The Telephone Network

An Engineering Approach

Ref: Digital Telephony (John Bellamy) and Fundamentals of Telecommunications (R. L. Freeman) Introduction to Telecommunications Network Engineering (Second Edition), (Anttalainen, Tarmo)

Introductory Concepts

- Telecommunication means "communications at a distance"
 - □ Tele in Greek means at a distance
- Electrical communications by
 - □ wire, radio, or light (fiber optics)
- Traditionally two distinct disciplines:
 - Switching: selects and directs communication signals to a specific user or a group of users
 - Transmission: delivers the signals in some way from source to the far-end user with an acceptable signal quality



Simple Transmission System



- The source may be a simple telephone microphone, keyboard
- The destination may be a simple telephone speaker, monitor



Transmission Media

It can be a seen as a single electrical medium



Or, as a cascade of electrical media



- Networks show a gain or loss.
- To understand these gains or loss, a good knowledge of the decibel and related measurement units is needed.



dB in Communications

- The db (decibel) is a relative unit of measurement commonly used in communications for providing a reference for input and output levels.
 - Power gain or loss.
- Decibels are used to specify measured and calculated values in
 - audio systems, microwave system gain calculations, satellite system link-budget analysis, antenna power gain, light-budget calculations and in many other communication system measurements
 - In each case the dB value is calculated with respect to a standard or specified reference.



Calculation of dB

The dB value is calculated by taking the log of the ratio of the measured or calculated power (P2) with respect to a reference power (P1).

$$\begin{array}{c} P_1 \\ \hline \end{array} \\ \hline$$

□ The result is multiplied by 10 to obtain the value in dB.

$$d\mathsf{B} = 10\log_{10}\frac{P_2}{P_1}$$

□ It can be modified to provide a dB value based on the ratio of two voltages. By using the power relationship $P = V^2/R$

$$d\mathsf{B} = 10\log_{10}\frac{P_2}{P_1} = 10\log_{10}\frac{V_2^2/R}{V_1^2/R} = 20\log_{10}\frac{V_2}{V_1}$$



Definitions of dBm and dBW

dBm indicates that the specified dB level is relative to a 1 milliwatt reference.



□ If Power is expressed in watts instead of milliwatts.

the dB unit is obtained with respect to 1 watt and the dB values are expressed as dBW.

$$dBW = 10 \log_{10} \frac{P_2}{1 W}$$



Examples

- Important Note: The decibel (dB) is "the logarithm of a power ratio" and NOT a unit of power;
- However, dBW and dBm are units of power in the logarithmic system of numbers
- Convert the following into dBm or dBW
- \Box P=1mW, P(dBm)=?
- □ P=0.1mW, P(dBm)=?
- □ P=10W, P(dBW)=?
- □ P=1W, P(dBm)=?





 $\Box dB value=10log_{10}4/2=10log_{10}2=10\times0.3010=+3.01dB\approx3dB$

- Memorize the above relationship
- The amplifying network has a 3-dB gain because the output power was the double the input power



Telephony

- The telephone is connected to Public switched telecommunications network (PSTN) for local, national, and international voice communications
- The same connections can carry data and image information (television)
- The connection to the PSTN may be via local exchange carriers (LEC)
- End-users, nodes, and connectivities



Voice Telephony

- Transmission of the human voice
 - Voice is a sound signal
- Analog voice-band channel
 - A channel that is suitable for
 - transmission of speech or analog



data and has the maximum usable frequency range of 300 to 3400 Hz.

- The local serving switch is the point of the connectivity with the PSTN
- □ It is the point where the analog signal is digitized.







Telephone Subset

- It is a device which converts human speech in the form of sound waves produced by the vocal cord to electrical signals. These signals are then transmitted over telephone wires and then converted back to sound waves for human ears.
 - Microphone
 - Earphone
 - Signaling functions





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Telephone Handset

- □ Microphone (mouthpiece)
 - consists of a movable speaker diaphragm that is sensitive to both amplitude and frequency
 - The diaphragm contains carbon particles that can conduct electricity.
 - As the human voice spoken into the transmitter varies, the amount of carbon granules that strike the electrical contacts in the mouthpiece also varies—thereby sending varying analog electrical signals out into the voice network.



Telephone Handset

Earphone (earpiece)

- □ Acts in an opposite direction to the mouthpiece.
- The electrical signal/waves produced by the transmitter are received at an electromagnet in the receiver.
- Varying levels of electricity produce varying levels of magnetism—that, in turn, cause the diaphragm to move in direct proportion to the magnetic variance.
- The moving diaphragm produces varying sound that corresponds to the sound waves that were input at the transmitter.



Conventional Telephony Operation





Dialing

- A combination of 350 Hz and 440 Hz sine waves sent to the Telephone from the central office (CO) indicating that the network is ready to receive calling instructions
- Dialing Modes: Pulse and Touch Tone or Dual-Tone-MultiFrequency



- Each button sends a dual frequency sine wave indicated by the corresponding row and column
- Telephone Numbers are decided by ITU internationally and NANP in North America [NP - numbering plan]



0

1336 Hz

1477 Hz

#

1209 Hz

*

941 Hz

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Subscriber Signaling







Basic Telecommunications Infrastructure

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- Common Signaling System 7, also called SS7 or C7, was developed by the in order to increase the efficiency of the public voice system. SS7 is a separate network whose duties are setting up, tearing down, monitoring, and routing calls on the PSTN.
- SS7 is akin to TCP/IP in that it operates at several layers of the OSI model. And, like TCP/IP, SS7 is packet-based. It is a softwarebased system that operates independently of the voice transport itself (the PSTN).
- SS7 works behind the scenes, so interacting with SS7 is something that the CO switch, not your phone or PBX, must do. SS7 is called an **out-of-band** signaling standard because, unlike DTMF, it doesn't use the same frequency band, or even the same transport, as the voice transmission.
- Out-of-band signaling is also called CCS, or common channel signaling. It's the technique used by all telecommunication vendors—including cellular phone service providers, long-distance companies, and local exchange carriers (LECs). All of these networks share one thing in common: a common bond in SS7.



SS7 and PSTN





Subscriber Loop Design

- Any use of telephone channels involves two unidirectional paths, one for transmission and one for reception.
- The local loop, which connects a telephone to a local exchange is a two-wire (2W) circuit that carries the signals in both transmission directions.
- Even asymmetrical digital subscriber lines (ADSLs) use this same 2W local



Two pairs of wires, one for each direction

To connect a 2W local loop to a 4W network a circuit called a 2W/ 4W hybrid is needed.

Normal Signal Flow



- □ 2- to 4-wire hybrid combines receive and transmit signals over the same pair
- □ 2-wire impedance must match 4-wire impedance





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2. Transmission Systems

- Two-Wire versus Four-Wire
 - All subscriber loops in the telephone network are implemented with a signal pair of wires
 - Both directions of transmission
 - Conversations are superimposed on the wire pair
 - Two directions of longer distances are separated
- □ Two-Wire-to-Four-Wire Conversion
 - Basic conversion function is provided by hybrid circuits
 - Impedance matching is important
 - Impedance mismatch causes "echo"



Transmission Systems

Link characteristics

- information carrying capacity (bandwidth)
 - information sent as symbols
 - 1 symbol >= 1 bit
- propagation delay
 - time for electromagnetic signal to reach other end
 - light travels at 0.7c in fiber ~8 microseconds/mile
 - NY to SF => 20 ms; NY to London => 27 ms
- attenuation
 - degradation in signal quality with distance
 - long lines need regenerators
 - optical amplifiers are here



How Does Echo Happen?

Echo is due to a reflection



Transmission Impairments

- Signal Attenuation
- Interference
 - Coupling between wires
 - Near-end crosstalk (NEXT) (From TX to RX at a common location)
 - □ Far-end crosstalk (FEXT) (From TX to RX at a distant location)
- Noise
 - Thermal noise White noise with a Gaussian (Normal) distribution of amplitudes
 - Noise measurement is important
 - Standard reference value is 1 pW \rightarrow -90 dBm



Transmission Impairments - Echo

- If only one reflection occurs, the situation is referred to as "talker echo"
- □ If a second reflection occurs, "listener echo" results
- If returning the signal is repeatedly coupled back into the forward path to produce oscillations, singing occurs.
 - □ If the loop gain is greater than unity.
- Echo suppressor Loss insertion to reduce echo
- Echo canceller -Cancel the echo signal from the return path.



Echo Is Always Present

Echo as a problem is a function of the echo delay, and the magnitude of the echo



Power Levels

- Read the dB Tutorial on the course web site
- The delivered signal power must be high enough to be clearly perceived
 - Not so strong that echo and singing result
- Transmission links are designed with specific amount of net loss
 Via net loss (VNL)
- Transmission Levels Point (TLP) are used as a convenient means of expressing signal loss or gain within a circuit.
 - The TLP is a point in the circuit expressed as the ratio (in dB) of the power of the signal at that point to the power of the signal at a reference point (0 TLP).
 - □ TLP is the measurement of the signal gain or loss relative to the 0 TLP.
 - □ dBm0 = Signal Power (dBm) TLP (dB)
 - "0" indicates that the specification is relative to the 0-TLP.
 - Ex: If an absolute noise power of 100 pW (20 dBrn or -70 dBm) is measured at a -6 TLP, it is expressed as 26 dBrn0.



dB Applied to the Voice Channel

- Noise and amplitude distortion
- Amplitude distortion is the same as frequency response.
- The noise annoys the listener
 - □ How much noise will annoy the average listener?
- □ The human ear is a filter as is the telephone earpiece

Amount of annoyance of the noise to the average listener varies

- □ We "shape" the VF channel
- as a function of frequency
- Weighting curve
- C-message response (NA)





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dB Applied to the Voice Channel

- The lowest discernible signal that can be heard by a human being is -90 dBm (800 or 1000 Hz)
- If noise power is measured with C-message weighting, dBrnC0 is used.
- 0 dBrnC=-92 dBm (with white noise loading of entire voice channel)





- Example: Using the above figure, determine each of the following: (a) the signal power to be applied at point B to determine if points A and C are at the proper levels; (b) the amount of gain (loss) a signal experiences when propagating from A to C; and (c) the amount of noise that would be measured at C if 27 dBrnC of absolute noise is measured at B and no additional noise occurs on the B-to-C link.
- Solution: (a) Because point B is -13 dB TLP, the proper test tone level is -13 dBm (0.05 mW) (b) Because the TLP values drop by 2 dBm, there is 2dB net loss from A to C. (c) An absolute measurement of 27 dBrnC at B is 40 dBrnC0. This is also 40 dBrnC0 at C. The absolute noise power measured at C would be 40-4=36 dBrnC.



Telephone Call Characteristics

Telephone calls can be:

Local-LATA

Inter-LATA

Intra-LATA

LATA = Local Access Transport Areas

Local loop---is—analog in character.

Trunk line----is—digital in character.

Interexchange circuit----digital in character.





Figure 2-4 Representative Voice Network Heirarchy

Telephone Numbering

- The numbering is hierarchical, and it has an internationally standardized country code at the highest level.
- An international prefix or international access number is used for international calls. It tells the network that the connection is to be routed via an international telephone exchange to another country.
- The country code contains one to four numbers that define the country of subscriber B. Country codes are not needed for national calls because their purpose is to make the subscriber identification unique in the world. A telephone number that includes the country code is called an international number and it has a maximum length of 12 digits.





Telephone Number Plans

3 Basic parts of US-calls:

□ 3-digit area code---(817)

3-digit exchange---(496)

□ 4-digit subscriber number---(3650)

<u>4 Basic parts of an International call:</u>

011

- Country code
- City code
- City number



Telephone Number



Is it a computer network?

- Specialized to carry voice
- Also carries
 - video
 - fax
 - modem calls
- □ Internally, uses digital *samples*
- Switches and switch controllers are special purpose computers



Concepts

- □ Single basic service: two-way voice
 - low end-to-end delay
 - guarantee that an accepted call will run to completion
- Endpoints connected by a circuit
 - like an electrical circuit
 - □ signals flow both ways (*full duplex*)
 - associated with bandwidth and buffer resources



The big picture



- Fully connected core
 - simple routing
 - telephone number is a hint about how to route a call
 - but not for 800/888/700/900 numbers
 - hierarchically allocated telephone number space



The pieces

- 1. End systems
- 2. Transmission
- 3. Switching
- 4. Signaling



1. End-systems

Transducers

key to carrying voice on wires

Dialer

Ringer

Switchhook





Dialing

Pulse

sends a pulse per digit

collected by central office

Tone

key press (feep) sends a pair of tones = digit

also called Dual Tone Mutifrequency (DTMF)



Transmission: Multiplexing

- Trunks between central offices carry hundreds of conversations
- Can't run thick bundles!
- □ Instead, send many calls on the same wire
 - multiplexing
- Analog multiplexing (Frequency Division Multiplexing)
 - bandlimit call to 4 KHz and frequency shift onto higher bandwidth trunk
 - Obsolete
- Digital multiplexing
 - □ first convert voice to *samples*
 - 1 sample = 8 bits of voice
 - 8000 samples/sec => call = 64 Kbps



Transmission: Digital multiplexing

Time division multiplexing

- trunk carries bits at a faster bit rate than inputs
- □ *n* input streams, each with a 1-byte buffer
- output interleaves samples
- need to serve all inputs in the time it takes one sample to arrive
- => output runs n times faster than input
- overhead bits mark end of frame



Transmission: Multiplexing

- Multiplexed trunks can be multiplexed further
- Need a standard
- US/Japan standard is called *Digital Signaling* hierarchy (DS)

Digital Signal Number	Number of previous level circuits	Number of voice circuits	Bandwidth
DS0		1	64 Kbps
DS1	24	24	1.544Mbps
DS2	4	96	6.312 Mbps
DS3	7	672	44.736 Mbps



Transmission: Link technologies

Many in use today

twisted pair

coax cable

terrestrial microwave

satellite microwave

optical fiber

Increasing amount of bandwidth and cost per foot

Popular

fiber

satellite



Transmission: fiber optic links

Wonderful stuff!

- lots of capacity
- nearly error free
- very little attenuation
- hard to tap

A long thin strand of very pure glass





Transmission: satellites

- Long distances at high bandwidth
- Geosynchronous
 - □ 36,000 km in the sky
 - up-down propagation delay of 250 ms
 - bad for interactive communication
 - slots in space limited
- Non-geosynchronous (Low Earth Orbit)
 - appear to move in the sky
 - need more of them
 - handoff is complicated
 - 🗅 e.g. Iridium



3. Switching

Problem:

- each user can potentially call any other user
- can't have direct lines!
- Switches establish temporary *circuits*
- Switching systems come in two parts: switch and switch controller





Switching: what does a switch do?

Transfers data from an input to an output

- many ports (up to 200,000 simultaneous calls)`
- need high speeds
- Some ways to switch:
 - space division
 - □ if inputs are multiplexed, need a *schedule* (why?)





Switching

Another way to switch

- Lime division (time slot interchange or TSI)
- also needs scheduling



To build larger switches we combine space and time division switching elements

4. Signaling

- Recall that a switching system has a switch and a switch controller
- Switch controller is in the *control* plane
 - does not touch voice samples
- Most common control signals
 - Dial tone, ringback, and busy tone
- Supervisory (conveying status) & information bearing signals
- Manages the network
 - call routing (collect *dialstring* and forward call)
 - alarms (ring bell at receiver)
 - billing
 - directory lookup (for 800/888 calls)



Signaling network

- Switch controllers are special purpose computers
- Linked by their own internal computer network
 - Common Channel Interoffice Signaling (CCIS) network
- Earlier design used *in-band* tones, but was severely hacked
- Also was very inflexible
- Messages on CCIS conform to Signaling System 7 (SS7) spec.





Cellular communication

- Mobile phone talks to a *base station* on a particular radio frequency
- Aren't enough frequencies to give each mobile a permanent frequency (like a wire)

Reuse

temporal

• if mobile is off, no frequency assigned to it

spatial

mobiles in non-adjacent cells can use the same frequency





Challenges for the telephone network

Multimedia

- simultaneously transmit voice/data/video over the network
- people seem to want it
- existing network can't handle it
 - bandwidth requirements
 - burstiness in traffic (TSI can't skip input)
 - change in statistical behavior
- Backward compatibility of new services
 - huge existing infrastructure



Challenges

Convergent Solution

- future telephone networks will be of single infrastructure supporting integrated services
- how to manage the transition
- Inefficiencies in the existing system
 - special-purpose systems of the past
 - 'legacy' systems
 - need to change them without breaking the network

