• A star network may be applied when traffic levels are comparatively low.
4.3 Traffic Engineering

• **Traffic** is a term that quantifies usage.
• A subscriber uses the telephone when he/she wishes to talk to somebody, we say that a call is initiated at a traffic source and received at a traffic sink (destination).
• As we have already mentioned, telephone exchanges are connected by trunks or junctions.
• The number of trunks connecting exchange X with exchange Y is the number of voice pairs or their equivalent used in the connection.
• **A traffic Path**: is a channel, time slot, frequency band, line, trunk, switch, or circuit over which individual communications pass in sequence.

• **Carried Traffic**: is the volume of traffic actually carried by a switch.

• **Offered Traffic**: is the volume of traffic offered to a switch.

• One of the most important steps in telecommunication engineering practice is to determine the number of trunks required on a route or connection between exchanges.
Continue…

• We could say we are **dimensioning** the route.
• To dimension a route correctly, we must have some idea of its **usage**, that is, how many people will wish to talk at once over the route.
• The usage of a transmission route or a switch brings us into the realm of **traffic engineering**.
• Traffic or Usage may be defined by two parameters:

1. **Calling Rate**: is the number of times a route or traffic path is used per unit period, or more properly defined as, “the call intensity per traffic path during the busy hour”.

2. **Holding Time**: it is the duration of occupancy of a traffic path by a call, or sometimes, the average duration of occupancy of one or more paths by calls.
Continue…

• To dimension a traffic path or size a telephone exchange, we must know the traffic intensity representative of the normal **busy season**.

• **Traffic Density**: is the number of simultaneous calls at a given moment.

• **Traffic Intensity**: the average traffic density during a 1-h period.

• Traffic is very random in nature.

• It varies from day to day and hour to hour.
4.3.1 Busy Hour (BH)

- **BH**: is a continuous 1-h period of a concerned time interval in which traffic volume or the number of call attempts is greatest.

- **Peak Busy Hour**: is the busy hour each day.

- **Time Consistent Busy Hour**: is the 1-h period starting at the same time each day for which the average traffic volume or call-attempt count of the exchange or resource group concerned is greatest over the days under consideration.
Continue…

Bar chart of traffic intensity over a typical working day (United States, mixed business and residential).
4.4 Measurement of Telephone Traffic

• **Telephone Traffic**: the aggregate of telephone calls over a group of circuits or trunks with regard to the duration of calls as well as their number.

• We can say that traffic flow \((A)\) is expressed as

\[ A = C \times T \]

• Where \(C\) designates the number of calls originated during a period of 1-h (**calls/hour**) and \(T\) is the average holding time (**hours/call**).
Continue…

• For example, if the average holding time is 2.5 min and the calling rate in the BH for a particular day is 237, then, the traffic flow \( A = 237 \times 2.5 \), or 592.5 call-minutes (Cm) or 592.5/60, or about 9.87 call-hours (Ch).

• 1 Ch: is the quantity represented by one or more calls having an aggregate duration of 1-h.

• 1 Cm: is the quantity represented by one or more calls having an aggregate duration of 1-m.

• 1 Cs: is the quantity represented by one or more calls having an aggregate duration of 1-s.
Continue…

• The preferred unit of traffic intensity is the **erlang**.
• The erlang is a dimensionless unit.
• One erlang represents a circuit occupied for 1-h.
• Considering a group of circuits, traffic intensity in erlangs is the number of Cs per second or the number of Ch per hour.
• 1erlang = 60 Cm.
• If we knew that a group of 10 circuits had a call intensity of 5 erlangs, we would expect half of the circuits to be busy at the time of measurement.
4.5 Blockage, Lost Calls, and Grade of Service

• Assume that an isolated telephone exchange serves 5000 subscribers.
• Also assume that no more than 10% of the subscribers wish service simultaneously.
• Hence, the exchange is dimensioned with sufficient equipment to complete 500 simultaneous connections.
• But, keep in mind between any two of the 5000 subscribers, there will be a connection.
• Assume that the 500 subscribers engaged the exchange.

• Now let subscriber 501 attempt to originate a call.

• He/she cannot, because all the connecting equipment is busy.

• This call from subscriber 501 is termed a lost call or blocked call, and we say that he/she has met blockage.
Continue…

• Blocked calls refer to calls that fail at first trial.
• The probability of meeting blockage is an important parameter in traffic engineering of telecommunication systems.
• Blockage can take place during the BH.
• A switch is engineered (dimensioned) to handle the BH load.
Continue...

- **Grade of Service (GoS):** in traffic engineering, it expresses the probability of meeting blockage during the BH and is expressed by the letter $p$.
- It is also defined in terms of erlang formula as the probability of blockage.
- A typical GoS is $p = 0.01$.
- This means that an average of one call in 100 will be blocked or “lost” during the BH.
Continue…

- **Example**: If there are 354 seizures (lines connected for service) and 6 blocked calls during the BH, what is the GoS?

\[
\text{Grade of service} = \frac{\text{Number of lost calls}}{\text{Total number of offered calls}} = \frac{6}{354 + 6} = \frac{6}{360}
\]

\[p = 0.017\]
4.6 Quality of Service (QoS)

- QoS means how happy the telephone company is keeping the customer.
- The transmission engineer calls QoS “customer satisfaction” which is commonly measured by how well the customer can hear the calling party.
- In our discussion of traffic, lost calls or blockage certainly constitute another measure of service quality.
Continue…

• Other items listed under service quality are:
  1. Dial-tone delay: is the delay before receiving dial tone.
  2. Post dialing delay: is the time from completion of dialing a number to first ring of telephone called.
  3. Availability of service tones such as busy tone, and telephone out of order.
Continue…

5. Reasonable cost to customer of service.
6. Responsiveness to servicing requests.
7. Responsiveness and courtesy of operators.
8. Time to installation of new telephone, and, by some, the additional services offered by the telephone company.