

CSIS 625 Week 5

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Overview

- TDM - Time Division Multiplexing
- Applications of TDM & FDM
 - T1 & xDSL
- Traffic Engineering
- Error Detection
- FEC - Forward Error Correction

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T1 - a little more information

- Original D1 channel banks
 - Used alternating 1/0 pattern in framing bit
 - Could get confused by 1000Hz tone
 - Used least significant bit of every data byte for signaling.
- D2-D4 channel banks
 - Used 12 bit pattern in framing bit
 - Used least significant bit data byte for signaling only in the 6th and 12th frame
 - This is AB signaling

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T1 - SF & ESF

- SF - Super Frame
 - Framing format used by D2-D4 channel banks
 - Also Called D4 Framing
- ESF - Extended Super Frame
 - Groups 24 frames together
 - Uses 6 of the framing bits for framing
 - Uses 6 of the framing bits for CRC
 - Uses 12 of the framing bits FDL - Facility Data link
 - Allows both ends to communicate
 - ABCD signaling
 - 6th, 12th, 18th, 24th frame least significant bit

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T1 - SF Line coding

- SF - typically uses AMI line coding
 - This requires that there are some 1's every so often.
 - This is a problem for pure data.
 - Solution - Use HDLC and invert logic levels.
 - After 5 ones in a row HDLC inserts a 0
 - When inverted this will create a 1 after every 5 zeros
 - Telephony - quiet tone is all 1's and all 0's is biggest amplitude.
 - All 0's very rarely occurs
 - No problems with AMI

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T1 - ESF Line coding

- ESF - typically uses B8ZS line coding
 - No Data dependencies
 - B8ZS makes sure that any data pattern can pass without problem.
- If you order a T1 from the phone company
 - Specify ESF
 - Specify B8ZS
 - Especially true for data, but true even for modem traffic or voice traffic
 - You get better protection and CRC error counts

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xDSL - A type of FDM

- DSL = Digital Subscriber Line
 - A way of sending digital data over the twisted pair intended for voice traffic
- ADSL - Asymmetric DSL
 - Targeted at home users
 - Asymmetric in that it has more bandwidth to the home than from the home
 - 0-25KHz for POTs (really only 0-4KHz used)
 - 25-200KHz for Upstream Data
 - 200-1100KHz for Downstream Data

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Traffic Engineering

- In telephony networks, not all phones are in use at the same time, so trunks between central offices are over-subscribed
 - This is a form of statistical TDM
- Agner Krarup Erlang (1878-1929)
 - developed equations on how the blocking probability relates to the amount of traffic and number of lines.

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Traffic Engineering Definitions

- Trunk - a communication line between two switching systems
- Poisson Distribution - A mathematical formula that defines the probability of x events occurring in a certain time
- Busy Hour - The one hour during the day or year that has the most traffic
- CCS - Centum Call Seconds - amount of traffic offered on a line.

– $60 * 60 = 3600$ seconds or 36 CCS

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Traffic Engineering

- Amount of traffic offered can be calculated from the average number of calls and average length.
 - For example: 2 calls / hour * 3 minutes / call =
 $2 * 180 = 360$ call seconds = 3.6 CCS
 - If one phone offers 3.6CCS, then 100 phones offer 360 CCS
- Often Erlangs are used in describe the amount of traffic offered.
 - 36 CCS = 1 Erlang

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Different Traffic Engineering models

- Poisson distribution - simplest
 - Assumes that blocked calls are held.
 - Infinite number of sources
- Erlang B
 - Assumes that blocked calls never return
 - Used originally for blocked calls that went to higher cost lines.
 - Infinite number of sources
- Extended Erlang B
 - Has a retry probability

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Different Traffic Engineering models

- Erlang C
 - Assumes that blocked calls are delayed
 - Infinite number of sources
 - Used for Call Center applications
 - “Trunks” are service people
- There are models for Finite number of sources, but they are used much less often.
 - Even if they should be used - people don't
- Equations given are nice, but either look up tables, or calculators are really used.

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Poisson Distribution

- Poisson assumes that blocked calls wait forever.
 - This will tend to over estimate the number of trunks needed
 - Equation for Poisson
 - N = Number of events to occur in a unit time (Number of trunks)
 - A = Average number of events occurring per unit time (Traffic in Erlangs)

$$P = 1 - e^{-A} \sum_{i=0}^{N-1} \frac{A^i}{i!}$$

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Erlang B

- Erlang B assumes that blocked calls never retry
 - This will tend to under estimate the number of trunks needed
 - Equation for Erlang B
 - N = Number of trunks
 - A = Traffic offered in Erlangs

$$P = \frac{\frac{A^N}{N!}}{\sum_{i=0}^N \frac{A^i}{i!}}$$

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Traffic Engineering example problem

– Given

- 100 homes, with average 1.5 phones / home
- First line of a home has 3.5CCS
- Second line of a home has 30CCS
- 50% of blocked calls retry immediately

– Calculate number of trunks to serve these homes with a blocking probability of 0.02

- $100 * 3.6 \text{ CCS} = 360\text{CCS}$
- $50 * 30 \text{ CCS} = 1500\text{CCS}$
- $360 \text{ CCS} + 1500 \text{ CCS} = 51.67 \text{ Erlangs}$
- From Extended Erlang B calculator - 63 trunks

Traffic Engineering Web pages

- <http://www.erlang.com/calculator/>
- [http://www.owenduffy.com.au/electronics/telecommunications.htm#Traffic modelling](http://www.owenduffy.com.au/electronics/telecommunications.htm#Traffic%20modelling)

Error Detection

- Errors always occur during transmission
- Bit Error - an error that changes only one bit
- Burst Error - an error that changes several adjacent bits.
- Coding Violations - When the line coding mechanism tells us of an error.
 - Need to use something like Bipolar-AMI, 8b10b, etc.

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Error Detection - Parity Bits

- Parity Bit - an extra bit of data sent with every data packet.
 - Even Parity - The extra bit is set so that the number of bits is always even
 - Odd Parity - The extra bit is set so that the number of bits is always odd
 - Receiver checks parity and discards data if parity is not valid
 - Regular parity is also known as Vertical Redundancy Check
 - Parity is sometimes mis-used as any redundant bit

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Error Detection - BIP

- BIP-8 - Bit Interleaved Parity - 8 bits
 - BIP is also known as Longitudinal Redundancy Check
 - Takes bytes and calculates a parity bit for each bit position
 - Diagram of BIP:
 - Provides better protection against burst errors

Byte 1:	1	0	1	0	1	0	1	0
Byte 2:	1	1	1	1	1	1	1	1
Byte 3:	0	0	0	0	0	0	0	0
Byte 4:	1	1	1	0	0	0	0	1
Byte 5:	0	0	0	0	1	1	1	1
BIP-8:	1	0	1	1	1	0	1	1

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Error Detection - Checksum

- Checksum - a byte added to the end of the frame to catch errors
- Simplest form is calculated by adding up all the bytes in the frame
- There are several algorithms - so check specifics on any one algorithm
- BIP-8 is sometimes called a checksum

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Error Detection - CRC

- CRC - Cyclic Redundancy Check
- Catches many errors that Parity or BIP-8 will miss.
- Adds bits to the end of a frame so that it can be evenly divided by a number
- Usually 8, 16, or 32-bit CRC
- Easy to implement in hardware with shift register and feedback xor's.
- See book for examples

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CRC - Strength

- All bursts of errors $\leq r$ (r = length of CRC)
- All odd number of errors
- Probability of missing error
 - if burst is $r+1 \Rightarrow 0.5^{r-1}$ ($0.5^{32-1} = 4.6E-10$)
 - if burst is $\leq r+1 \Rightarrow 0.5^r$ ($0.5^{32} = 2.3E-10$)
- CRC's are considered quite strong
- See also:
 - <http://www.ross.net/crc/>

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Error Rates - BER

- BER - Bit Error Rate - the probability of a bit being changed
 - Used to describe transmission lines
 - All transmission lines have some non-zero BER
 - Calculate by counting the number of errors and dividing by the number of bits
 - Need to adjust for errors that occur but are not detected
 - For example - an odd number of errors when using parity

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Error Rates - BER

- Normal practice is to measure 10 times the period to report a BER
 - This means that to state the line has a $1E-10$ error rate (or better) you must measure $1E+11$ bits
 - A T1 would require 18 hours to have $1E+11$ bits go through.
- Voice sounds ok at BER of $1E-5$
 - Still intelligible at $1E-3$
- Data doesn't work very well below $1E-7$

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FEC - Forward Error Correction

- Sometimes it is advantageous to correct an error instead of just detecting it.
- Brute force is to send data repeatedly
 - To correct n errors, send data $2n+1$ times
 - Not very efficient - there are better ways.
- Hamming codes or Reed-Solomon codes do it much more efficiently

Hamming Distance

- Hamming distance - the number of bits that have to be changed to go from one valid code to another.
 - To detect d errors -Hamming distance of $d+1$
 - parity gives a Hamming distance of 2, so it detects up to one bit error
 - To correct d errors - Hamming distance of $2d+1$
 - Need to be able to distinguish “closest” valid code

Hamming Code

- Hamming Code - an error correcting code to correct 1 bit error
 - For 4 data bits, 3 redundancy bits needed
 - For 8 data bits, 5 redundancy bits needed
- Rule for Hamming Codes:
 - $(m + r + 1) \leq 2^r$
 - m = message bits
 - r = redundant bits
- To handle burst errors, multiple codes can be interleaved.

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Reed-Solomon codes

- Another error correcting code
- Designed to have redundant symbols
- Allows for whole symbols to be errored
 - It handles bursts of errors
- Common applications
 - CD Players,
 - Spacecraft communication
 - DSL lines

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Reed Solomon Codes

- Notation - RS(NN, KK)
 - MM - the code symbol size in bits
 - NN - the block size in symbols ($2^{MM} - 1$)
 - KK - the number of data symbols per block
 - $KK < NN$
- Can correct $(NN - KK)/2$ errors per block
- If known that there are missing symbols, then RS can correct $NN - KK$ “erasures”

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Common Reed Solomon Codes

- RS (255,223)
 - Sends 255 8 bit characters, 223 of them are data and 32 are parity
 - Can correct 16 errors or 32 erasures
- RS(204,188) - Used in Digital Video
 - Sends 204 8 bit characters, 188 of them are data and 16 are parity
 - Can correct 8 symbol errors
- Can be done on other than 8-bit characters

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More on FEC

- FEC is often used to improve the BER of lines.
 - Can be more cost effective than boosting the power sent over the line
 - Retransmission at higher levels may not be practical
- Error Correcting web pages
 - <http://www.piclist.com/techref/method/errors.htm>
 - <http://people.qualcomm.com/karn/code/fec/>
 - <http://www.engelschall.com/u/sb/hamming/>

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Technology topics for future lecture

- Let me know of any that I don't have here at droelke@stthomas.edu
 - xDSL
 - ADSL, HDSL, VDSL, RADSL, etc
 - Cellular
 - Analog, Digital, PCS, 3G
 - Other Wireless
 - Bluetooth, 802.11, LMDS
 - FTTC/FTTH - PON technology
 - Ethernet - 10/100/1000Base-T, etc

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