ELE3305 Computer Systems & Communications Protocols

Module 5: Local Networks

Local Networks

A LAN is a Local Area Network. Used for:

- Office Workstations, Resource Sharing
- File Servers (reduced software cost)
- Communications (email)
- Factory automation

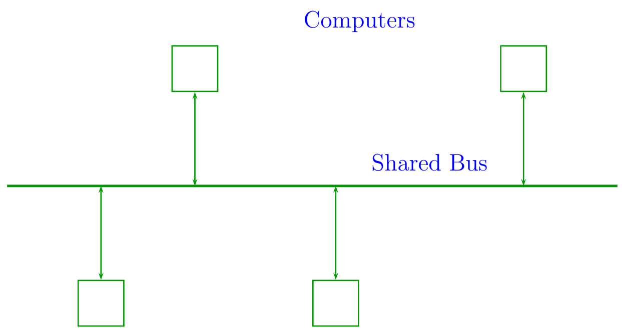
We'll look at the operation of Bus, Ring, Star LAN's. The concentration will be more on Ethernet, since it's by far the most widely deployed.

LAN Characteristics

- Shared medium → bandwidth contention.
- 10's to 100's m distances.
- High data rate (10-100Mbps)
- Coax, Twisted Pair, Optical Fibre
- Often have external gateway to other LAN's & Wide Area Network (WAN)

Ethernet

Similar in nature to IEEE 802.3 standard. *Very* widely used.



Ethernet

- Common *bus* – typically coaxial cable.
- Manchester baseband encoding.
- Shared media, so that
  - All stations can listen.
  - Collisions occur if two or more transmit simultaneously.
- Carrier Sense Multiple Access with Collision Detect (CSMA/CD) algorithm used to solve contention problem.

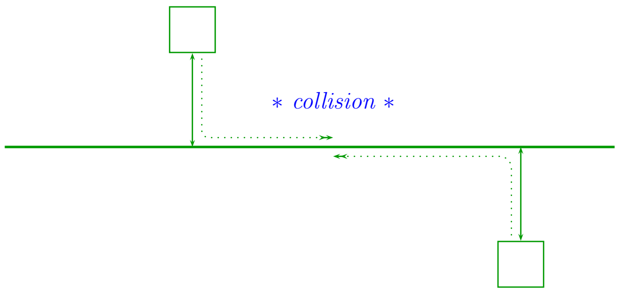
CSMA/CD Algorithm

Carrier Sense, Multiple Access with Collision Detect
(Ethernet Bus Topology)

- Each station listens for data ("Carrier Sense").
- If no data → OK to transmit.
- If two stations decide to transmit simultaneously, have a **collision**.

Common Carrier Collision

If two (or more) stations on the LAN decide to transmit simultaneously, the data on the wire gets garbled.



CSMA/CD Algorithm

- Worst case *collision window* = 2× propagation time.
- When detected, *enforce* collision: keep transmitting for a further 32 to 48 bits.
- After collision, stations wait for a time and try re-transmission of the data.
- If all stations waited the same time, could have to wait forever! → Needs some 'randomness'
- The collision algorithm: "Truncated Binary Exponential Backoff"

CSMA/CD Algorithm

Collision Avoidance

- After the first collision, wait either 0 or 1 slot times at random (1 slot = 512 bits, due to propagation delay)
- After the second collision, wait either 0,1,2 or 3 slot times.
- After the third collision, wait $rand(0, 2^3 - 1)$ slot times.
- After the n^{th} collision, wait $rand(0, 2^n - 1)$ slot times.
- $\longrightarrow$ hence "binary exponential backoff"

CSMA/CD Algorithm

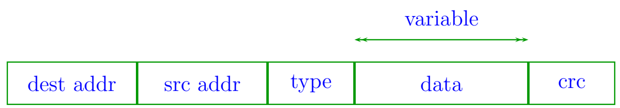
Collision Avoidance *continued*

- After 10 collisions, upper limit of wait set to 1023 slot times. (could occur under heavy network load, ie many stations trying to transmit)
- $\longrightarrow$ hence "truncated"
- Tradeoff: reducing likelihood of another collision under heavy network load *vs* longer wait under light load.

CSMA/CD Algorithm

- Can never determine worst-case transmit time - statistical likelihood only.
- Asymptotic efficiency under load 30% (64 bytes/frames) to 80% (1024 bytes/frames)
  (*Computer Networks*, A Tanenbaum)

Ethernet Frame Format



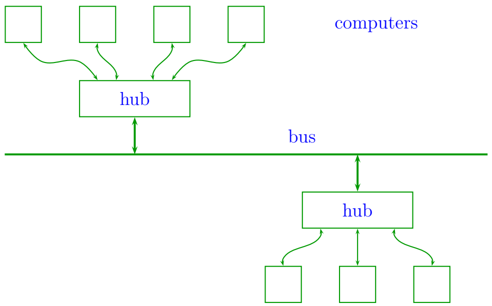
Ethernet Frame Format

- Dest Addr = destination address, 48 bits
- Src Addr = source address, 48 bits
- Type (16 bits - covered later under "TCP/IP")
  - IP (Internet Protocol) datagram
  - ARP (address resolution protocol) request/reply
  - RARP (reverse arp) request/reply
- Data = 46-1500 bytes (variable)
- CRC = 32 bit Cyclic Redundancy Check
- Minimum frame size 46 bytes (hence padding may be added)

Implementations

- 10BASE5 designation: baseband coax, 500m max
- 10BASE2 designation: baseband thin coax, 185m max
- 10BASET designation: star topology (hub), unshielded twisted pair. Used for lower cost over short distances.

Implementations - 10BASET



Token Bus LAN

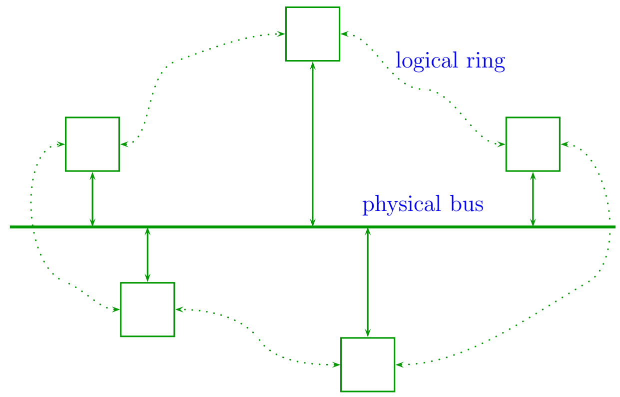
- Problem with CSMA/CD is the probabilistic nature – cannot determine the worst-case frame transmission time.
- Real-time systems (eg robot assembly line) require *deterministic* access (worst-case upper bound for transmission time)
- Prioritization is also desirable (more urgent frames sent ahead of less urgent frames)
- IEEE 802.4 Standard
- Uses broadband media (PSK)

Token Bus LAN

Token Bus is *physically* a bus, but *logically* a ring.

- Instead of CSMA/CD to share the bus, use a token-passing method.
- Token passed from one station to another.
- Can only transmit when station possesses the token, then must pass the token on to the next station.

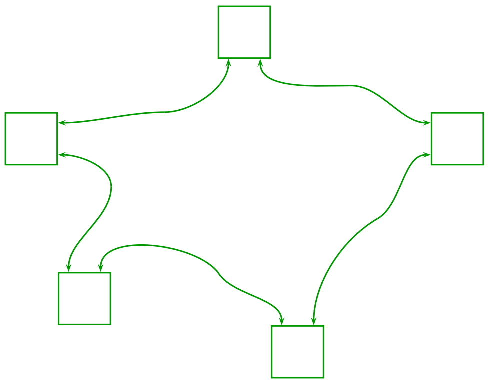
Token Bus LAN



Token Bus LAN

- 'token' is a special control frame.
- As each station acquires the token, it can transmit.
- If no data or time window elapsed - pass token.
- Problems:
  - How to pass the token (each station must know it's predecessor and successor)
  - Stations entering/leaving (power down)
- **Advantage:** Under worst case conditions (all stations waiting to transmit), token is passed from one to the next & everyone gets a chance to transmit within a known time.

Token Ring LAN

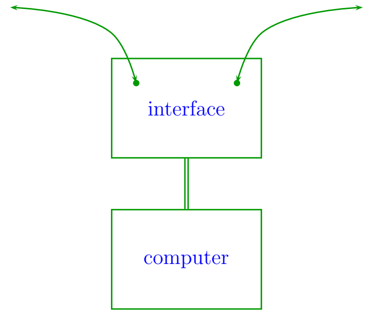


Token Ring LAN

- Ring is effectively collection of point-to-point links.
- No problem with bandwidth contention.
- Problem if one station powered down or malfunctioning.
- IEEE 802.5 Standard

Token Ring LAN

- Frames circulate in the ring. A station transmits it's frame one bit-at-a-time, and removes the frame after circulation.
- Requires a special 'ring interface'.
- Efficiency good under load (unlike CSMA/CD)



High-Speed LANs and Wireless LANs

- High-speed LANs: 100MBps and beyond
- Understanding of wired LAN essential to understanding WLAN
- WLAN: considerable uptake, many emerging developments
- Research issues: efficiency, throughput, QoS (Quality of Service)

LAN Beginnings

- Original Ethernet paper, Bob Metcalfe, David Boggs, "Ethernet: Distributed Packet Switching for Local Computer Networks", Communications of the ACM, July 1976
- Note: evolved since then; frame format very different
- 1972, Bob Metcalfe (Xerox Palo Alto Research Center, PARC) describes Ethernet concept
- based on Aloha, University of Hawaii (Norman Abrahamson) radio network for communicating among Hawaiian islands
- Aloha: transmit anytime, if collision occurs just try again
- around 18% channel utilization
- Slotted Aloha - assigned slot times, around 37% utilization

LAN Standards

- 10MBps Ethernet standard developed by DEC, Intel and Xerox
- Standardized by IEEE: 802 series, mainly 802.3 Ethernet CSMA/CD
- Various Evolutions:
  - 802.3a-1985 10BASE2 thin Ethernet
  - 802.3i-1990 10BASE-T twisted pair
  - 802.3j-1993 10BASE-F fibre optic
  - 802.3u-1993 100BASE-T Fast Ethernet & Auto-Negotiation
  - 802.3x-1997 Full Duplex
  - 802.3ab-1999 1000BASE-T Gigabit over twisted pair
  - 802.3ac-1998 1522 byte VLAN tag extensions

LAN Designations

- 10BASE5: Original Ethernet, thick coax, baseband, 10MBps, 200m
- 10BASE2: thin coax (actually 185m)
- 10BASE-T twisted pair
- 10BASE-F fibre optic
- 100BASE-T 100MBps, twisted pair and fibre
- 100BASE-X 100MBps uses 4B/5B encoding
- 100BASE-TX twisted pair, two-pair, category 5 cables
- 100BASE-FX fibre
- 1000BASE-T gigabit ethernet

LAN Physical Layer

- LLC Logical Link Control
- MAC Medium Access
- Physical Layer

Frame fields

	preamble	dest addr	src addr	type/length	data	CRC
bits	64	48	48	16	46-1500 bytes	32

LAN Physical Layer

Cabling: RJ-45 connector, 10BASE-T , 8-pin

pin	signal	Color (usual)
1	TD+ Transmit data	white/green
2	TD- Transmit data	green/white
3	RD+ Receive data	white/orange
4	unused	blue/white
5	unused	white/blue
6	RD- Receive data	orange/white
7	unused	white/brown
8	unused	brown/white

(from front-on, clip down: pin 1 on right, pin 8 on left)
Category 3 - 100ohm, UTP, 16MHz. OK for 10BASE-T; typ 6 twists/m
Category 5 - 100ohm, UTP, 100MHz. OK for 10BASE-T, 100BASE-TX, 1000BASE-T, typ 60 twists/m

LAN Encoding

- 100BASE-TX
- cat 5 cable reqd, two pairs of UTP wires
- 4B/5B: +/- 1V, baud rate 125MBaud
- 4 bits of input data encoded as 5 bits; max frequency 31.25MHz
- if 100BASE-TX used Manchester, would require 100MHz bandwidth
- MLT3 line encoding - 3 levels (+, 0, -).
- Input 1 bit, transition to next level. Input 0 bit, no transition.
- Uses levels of +1, 0, -1, 0.
- Net result is that the main frequency component is one-quarter of the transition rate.

LAN MAC

- CSMA/CD.
- Carrier Sense, Multiple Access with Collision Detection
- Issues: access time, efficiency.
- Note: No "acknowledge" (ACK)
- CSMA/CD efficiency depends on frame size: 46 byte frames, 55%, 1500 byte frames 97%
- depends on number of stations.
- Theoretically 37 % under worst-case conditions (256 stations, all wanting to transmit) - never seen in practice
- See David R. Boggs, Jeffrey C. Mogul & Christopher A. Kent,
- "Measured Capacity of and Ethernet: Myths and Reality", Proceedings of ACM SIGCOMM, Aug 1988
- (Also Digital Western Research Laboratory, Research Report 88/4)

Topology Handling

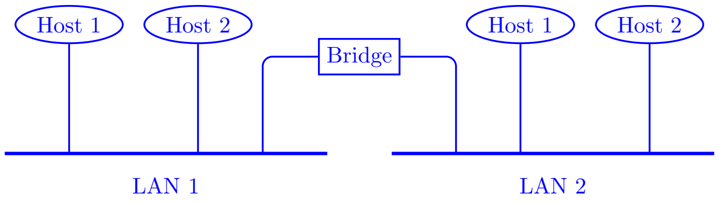
- Ethernet addresses variously called MAC, NIC, physical, hardware
- switch vs hub
- hub is simply a repeater
- switch requires buffers and learns MAC addresses
- hubs are only half-duplex
- switches are full-duplex
- store-and-forward vs cut-through
- cut-through reads only layer 2 header (address) and starts forwarding address learning
- full duplex/half duplex

Bridge

- bridge: originally just to extend LAN segment length
- simple bridge also called transparent bridge
- can also reduce collisions if some intelligence built-in
- originally 2-port bridge to span two LAN segments
- now multiport - typ 12/24 ports

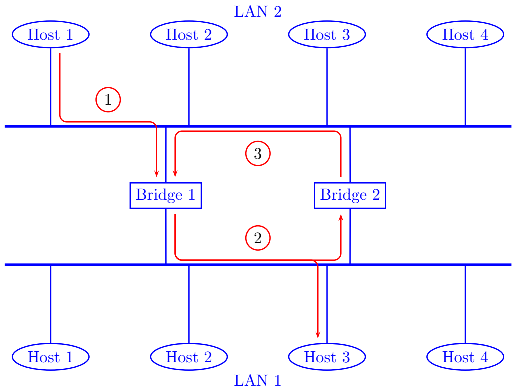
LAN Bridge

- To connect two LANs together
- Note: *not* at IP layer (that would be a router)



LAN Bridge

- problem is potential for loops in complex topology
- cisco spanning tree algorithm
- periodic announcement in case topology changes
- bridge sends out BPDUs (bridge protocol data units)



USB – Universal Serial Bus

- Half-duplex (take turns to send/receive)
- Transfer made up of transactions
- Transfer types: control, bulk, interrupt, isochronous
- Isochronous: guaranteed delivery rate, no error correction
- Transactions contains token packet, and possibly data and handshake packets
- Packet: PID (packet ID), info, CRC
- Handshaking: ack, nack, stall, nyet (not yet), err
- data packets: low-speed max 8 bytes. Full speed 8, 16, 32 64 bytes. High speed 64.

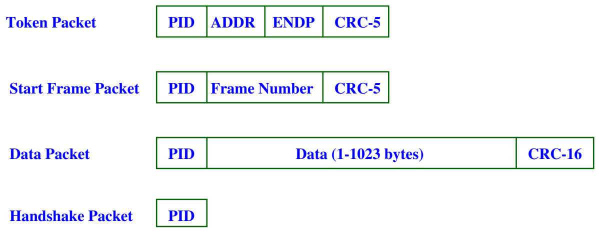
USB Transfers

Transfer Type	use
Control	setup/config
Bulk	scanner
Interrupt	mouse
Isochronous	audio

Transfer Type	stages
Control	setup, data, status
Bulk	data
Interrupt	data
Isochronous	data (no handshake)

USB Packet Format

Name	bits	purpose
SYNC	8	start of packet synchronization
PID	8	packet identifier
address	7	identify function address
endpoint	4	identify endpoint
frame no.	11	identify frame
data	0 to 8192 (2.0)	data
CRC	5(address) or 16 (data)	error detection



Packet ID (PID) 8 bits
Frame Number 11 bits
Address (ADDR) 7 bits

USB Tools

See USB devices: *usbview*
`http://www.srigc.com/softdl.htm`

USB Packet sniffer – *USB Snoopy*:
`http://www.wingmanteam.com/usbsnoopy/`

Wireless LANs

- Many new challenges:
- Throughput, reliability, QoS
- Routing, organization
- Compatibility...

Wireless LAN Issues

- Lower data rate
- Lower throughput
- Increased bit error rate (frame errors)
- Medium access is harder
- Address allocation (mobility, “ad hoc” networks)
- Security (eavesdropping)
- Power consumption

Wireless LANs

IEEE Standards in 802 LAN family

802.2 Logical Link Control (LLC)

802.11 Medium Access Control (MAC) Frequency Hopping Spread-Spectrum (FHSS) or Direct Sequence Spread Spectrum (DSSS)

802.11a Orthogonal Frequency Division Multiplexing (OFDM). 5GHz, up to 54Mbps. modulated BPSK (up to 9Mbps), QPSK (up to 18Mbps), 16-QAM (36 Mbps), 64-QAM (64 Mbps). Uses FEC

802.11b High-Rate DSSS, 2.4GHz, 1Mbps, 2Mbps, 5.5Mbps, 11Mbps

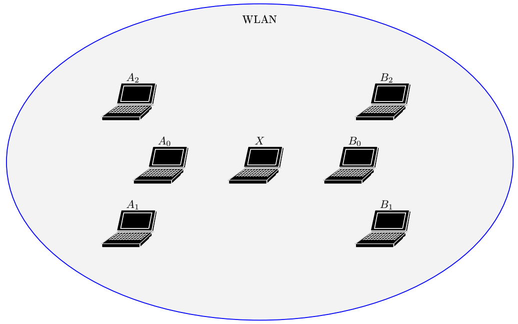
802.11g OFDM, 2.4GHz, 54Mbps, FEC

802.1d Bridging

802.1q VLANs

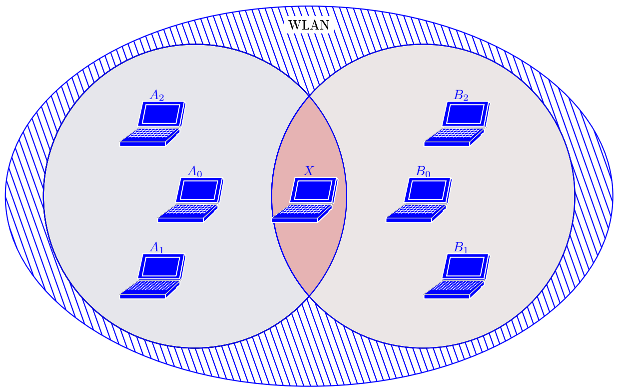
802.11 MAC

- Uses CSMA/CA (Collision Avoidance), positive acknowledgements (all frames must be acknowledged)
- Uses RTS/CTS sequence, then frame with ACK. Not used, only in high capacity environments because of latency in RTS/CTS sequence. If frames above an RTS threshold, RTS/CTS is used. Shorter frames are sent without waiting, provided medium is clear.



802.11 MAC

- Hidden node problem: a transmission cannot be heard by the intended destination, but can by others in the network boundary (obstacles, distance)



CSMA/CA

DCF Distributed Coordination Function. Checks to see if medium is free, uses random backoff after each frame, first transmission seizes channel. May also use RTS/CTS.

PCF Point Coordination Function. Uses point coordination stations to ensure contention-free service. Only for infrastructure networks. Not widely used.

Virtual Carrier

- Carrier sensing uses a virtual carrier sense Network Allocation Vector (NAV). Frames carry a duration field, and can reserve the medium for a fixed time.
- Using both RTS and CTS solves hidden-node problem. Stations defer transmission when they hear a RTS for the required NAV.

Interframe Spacing

SIFS Short Interframe Space. Used for high priority transmissions such as RTS/CTS and positive ACKs. High-priority transmissions can begin once SIFS has elapsed.

PIFS PCF Interframe Space. Used by PCF during contention-free operation. Stations can transmit after the PIFS has elapsed to preempt contention-based traffic.

DIFS DCF Interframe Space. Minimum idle time for contention-based services. Stations can transmit after it has been free for the DIFS period.

EICS Extended Interframe Space. Not fixed, used when there is an error in frame transmission.

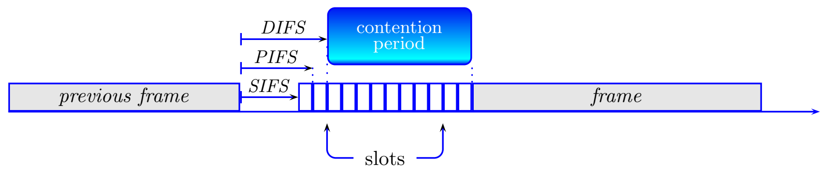
Contention-Based Access using DCF

DCF uses exponential backoff, similar to Ethernet

- Stations must check medium
- If medium free for longer than DIFS, can start immediately
- If previous frame was OK (no errors), must wait for for DIFS (EIFS if previous frame contained errors)
- If medium is busy, must defer access. Wait for DIFS and begin exponential backoff procedure.

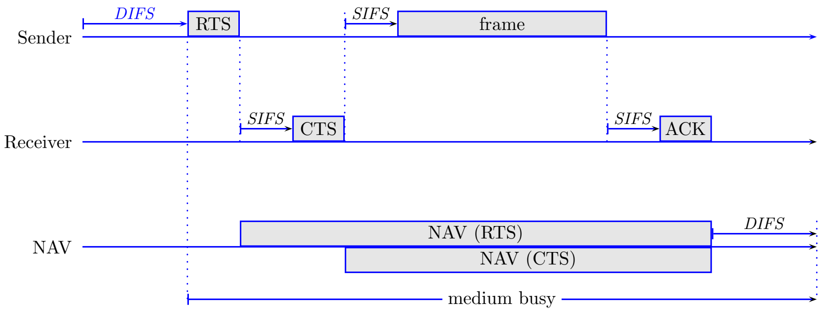
Contention window or backoff window follows DIFS. Divided into slots (depends on medium). Wait $2^n - 1$ slots, where n increases for each retry.

CSMA/CA



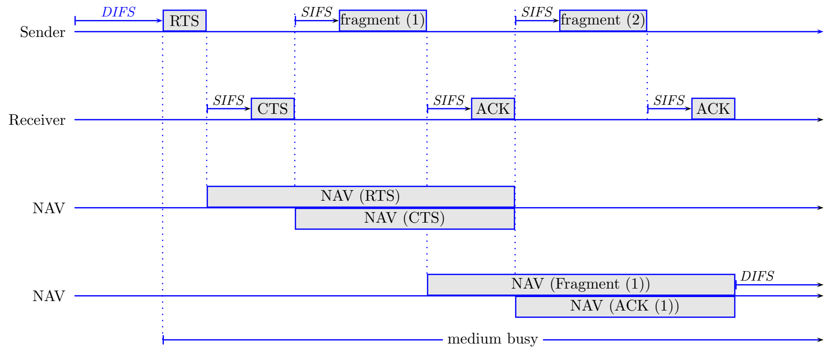
Network Allocation Vector

"virtual carrier" sensing.



Fragmentation

Fragmentation burst - when a station has a large frame to send, it uses a series of fragments, each sent straight after the ACK. In effect seizes the channel



Further Technology

- 802.11n – 100Mbps+
- http://www.wi-fiplanet.com/
- Standards required by vendors: Belkin, Qualcom, Motorola, Atheros, etc

Further Technology

- New development: 802.16a ("WiMAX")
- WiMAX = "Worldwide Interoperability for Microwave Access"
- See http://www.wimaxforum.org/
- initial IEEE 802.16 standard wireless MAN 10-66 GHz December 2001
- 802.16a extension for sub-11 GHz approved in January 2003
- 802.16-2004 standard was ratified by the IEEE in June 2004.
- "802.16e standard is being reviewed by IEEE and is expected to be approved in mid-2005" (see http://www.wimaxforum.org/about/faq/

Further Research Issues

- TCP Throughput
- Windows 2000 registry: `http://www.speedguide.net/read_articles.php?id=157`
- HKEY_LOCAL_MACHINE\SYSTEM\CurrentControlSet\Services\Tcpip\Parameters (use “regedit” to edit the Windows registry)
- WinXP: `http://support.microsoft.com/default.aspx?scid=kb;en-us;314053`
- Performance optimization, routing, low-power devices, auto-configuration
- MIMO – Multiple-input, Multiple-output “smart” antennas

Module Summary – Important Points

1. Ethernet – data format, CSMA/CD algorithm
2. Ethernet topology – switches & bridges
3. USB – basic concepts
4. Wireless LANs – important practical differences with wired LANs