EEEN20060 Communication Systems

Medium Access Control

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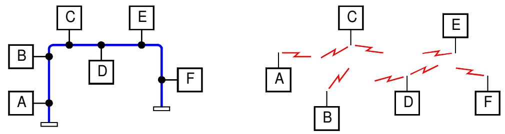
Scoil na hInnealtóireachta Leictrí, Leictreonaí agus Cumarsáide UCD

Medium Access Control (MAC)



- Applies to shared channel only
  - cable with many devices connected
  - or radio channel, shared bandwidth
- Organises sharing of the channel
  - controls how & when each device transmits
- Part of link-layer protocol
  - viewed as separate sub-layer
    - closer to physical layer
    - sometimes needs support from physical layer

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Sharing ?

Nestlé

- Different ways of sharing…

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Options for Sharing…

- Sharing by dividing the channel
  - divide the channel capacity into N small parts
    - often fixed and equal sections, but not always
  - allocate one part to each device or user
  - N devices can transmit simultaneously
- Good for:
  - devices or users with steady flow of data
    - make use of allocated capacity all the time
  - predictability – each user has separate capacity
    - throughput independent of other users
- Bad for:
  - varying or bursty traffic
    - if device has no data to send, its share remains idle
    - even if others have backlog of data…

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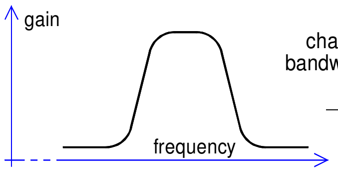
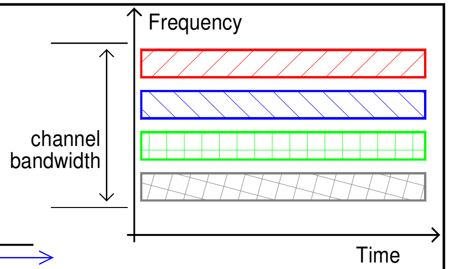
Frequency Division





- Divide channel bandwidth into sub-channels
  - transmit each signal at different frequency
    - *modulate* onto different carrier frequency
  - receiver uses filters to separate signals
    - one band-pass filter for each signal
    - then *de-modulate* to recover original signal
  - as filters not perfect, need *guard-bands*
    - gaps between signals

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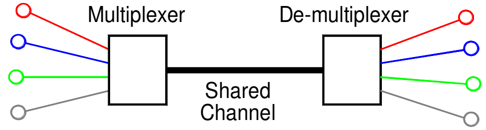
Frequency Division Multiplexing (FDM)



- Multiplexing
  - combining many signals onto one channel
    - all signals enter channel at one point
    - separated by de-multiplexer at receiving end
- Example
  - was used in analogue telephone system
  - send many speech signals on one cable
    - each with 4 kHz slice of bandwidth…
  - usually for longer-distance links
    - cheaper than having many separate cables

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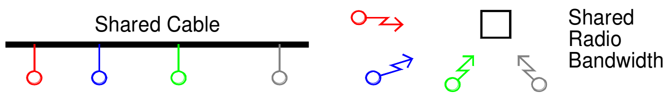
Frequency Division Multiple Access (FDMA)



- Multiple Access
  - many signals on one channel
  - each signal enters channel at different point
  - each may be received at different point(s)
- Example
  - radio or TV broadcasting
    - each radio station allocated different frequency
  - mobile phone systems
    - different phones on different frequencies
    - now combined with other techniques…
    - capacity assigned on demand…

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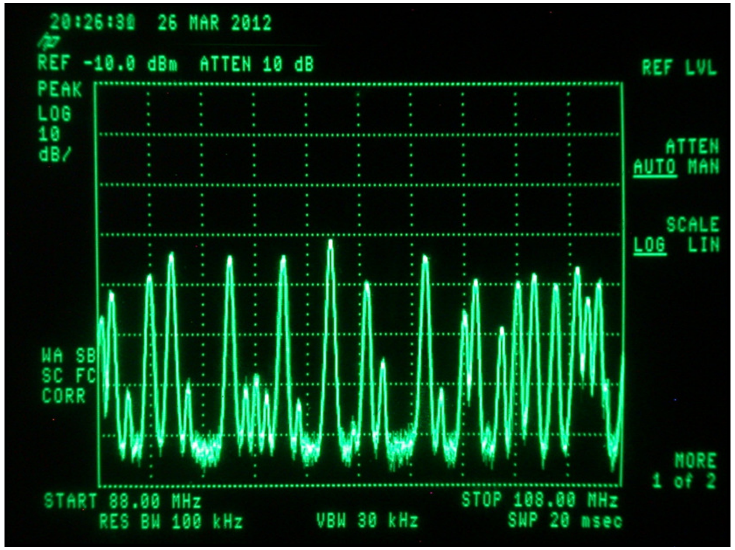
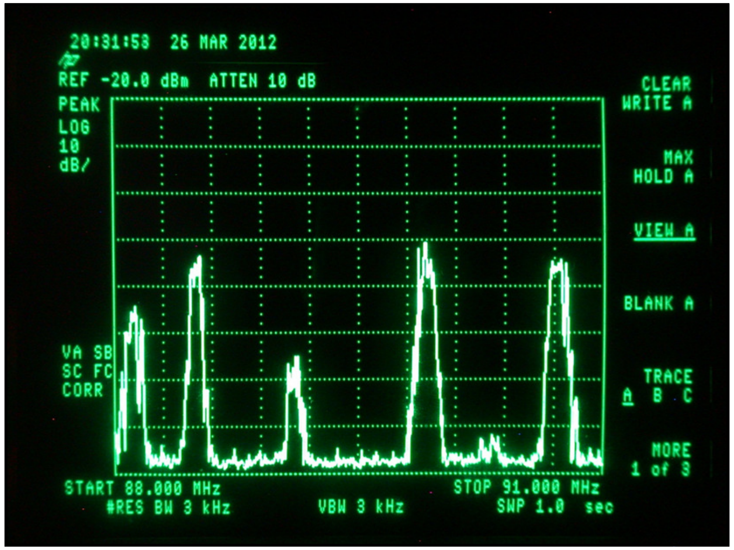
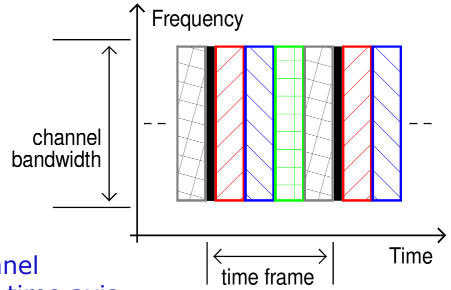




Time Division

usually only with digital signals



- Divide channel capacity on time axis
  - each device or user has full bandwidth
  - but only for a fraction of the time
  - repeats for each *time frame* (or *frame* !!!)
- Time Division Multiplexing (TDM)
  - all signals enter channel at one point
  - add marker so de-multiplexer can identify...

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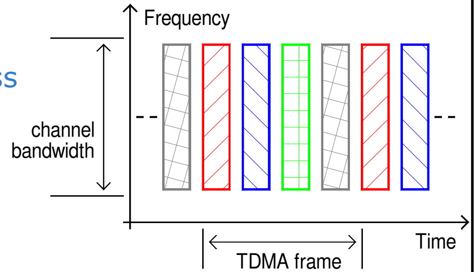
Time Division Multiple Access (TDMA)



- Signals from different devices
  - timing not perfect, need gaps – *guard times*
  - each transmission may be a link layer frame
  - each transmission may identify itself
    - no marker shown in diagram...
- Receiver must work at full speed
  - receive all data, discard unwanted data

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Assignment on Demand

- Divide channel into N sections
  - either in frequency or in time (or both...)
  - shared by group of K users, $K > N$, often >> N
- No permanent assignment to any user
  - frequency or time slot assigned when needed
  - released when no longer needed
  - need mechanism to request an assignment...
- Good for connection-based system
  - users request connection when needed
  - communicate for relatively long time, then clear
  - user may be idle most of the time
    - but no resources wasted...
  - design for low probability of *blocking*
    - resource not available when requested...

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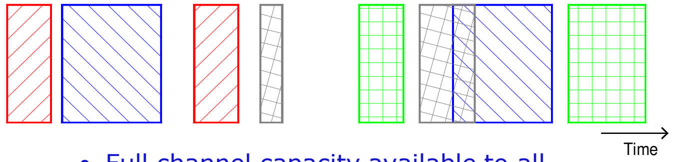
Telephone System Examples

- Fixed telephone system
  - cables connect exchanges in Dublin & Cork
  - capacity divided, FDM (originally) or TDM
  - allow *N* simultaneous conversations
  - *N* << population of Dublin...
- Mobile telephone system
  - fixed radio bandwidth available in each area
  - divided, each section can carry 1 speech signal
  - allocated to phone for duration of call only
- Example: GSM (second generation system)
  - FDMA – allocates bandwidth in 200 kHz sections
  - TDMA – each freq. allocation shared by 8 phones
    - 8 time slots in TDMA frame of 4.615 ms...

Sharing Without Division

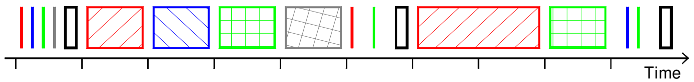


- Full channel capacity available to all
  - usually no fixed divisions
  - but only one device should transmit at a time
- Overlapping transmissions will not succeed
  - *collision* - usually both frames damaged
    - can design physical layer so one gets through…
- Good for varying, unpredictable traffic
  - but get varying, unpredictable delays…
    - as devices have to wait to transmit
    - or try more than once before succeed…

How to Arrange Sharing?

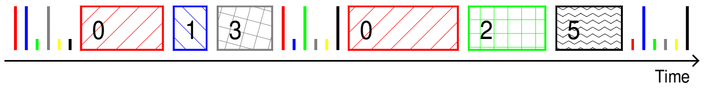
- Scheduled access
  - devices given permission to transmit
  - arranged so only one transmits at a time
  - no collisions
  - but time used in scheduling, giving permission
  - delays waiting for permission
- Random access
  - also called *contention* – fight to get on channel
  - in purest form, device can transmit when ready
    - other forms impose some restrictions
  - collisions likely – re-transmit damaged frames
  - less delay waiting to transmit
    - but may have to re-transmit many times

Scheduled Access



- Fixed TDMA – simple, but no flexibility
  - equal shares for all
- Demand-assigned TDMA - better
  - but use capacity for requests and grants…
  - easiest with a *master* device to control
  - example – use mini-slots in first time-slot
    - one per device, so each device can request
    - then master can broadcast the assignments…
  - example – random access in one time slot
    - then master announces winners…
  - more flexible if allow multiple time slots
    - or variable length allocations (more complex)

Example: Bit-Map Reservation



- Scheduled access, but no master device
  - just need devices to be numbered
- Variable length time frame
  - each frame starts with mini-slots
    - one per device, could be just one bit each – *bit-map*
  - devices broadcast *intention* to transmit
  - then devices transmit data in order
    - all received bit-map at start of frame
    - so all know who will transmit and who will not
    - when one device stops tx, next device starts
  - can allow fixed tx time, or variable, up to limit
    - when all have tx'ed, know to start next bit-map...

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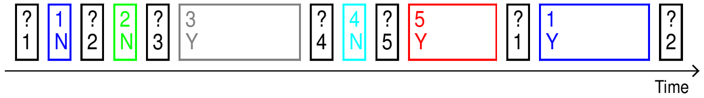
Scheduled Access: Polling



- Polling ⇒ asking if want to transmit
- Easiest with master – centralised polling
  - master polls each device in turn
    - may also send data to device in same LL frame
    - device with data to send, transmits data (limit?)
    - idle device could transmit short NO, or nothing
  - can be slow, esp. if long delay on channel...
  - use for systems with natural master
    - often all data flow to and from master
    - e.g. factory automation – control computer & robots
    - e.g. data acquisition, security system, many sensors
    - response to poll confirms sensor working...

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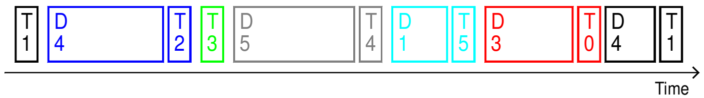
Example: Token Passing



- Distributed polling – no master
  - token is special frame or signal
  - addressed to a particular device
  - gives permission to transmit (with limit)
    - one frame or multiple frames? time limit?
  - or device can become temporary master
    - can transmit and request replies...
  - after transmitting, must send token to next...
- Questions?

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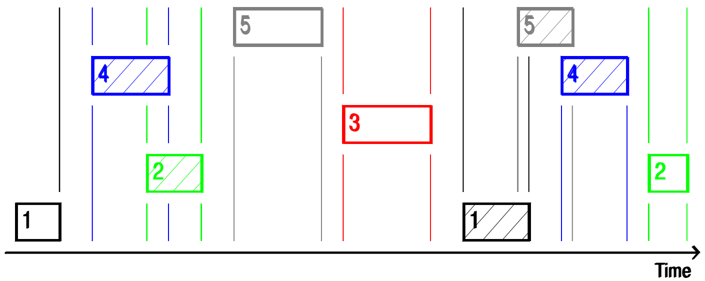
Random Access

9 transmissions
How many succeed?



- Simplest system
  - users can transmit whenever ready
  - if two or more transmissions overlap, collision
    - usually all frames involved are damaged/lost
  - only works well if channel mostly idle!

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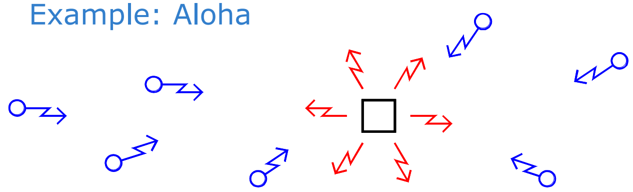
Example: Aloha



- First such system, basis for many others
  - developed in University of Hawaii
  - radio-based system, using repeater
    - users all transmit to repeater on same frequency
    - repeater broadcasts everything on different freq.
    - all users receive all transmissions from repeater
  - user may transmit whenever ready
    - listens for broadcast – knows if collision occurred
  - if collision, wait random time, then try again
    - why random wait? called *back-off*

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Aloha continued

- Same principle with satellite, longer delays
- On cable, all devices receive all tx anyway
  - no need for repeater or second frequency
- Simple and quick
  - no delays waiting to transmit
  - no capacity used to request/grant permission
  - no master device needed (on cable)
- But time wasted on collisions
  - need low traffic for low prob. collision
    - so channel idle most of time, efficiency low
  - if traffic increases, get more collisions
    - so more re-tx attempts, even more traffic on channel
  - eventually, throughput falls as demand rises
    - and delays increase rapidly…

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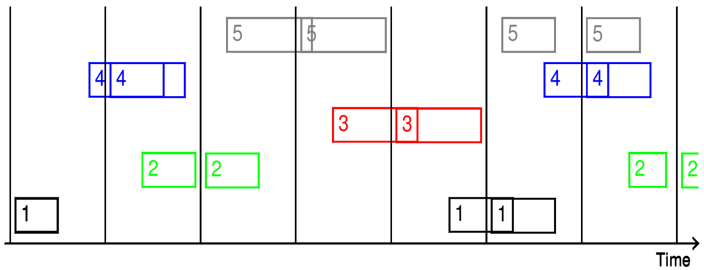
Improvement: Slotted Aloha



- Divide channel into time slots
  - e.g. repeater transmits regular marker signal
  - user must wait for start of time slot to tx
- Improved performance
  - frame is safe from collisions except at start
  - less time wasted by each collision

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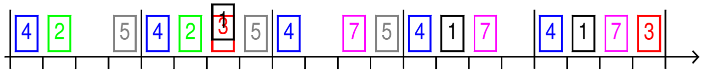
Improvement: Reservation Aloha



- Extension of slotted Aloha
  - group *N* slots into time frame
  - each slot reserved for user who used it in previous frame
  - if slot left idle in one frame, then available for contention in next frame
- Effectively demand assigned scheduled access
  - using contention to assign time slots
- Benefit if users send long messages
  - will use many time slots in consecutive frames
    - no collisions except on first block of message
  - price paid is idle slot at end of message

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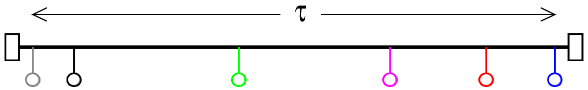
Random Access – How to Improve?



- One obvious addition is *channel sensing*
  - users listen to (sense) channel before tx
  - if channel busy, do not transmit
  - called channel-sensing multiple access (CSMA)
- Does not eliminate collisions
  - two users may sense at ~same time
    - both think channel is idle, start to transmit – collision!
    - "~same" means within propagation delay…
  - not reliable on radio network
    - no guarantee all users hear all transmissions…
  - no use with long propagation delay
    - e.g. on satellite network

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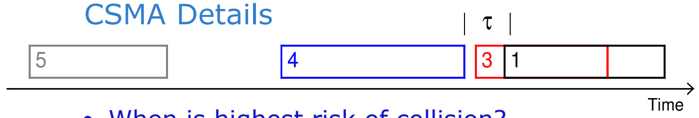
CSMA Details



- When is highest risk of collision?
- Collision avoidance
  - what can we do to reduce the risk?
- Non-persistent CSMA
  - want to tx, sense channel, if idle, transmit
  - if busy, wait random time, then sense again
- *p*-persistent CSMA
  - if busy, sense continuously until idle
  - then random decision: transmit with prob. *p*
  - or wait propagation delay and start again
  - adjust parameter *p* to control performance
    - 1-persistent CSMA is possible, but many collisions

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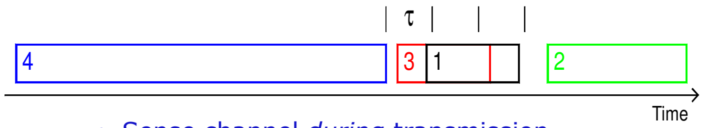
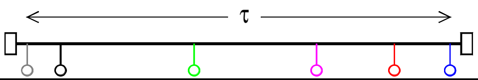
CSMA/CD – Add Collision Detection



- Sense channel *during* transmission
  - detect collision – signal not as expected…
  - stop transmitting, so waste less time
- Only possible on cable, or radio with repeater
  - not simple radio network, tx & rx on same freq.
    - cannot detect other signals while transmitting
    - tx power >> receive power, so only see own signal
- Need minimum transmission time ≥ 2τ
  - to ensure both devices detect collision



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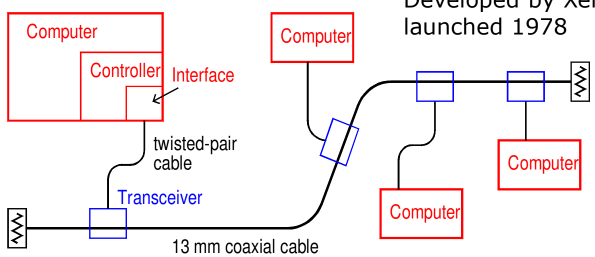
Example: Ethernet

Developed by Xerox, launched 1978



- Physical Layer
  - 10 Mbit/s, Manchester coding, ±0.85 V signals
  - thick coaxial cable, max. 500 m, no branches
    - terminating resistor at each end
  - *transceiver* attached to cable (bus) (in parallel)
  - computer-to-transceiver cable, max. 50 m
    - twisted-pair cable, 5 pairs

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Ethernet MAC

- 1-persistent CSMA/CD
  - listen before tx, wait until idle, then transmit
  - fast access to channel, but high prob. collision
- Detect collisions as they occur
  - invalid or unexpected voltage on cable
  - stop frame tx, transmit 48-bit jam signal
    - ensures all users detect collision
    - *slot time*: time to detect, jam, clear channel ~50 μs
- Re-transmission attempts – random delay
  - after n^{th} collision, delay r slot times
    - r random integer, uniformly distributed, 0 to 2^n-1
    - called *binary exponential back-off*
    - n stops increasing at 10, fail after 16 collisions
    - n reset to 0 after success

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Ethernet Frame

Bytes: 8	6	6	2	46 to 1500	4
Preamble	Dest. Addr.	Source Addr.	Type	Data	CRC

- Preamble: 7 bytes 10101010 10 MHz periodic
  - allow receivers to synchronise with signal
  - last byte 10101011 signals start of frame
- Addresses: 48 bits, unique to each interface
- Type: type of payload, which network protocol
  - can also be data length, in bytes, if ≤ 1500
- Data: max 1500 bytes, min 46 bytes
  - so min frame 512 bit, for collision detection
- CRC: 32-bit – reliable error detection
  - bad frames discarded, higher layer must fix

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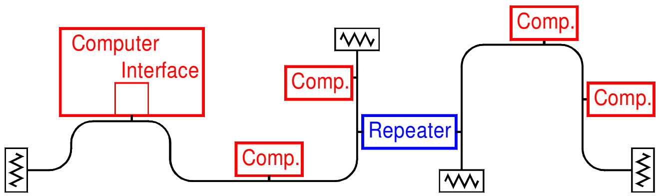
Ethernet Developments



- Thin coaxial cable (~5 mm)
  - max 185 m, max 30 devices, attached directly
- Repeaters connect cable segments
  - signal arriving on one port is tx on other(s)
  - no delay, no collision detection
    - so whole network still one collision space
- Efficiency when busy $\eta \approx \dfrac{T_F}{T_F + 5\tau}$

  T_F frame tx time, τ prop. delay

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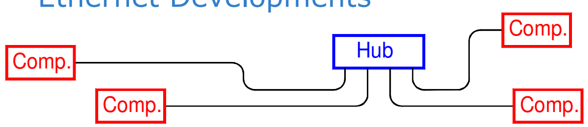
Ethernet Developments



- Move from bus topology to star
  - twisted-pair cables from device to *hub*
  - max 100 m to 200 m, depends on cable quality
  - hub is multi-port repeater – one collision space
- Replace hub with *switch* – store and forward
  - receives frame, re-tx only on destination port
  - if two frames for same dest. port, queue…
    - operation much more complicated than hub
  - each cable is separate collision space
  - now can increase bit rate: 100 Mbit/s, 1 Gbit/s

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Ethernet Developments

- 100 Mbit/s – change physical layer
  - 4B/5B encoding, more efficient than Manchester
    - group of 4 bits encoded as group of 5 bits
    - choose 5-bit patterns to give transitions
    - signal changes max. 125 MHz
- Separate channel in each direction on cable
  - *full duplex* – no more collisions
  - use separate pair of wires for each direction
- 1 Gbit/s – change physical layer again
  - use 4 pairs of wire, 125 Msignals/s on each
  - 5-level signals, each carries 2 bits
    - complex mapping provides for transitions…
  - same wires used to send in both directions
    - complex signal processing to separate signals

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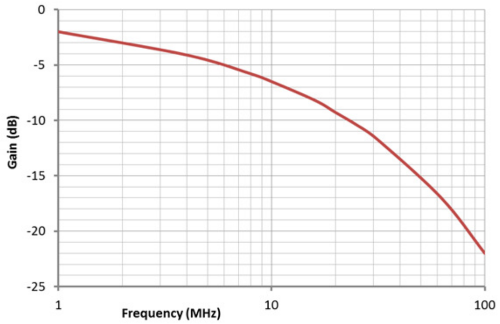
Attenuation Example

100 m length of Cat5 cable

decibel used to express power ratio



$$\text{Gain (dB)} = 10\log_{10}\left(\frac{P_{out}}{P_{in}}\right)$$

- Attenuation or loss = 1/gain
  - more attenuation at higher frequency
  - at 8.5 MHz, 25% of tx power arrives at rx
  - at 85 MHz, 1% of tx power arrives at rx

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