T1 and the T Carrier System

T1 and the T Carrier System

- First Successful system designed to carry digitized voice
- Identified many standards used today
- Transmission rate established at 1.544 Megabits per second
- Defined many of the rules, protocols and constraints in use today

Analog Trunk lines

- Before 1960, trunk lines between Telco offices used analog over 2 or 4 wire connections
- Older system called N-carrier multiplexed 12 or 24 calls over an analog channel
- As digital technologies emerged, Telcos switched to digital over installed cable plant.
- Terms: Inside Plant, Outside Plant, Transmissions

Analog to Digital Conversion

- Analog waves must be sampled in order to convert them to a digital bit stream.
- Digital bit stream must contain enough information to reconstruct the analog signal.
- Nyquist Theory of sampling states that the sampling rate of an analog wave must be twice the highest frequency of the analog wave.

Range of the voice

- The human voice contains most of the understandable energy between 300 and 3300 Hz
- A sampling rate of 6600 samples per second should be sufficient to encode human voice.
- To guarantee a good reproduction of the voice a sampling rate of 8000 samples was chosen for the T carrier system

Encoding the sample

- A sample of the amplitude of the wave must be taken 8000 times every second.
- The amplitude of the wave can vary from a positive value through zero to a negative value.
- For the T-carrier system each sample consisted of 8 bits or 128 + and 128 - possible values.

PCM Pulse Code Modulation

- Get a sample amplitude of the analog wave
- PAM Sample
  - Pulse Amplitude Modulation sample
- The amplitude of each sample is equal to the instantaneous amplitude of the analog wave
- Translate the PAM sample into binary values

PCM Pulse Code Modulation

- The process of translating the PAM sample into a digital bit stream is called PCM
- The digital bit stream can be used to recreate the original wave form, provided that it is sampled at a fast enough rate (Nyquist Theorem)
- Sampling Quantizing Encoding

Sampling

- The wave form is sampled 8000 times per second

Quantizing

- Each Sample is turned into one byte of data which is a digital number between 0 and 256
- Better to think of 0 to 127 positive and 0 to 127 neg
- left most of the eight bits represents the sign
- 1 1 1 1 1 1 1 1 is + 127
- 0 1 1 1 1 1 1 1 is - 127
- There are various PCM quantizing formulas.
- The smaller amplitudes are expanded
- In some formulas the zero is sent as 01010101 to keep the timing intact

Encoding

- T1 - encoding combines 24 channels into one frame using TDM.
- Each frame contains 1 sample of 8 bits from each of the 24 channels. Added to this is a framing bit for a total of 24x8 + 1 = 193 bits
- In order to keep up with the sampling, the frames are sent out at 8000 frames per second.
- 8000 x 193 = 1 544 000 bits per second

AMI Bipolar Format

- T carrier format places voltage on a twisted pair copper wire to encode the bit stream
- A zero is represented by zero volts on the line
- A one is represented by alternating +3v and -3v
- This alternating voltage is known as Alternate Mark Inversion. Or Bipolar Format
- 0 1 0 11000111 would be represented by the voltages 0v +3v 0v -3v +3v 0v 0v 0v -3v +3v -3v

Use of bipolar format

- Brings average line voltage to zero
- Reduces the bandwidth necessary by half
- Allows use of isolation transformers
- Allows DC voltage to be placed on the line to power repeaters (As much as 130 V)

Alternate Mark Inversion

Bi Polar Violation

T1 Basics Review

- Four Wire Circuit (from older technology)
- Duplex
- Digital
- Pulse Code Modulation
- Framed Format
- Bipolar Format
- Byte Synchronous Transmission
- Channelized or Non-channelized

DS1 Frame Format

- voice lines are digitized using PCM
- Each digitized stream is a 64 kbit/s signal called a Digital Signal level 0 because it has zero multiplexing at this point.
- 24 digital signals are multiplexed using TDM into one channel called digital signal level 1 or DS1

DS1 Signal

- After 24 channels are sampled quantized and encoded the resultant bit stream is called a frame.
- PAM sample is 8 bits
- A frame is 1 sample from 24 channels + 1 bit
- Frames are produces at 8000 per second
- A frame has a time duration of 125 micro seconds. 1 second / 8000 samples = .000125
- the bit duration is 648 nanoseconds 125/193 = 648 nano seconds

Advantages of bipolar format

- Most of the energy of signal concentrated at 1/2 repetition frequency.
- Maximum frequency of all ones is 772 Khz
- Less energy is coupled into other systems in the same transmission cable
- Bipolar pulses do not have direct current component, thus permitting transformer coupling
- Unique alternating pattern can be used for error detection.

Data Rate of DS1

- 24 channels
- x 8 Bits per PAM sample
- ----------
- 192 Word Bits per Frame
- + 1 Framing Bit
- ----------
- 193 Bits per frame
- x 8000 Sampling rate / Second
- 1,544,000 Bits per second

Synchronization

- T1 timing comes from transmitted pulses
- 1’s transmit as pulses 0’s transmit as no pulses
- A string of zeros results in no pulses and transmitting and receiving devices lose timing
- 1’s density rule indicate a certain amount of 1’s or pulses must be present in the bit stream

One’s Density Rule for DS1

- In every 24 bits of information to be transmitted, there must be at least 3 pulses.
- No more than 15 zeros can be transmitted consecutively.

- AT&T insisted on a “1” in each 8 bits.

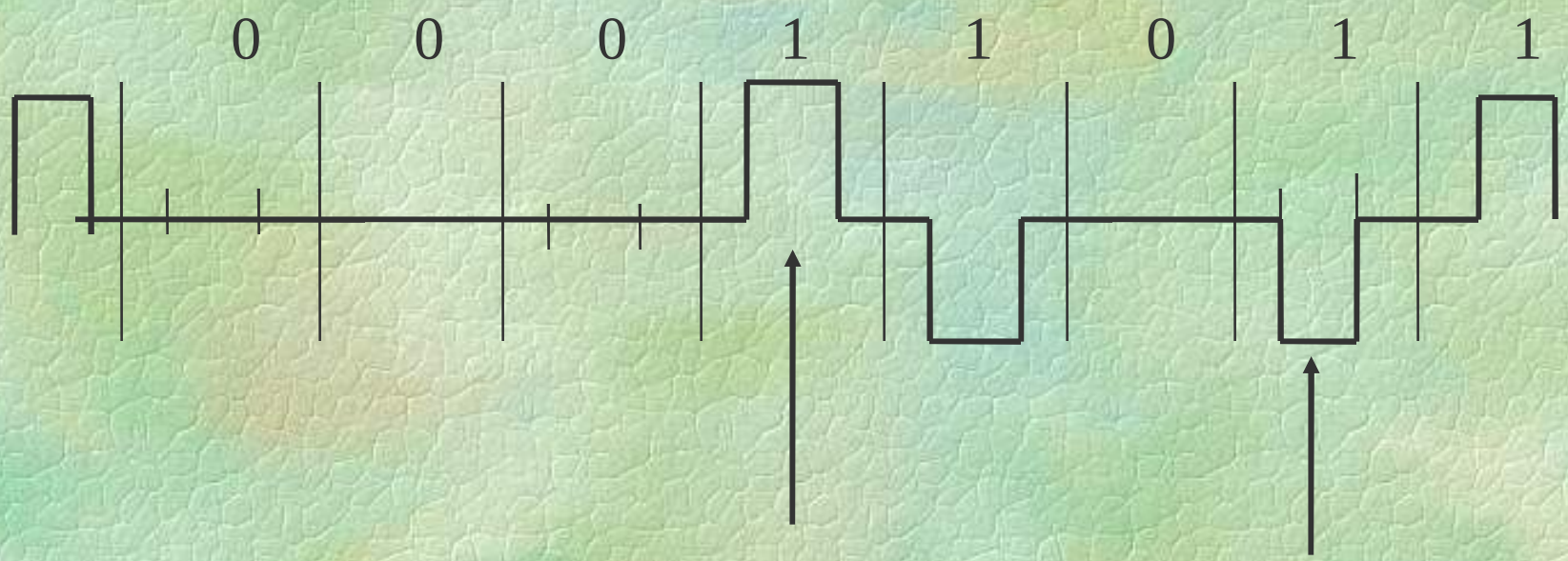
Bit stuffing

- One way to solve the 1’s density rule is with bit stuffing.
- Place a “1” in each byte of data.
- 7 data bits and one stuff bit
- This reduces throughput from 64,000 bits per second to 56,000 bits per second per channel
- This is not the ideal solution

Bipolar Eight Zero Substitution B8ZS

- B8ZS is implemented in the CSU
- a string of 8 or 16 or 24 zeros is recognized
- The zeros are removed from the data stream
- A fictitious byte is substituted for the 8 bits
- 00011011
- Two bipolar violations are inserted in the byte to let the receiving end know that it is a substitution for zeros

B8ZS



Forced Bipolar Violation

in 4th and 7th position of substituted byte

Digital Signaling Hierarchy

- DS0 single voice line no multiplex 64kb/sec
- DS1 one level of multiplex 24 D0 1544000
- DS1C two DS1's 3.152 Megabit/sec
- DS2 4 DS1's or 96 DS0's
- DS3 28 DS1's or 672 DS0's 44.736 Meg/sec
- DS4/NA 3 DS3's 139.264 Meg /sec
- DS4 6 DS3's 4032 DS0's 274.16 Meg/sec

Channelized or Non-channelized

- Original T-1 used for 24 voice circuits
  - channelized service
- single channel of data or video may be carried over the same type of media with the same type of signaling
  - non channelized
  - Typical use is Internet connection

Framed Format

- Frame consists of 24 8 bit channels plus framing bit
- Framing has gone through a number of changes
- 8000 frame bits per second are transmitted
- Framing can carry timing information
- Some framing schemes rob bits from the data

Framing types

- D1 Voice grade Alternating 1 and 0
- D2 Voice 12 Frame sequence super frame
- D3 voice Superframe format and sequence bits
- D4 voice and data Superframe
- ESF voice and data plus maintenance
  Extended Superframe

D4 Superframe

- Framing pattern for voice and data
- Repeating pattern of 12 bits 1000 1101 1100
- Allows bits to be robbed from the 6th and 12th frame of the superframe
- The 8th bit from each sample from frame 6 and 12 is used to provide signaling.