COMP28411 Computer Networks

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Link Layer - 4

Some material from:

Kurose & Rose – Chapter 5 + Slides

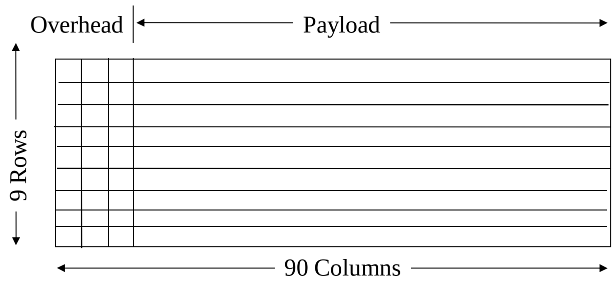
Overview Repeated - 2

- Link Layer Framing
  - Framing for ADSL and other Link Layer Carrier Connections
  - Byte oriented
    - Point to Point (PPP)
  - Byte Counting (sort of)
    - IEEE 802.11 (WiFi) not strictly byte counting but similar example
  - Bit Oriented
    - High-Level Data Link Control (HDLC)
  - Clock Oriented
    - Synchronous Optical Network (SONET)
  - Some differences between wired and wireless frames.
- Encoding:
  - How are bits and bit sequences represented so we can recover them?
- Modulation:
  - How is data encoded on to Bits?

Today

Clock-Oriented Frame Protocols

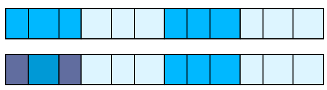
- Synchronous Optical Network (SONET)
  - The dominant technology for long distance optical fibre networks.
  - SONET STS-1 runs at 51.84Mbps
  - First 2 bytes contain start pattern. No *stuffing*. Pattern expected to re-occur regularly every 9x90 = 810 bytes.
    - Synchronise by finding pattern and looking for regular repeats.
  - STS-1 frame is 9 rows of 90 bytes
  - First 3 bytes per row are **overhead**.



Care needed to ensure rare occurrences identical start pattern and overhead bytes is rare!

SONET Encoding

- **Overhead** bytes are simply encoded using NRZ which can result in weak clock recovery for these few bytes.
- All others are XOR'd with a pattern with lots of 0s and 1s that yields plenty of transitions. So the clock can be recovered.
- At STS-N rates, each frame can hold multiple lower rate frames.
  - For example, 3 STS-1 frames fits exactly into an STS-3c frame.
  - The bytes are interleaved – giving even spacing. At STS-3 rates an STS-1 frame still arrives at STS-1 rate.
  - Frames are concatenated – hence the "c".
  - AN STS-12 frame might be:
    - 4 * STS-3c, 3 * STS-1 + 3 * STS-3c, etc.



- This overall gives extreme scalability to higher and higher rates.

The Real World is Never Synchronous!

- In real networks not everything is exactly synchronized.
  - Or at exactly the wanted (light) frequency.
- This could cause out of synchronization frames at different rates to be cached until the start or end of the next frame.
- Across a network with many junctions the extra delays and memory/hardware costs would be significant.
- So SONET uses offset pointers (in the overhead) to allow multiplexed data to start and end away from frame boundaries and to overlap from one frame to the next.

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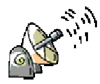
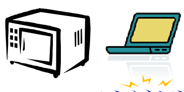


Framing for Wireless



- Wireless networks – much more open to noise and interference.
  - Need good error detection.
  - Error correction without re-transmission?
  - Fast re-transmission – detect duplicates etc. like TCP.




- Varying data rates.
  - Low data rate much more robust.
  - Much greater coverage.
  - **Want as many possible sources of interference to know what I am doing. Don't want non interferers to know**
  - **I want to know what others are doing** – **when they will shut-up so I can use the medium.**

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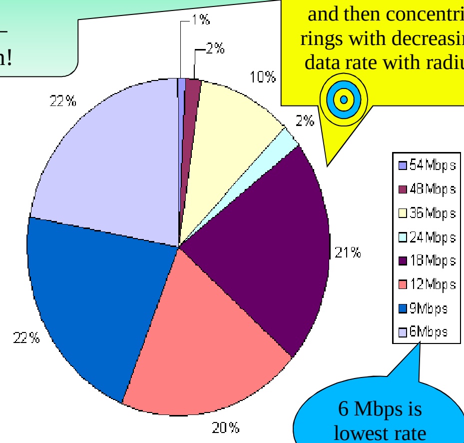
IEEE802.11a Data Rates and Ranges

- In a typical office environment.
- 1 Access Point (AP) in the centre.
- Highest rate only in a small area near the AP.
- Average rate around 12 Mbps.
- **Important all hear and understand the headers.**
- **Irrelevant if anybody other than the destination hears the data.**

Not really rings/circles – simplification!

Think of AP in middle and then concentric rings with decreasing data rate with radius



6 Mbps is lowest rate for 802.11a

Atheros [“Measured Performance of 5-GHz 802.11a Wireless LAN Systems”, James C Chan, Jeffery Gilbert. Atheros.]

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Explaining Some of the Differences for IEEE 802.11 Wireless Frames - 1

Stylised 802.11 MAC frame

← **Sent at lowest data rate** → ← **Sent at low data rate** → ◄ Fast? ►

Preamble	Frame Control	Duration	Addr-1	Addr-2	Addr-3	Sequence Control	Data	CRC

- **Longer pre-amble – establish clock and symbol (0/1) identification.**
- Instead of length send “**duration**” plus in the “**frame control**” (header data) set the data rates.
- Address fields taken from Ethernet.
- **Frequently different data rates for header/addresses etc. and data.**
  - Data may be very fast but with small coverage area – where the signal can be understood. 54Mbps needs 1000 times the power 1Mbps needs but, transmit power is limited so normally range (coverage) varies.
- **Preamble + control + duration – want every possible interferer to understand – so low data rate.**
  - **Addresses + sequence control – might be less resilient than headers** – might be higher data rate but perhaps not as fast as data.
    - Want destination to understand even if the data is corrupted!
    - Do not care if non-destination hosts miss addresses and data provided they did understand the “duration” so as not to cause interference!

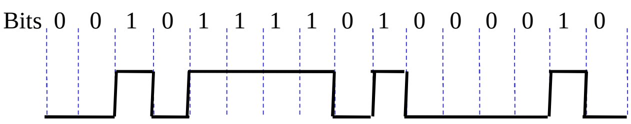
Explaining Some of the Differences for IEEE 802.11 Wireless Frames - 2

- Protection: CRC32 is not bad **+ strong physical layer error protection.**
  - Forward Error Control (FEC) – convolution + Viterbi decoder to protect data.
  - This is one parameter that is varied to provide different data rates.
    - The other is usually the type of modulation but lots of other ways are possible.
- Also has small control frames for ACK + to negotiate use of medium (RequestToSend/ClearToSend).
- Most frames have 2 addresses – source + destination. 3 addresses used for bridging through an Access Point.
- 4 address frames introduced to support wireless mesh.
  - Destination, source, intermediate transmitter, intermediate receiver.

Encoding Bits

- Signals travel through the physical medium between hosts.
  - For example, as Voltages – Analogue.
- Bits must be encoded into signals by the sender's network adapter and then decoded by the receiver's network adapter.
- We can consider a mapping:
  - 1 to a HIGH value.
  - 0 to a LOW value.

  voltage, current, phase, frequency …..
  - This is called **Non Return to Zero** (**NRZ**)



  - Where is the clock? How does the receiver work out where transitions take place, by how much the voltage changes at transition?

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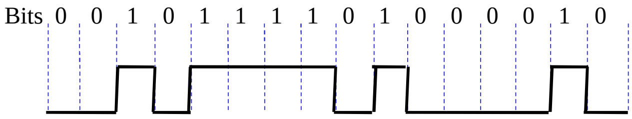
Non Return to Zero (NRZ)



- Clock Recovery
  - We do not waste a wire/channel sending a clock for synchronization.
  - Must recover clock at the receiver from 0 → 1 and 1 → 0 <u>transitions</u>.
  - No transition means clock drift becomes an issue.
- Baseline wonder
  - At the receiver the signal is not so clean and clear.
  - Receiver uses an average of the signal so far.
    - All zeros means the average drops towards zero.
      - A small increase may be interpreted as a 1
    - All ones means the average rises towards 1.
      - A small decrease may be interpreted as a zero

Ideal synchronization pattern something like 010101….preamble end sequence such as 0110/1001 i.e. different.

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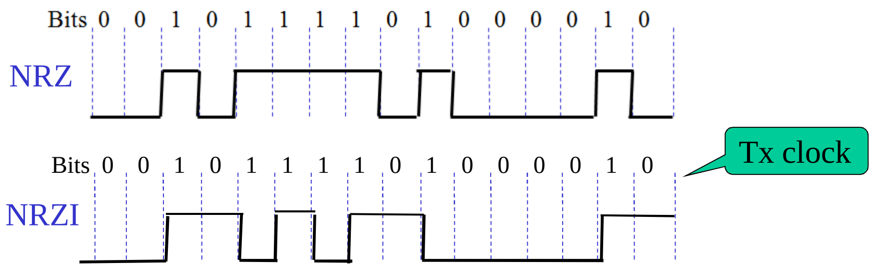
Non Return to Zero Inverted (NRZI)

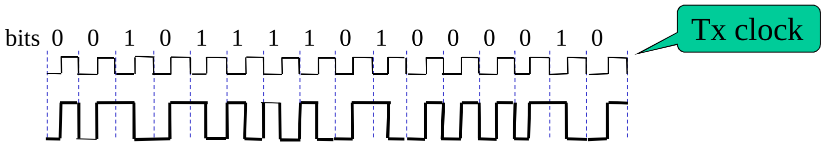


- Always make a transition to record a 1. By inversion.
- Stay at current signal for a zero.
  - Consecutive 1’s give good clock recovery.
  - With no consecutive 1s. But zeros….
    - Real systems use Run Length Limited encoding (RLL) but results varying data rate.
      - USB inserts additional bits to get around this.

Ideal synchronization pattern something like 1111111…._end_sequence such as 0110 i.e. different.

Manchester Encoding

- Used in IEEE 802.3 Ethernet



- Sends the XOR of the NRZ signal and the clock.
- Now zero and one are encoded by transitions leading to a transition per bit or per complete clock cycle.
- But, the bit rate is now twice the baud rate!
  - Or the clock must be twice the bit rate – NRZ and NRZI could go twice as fast if it is possible to keep up. But need RLL.
  - So only 50% as efficient.
  - But, much easier clock recovery.

Much less bothered about synchronization pattern. Likely to have strings of same adjacent digits though.

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4B/5B

- Used in 100BASE-TX Cat 5 Ethernet.
- Insert extra bits to break up strings of 1s and 0s.
  - Max one leading zero
  - Max 2 trailing zeros
  - Therefore no pair of codes has a string of more than three 0s in a line.
  - Sent using NRZI so 1s always have a transition.
  - 80% efficiency compared 50% for Manchester encoding.
  - Space for 32 codes – uses 16 = spares for
    - 11111 == idle
    - 00000 == dead
    - 00100 == halt
    - 6 for control signals if needed
    - 7 unusable as break 0s in line rules.
- Several other variants of this idea exist.

4 Bit Data Symbol	5 Bit Code
0000	11110
0001	01001
0010	10100
0011	10101
0100	01010
0101	01011
0110	01110
0111	01111
1000	10010
1001	10011
1010	10110
1011	10111
1100	11010
1101	11011
1110	11100
1111	11101

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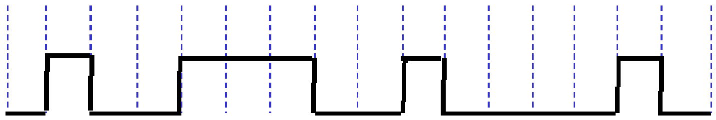
Encoding Quiz



- What bit sequence does the above represent using:

1. NRZ
2. NRZI

……

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Overview

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  - Byte oriented
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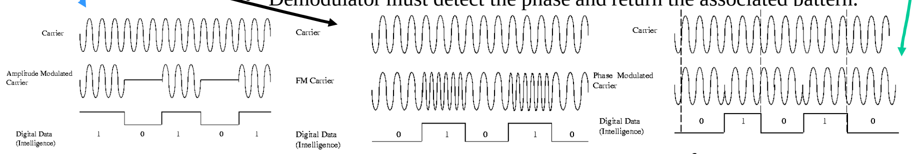
- **Modulation:**
  - **How is data encoded on to Bits?**

Signals and Modulation 1

- Whatever the media – propagate **signals**.
  - Usually **electromagnetic waves** – **Speed of Light** (**SoL**).
  - **SoL** is media dependent – velocity factor ≈ 2/3 for copper.
  - Must **modulate** binary data (0 and 1) on to the wave.
    - Simple – On/Off e.g. Morse code (**Carrier Wave** (**CW**) modulation)
    - Amplitude (**AM**) – Vary the strength/Voltage.
    - Frequency (**FM**) – Vary the frequency +/- Hz
    - Phase (**PM**) – Vary the angle of the Sine wave
      - **Phase Shift Keying** (**PSK**) – digital PM uses N different phases each with a unique pattern of bits.
        - Demodulator must detect the phase and return the associated pattern.



Images from: www.rigacci.org

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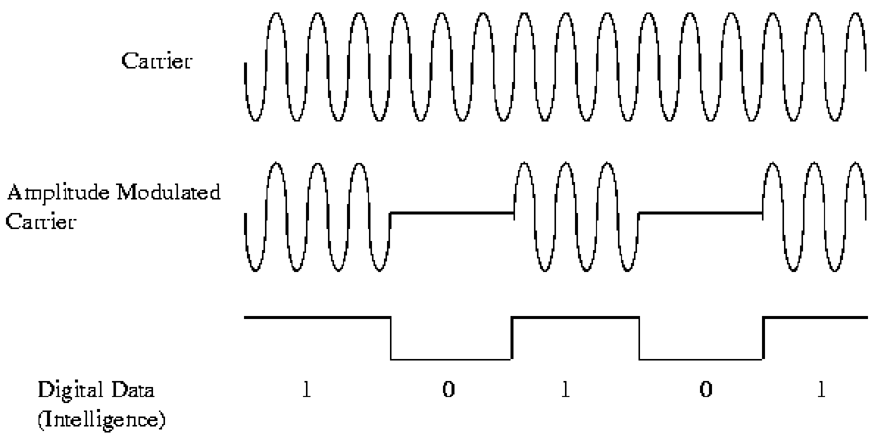
Amplitude Modulation



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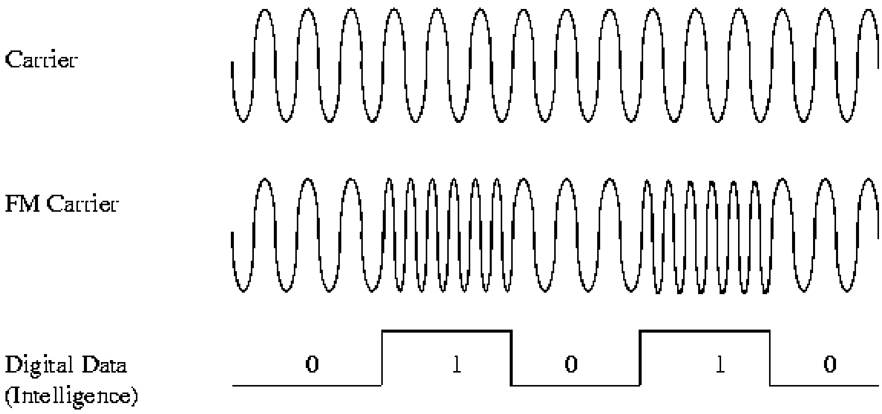
Frequency Modulation



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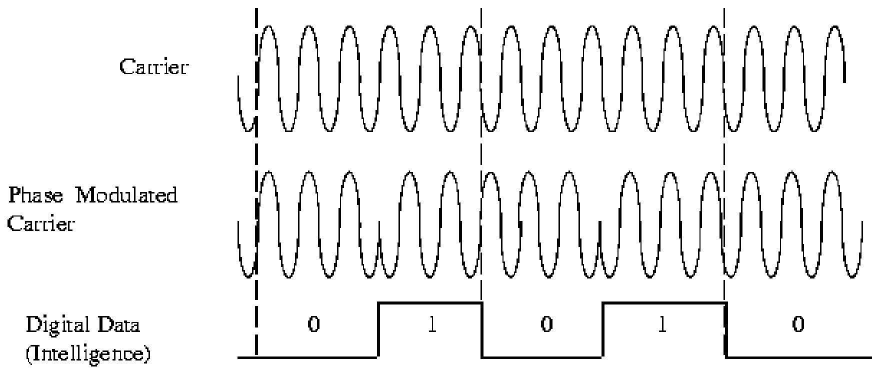
Phase Modulation



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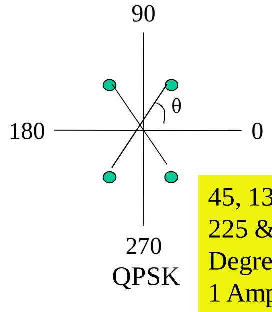
Signals and Modulation 2

- Most modems use a combination of modulation techniques:
  - Often multiple amplitudes and phase shifts

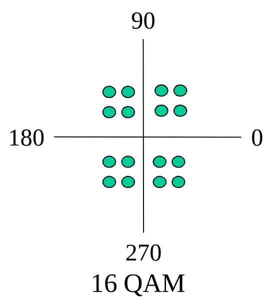


Frequency mainly used now days for channel determination in digital communications.

45, 135,
225 & 315
Degrees.
1 Amplitude
– presence/absence of signal.
2 bits/symbol from phase.

- 2 more examples :-

16-QAM



4 amplitudes,
4 phases
= 4 bits/symbol

Quadrature Amplitude Modulation

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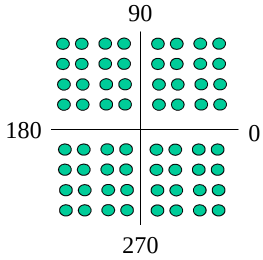
64-QAM



6 bits/symbol

64 QAM

- Modulation is mainly an EE problem!
  - But we must be a little aware of it for wireless and new wired high speed technologies.

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Maximum Data Rates

- In 1927 Nyquist determined that the maximum number of pulses a channel can carry is:
  - No. symbols per second f_{pulse} = 2 * Bandwidth B_{Hz}
- Hartley then formulated a rule for the gross bit rate.
  - Where M is a message or symbol.
  - Depends on signal amplitude [-A ... + A] Volts.
  - Sensitivity/precision of the receiver +/- ΔV Volts.
  - The information per pulse in bits per pulse/symbol is then the base 2 logarithm, to derive the line rate R_{bps}.
  - To allow for Analog Bandwidth vs digital R values this is converted to a proportion.

$$M_{Pulses} = 1 + \frac{A}{\Delta V}$$

$$R_{bps} = f_{pulse} \log_2(M)$$

$$R_{bps} \leq 2B \log_2(M)$$

- Shannon then introduced the idea of noisy channels where there is some wanted signal and some unwanted signal.

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Shannon-Hartley theorem

- With channel capacity C and data rate R:
  - **If** R < C there are codes for transmitting information where the probability of error at a receiver is arbitrarily small.
    - Below rate C we can find codes that will work.
  - **If** R > C then the probability of errors increases as R increases.
    - Cannot guarantee correct transmission.
  - We know of codes that come very close to the Shannon limit – Turbo codes, Reed Solomon codes
- In channel with AWGN and B_{Hz} bandwidth:
  - Additive White Gaussian Noise = wideband with a flat power spectral density. *Close to real world.*

$$C = B\log_2\left(1+\frac{\text{Signal Power}}{\text{Noise Power}}\right)$$

Here: Signal and Noise power are measured in Watts giving a power ratio. In engineering often Decibels (dB) are used for ratios. If given dB a conversion will be needed!

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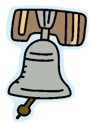
Some Useful Info for Calculations

$$X_{dB} = 10\log_{10}\left(\frac{X}{X_0}\right) \longleftrightarrow \frac{X}{X_0} = 10^{\left(\frac{X_{dB}}{10}\right)}$$



- X_{dB} represents the ratio between the measured value X and a reference X_0 expressed in Decibels. For example 30dB is a power ratio $10^{30/10} = 10^3 = 1000$.
- Decibels are the unit of choice for power in many communications applications as the numbers are easier than Watts for very small or big values.
- Maths Reminder:
  - Converting to logs in Base N

$$\log_N(X) = \log(X)/\log(N) \text{ so :}$$
$$\log 2(X) = \log(X)/\log(2)$$

Convert back using x^y e.g. 10^y for $\log_{10}$ or 2^y for $\log_2$. Also use Natural Logs to base "e".

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Shannon-Hartley Limit Examples

- Old telephones (POTS) have an approx 4Khz bandwidth and a typical SNR of 20dB (= 100). So:

$$C = 4000\log_2(101) = 26{,}632 = 26.6Kbps$$

- A radio link needs 200Mbps in less than 20MHz bandwidth so we need SNR?

$$\log_2(1+S/N) = \frac{C}{B} = \frac{200\text{x}10^6}{20\text{x}10^6} = 10$$

$$1+S/N = 1024 \text{ SO } \frac{S}{N} = 1023 \text{ or } 30\text{dB}$$

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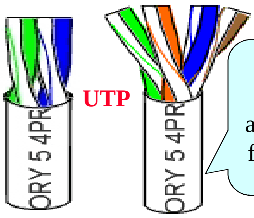
Building Block – Twisted Pair



Velocity Factor about 0.64 for CAT-5 cable

Categories of Guided Media

- **Twisted pair cables**
  - Unshielded (**UTP**)
  - Shielded (**STP**) - more expensive but less susceptible to noise
  - Two insulated wires twisted around each other to reduce the effects of outside interference (affects both conductors evenly); Each pair consists of two wires which provides a signal path and a return path.
  - Typically two or four pairs contained in a single cable;
  - Unshielded or shielded forms (individual pairs may also have separate shields);
  - Shielded cable was introduced for use with data transmission (unshielded for voice) but good quality unshielded twisted pair now being used for LANs;
  - Relatively the cheapest and the most popular of all media.

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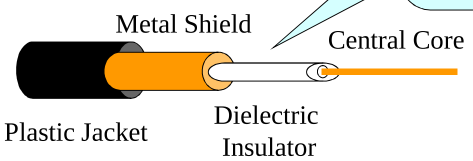
Building Block – Coaxial Cable

Velocity Factor roughly 0.66 of Speed of Light (SOL). i.e Light travels at 2×10^8m/s not 3×10^8m/s in coax

- Coaxial cables: commonly used in TV

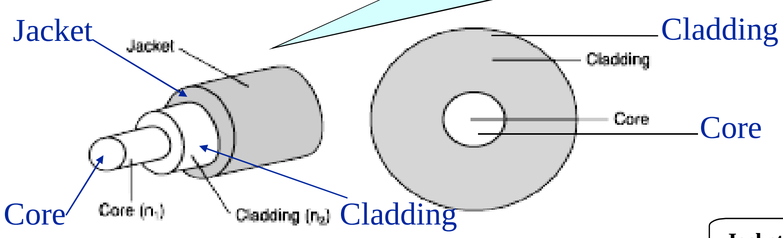


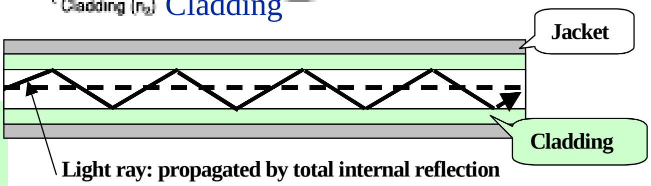
- **Designed for high frequency shielded transfer of electromagnetic waves.**
- **Mainly still used for wireless down leads and cable TV connections.**

Building Block – Fibre Optic 1

- **Fibre-optic cables**

Velocity Factor generally much slower than coax or twisted pair due to refractive index about 1.48 (0.66 SOL) + non straight line travel + latency in transducers at each end. Range is 0.4 to 0.7.





- Propagation of light down a fibre optic cable

Summary

- Today we have talked about:
  - Link Layer Framing
    - Byte oriented
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    - Bit Oriented
      - High-Level Data Link Control (HDLC)
    - Clock Oriented
      - Synchronous Optical Network (SONET)
  - Framing for ADSL and other Link Layer Carrier Connections
  - Some differences between wired and wireless frames.
  - Encoding binary values for transmission
  - Modulation – Conversion of digital to analogue symbol representations.
- **That's All Folks!**

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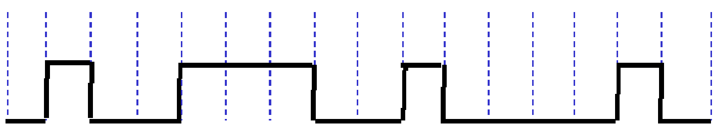
Quick Quiz Answer

A4



- What bit sequence does the above represent using:

1. NRZ 0100111001000010
2. NRZI ?1101001011000110

Is 1st digit Ambiguous ?
I do not think so – It's a 0 as no transition is shown.

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Questions ?

- Suggest a high quality frame preamble sequence for an:
  - NRZ
  - NRZI

  coded frame header?
- Why is NRZI generally better for clock recovery than NRZ?
  - When does NRZI fail badly?
- Which 4B/5B 4 bit data symbols provide the best clock synchronization?
- A 64 QAM system sends frames at 72Mbps. What is the baud rate of this system?
  - What would the baud rate if:16 QAM, QPSK or BPSK had been used instead of 64 QAM?