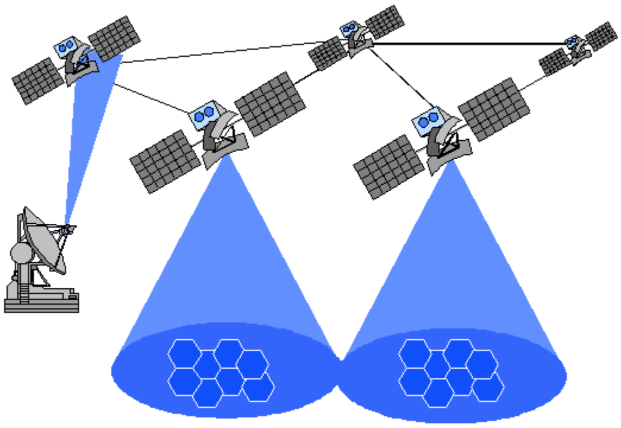
Simplified Satellite Broadcasting

As an introduction to Local Area Networking, and multiaccess communication, let's take a very simplified look at satellite broadcasting:

- Many users share a **single** channel.
- Propagation at the speed of light, 300 000 km/sec.
- However, the *distance* travelled is large - 35,880km for conventional TV satellites, resulting in round trip times of ~270-700*msec*.
  We can contrast this with the emerging constellations of *Low Earth Orbit* (LEO) satellites between 200-2000km, with round trip times of ~35*msec*.
- Bandwidth, typically 500Mbps, is currently 5x higher than typical LAN-based networks because it is less limited by the speed of local infrastructure.
- **Cost** is the same whatever the distance between sender and receiver. Satellite costs have dropped dramatically in the last few years.
- Satellite acts as a *repeater* of incoming signals, amplifying and re-broadcasting these signals.
- If two stations broadcast simultaneously the satellite will receive and re-broadcast the *sum* of these two signals, resulting in garbage. Such simultaneous broadcasts are termed **collisions**.
- A sender can listen to the re-broadcast of their*own* packets and determine whether a collision has occurred. Notice that there are **no acknowledgements**.
- Users are uncoordinated and can only communicate via the channel.

Implications for Network Protocols

Therefore, the satellite channel must control *its own* allocation:



The advantages of this "shared medium" approach are:

- No Data Link Layer acknowledgements needed, each sender can verify the correctness of their own messages (because they can hear them).
- No routing problems in the Network Layer subnet (no subnet!).
- No congestion problems or topology optimization.
- Mobile users may be supported.

The disadvantages of this approach are:

- Long propagation delay of at least 270*msec*.
- All users receive all messages, introducing security implications, and there can be no central control of unethical users.

Question: How can a single communication channel be efficiently shared between uncoordinated users?

Conventional Channel Allocation

We can employ two common schemes to share the medium:

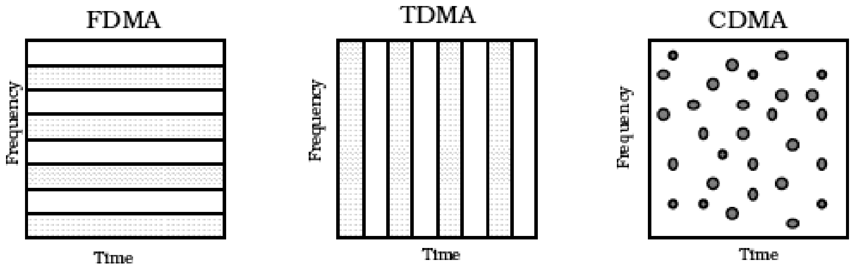
Polling

Either the satellite or a ground station *offers* the channel to an individual user for a specified amount of time.

Delays of 270*msec* make this impractical.

Who should be polled? Should priorities be given to the 100s or 1000s of potential customers?

Frequency and Time Division Multiplexing



There are two significant forms - frequency division multiplexing allocation (FDMA) and time division multiplexing allocation (TDMA).

Using FDMA the channel is divided into N frequency bands (slots) for a maximum of N users. *Guard bands* are placed between these to limit interference.

Using TDMA the channel is divided into slots based on time intervals, typically 125*usec*. Each potential user may then use the whole channel for their time quantum (in a manner similar to operating system timesharing).

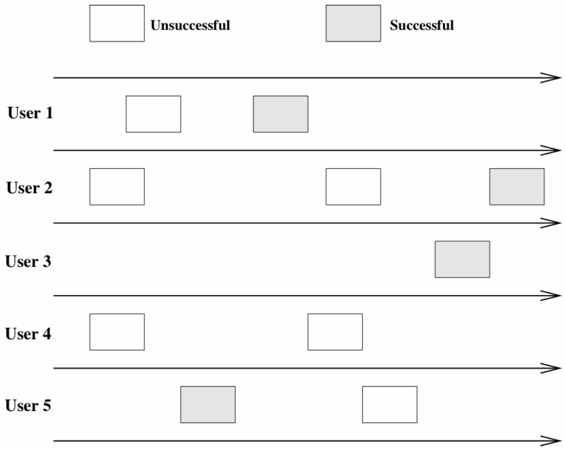
Both FDMA and TDMA are very inefficient since the actual number of users, M, is generally <<N or >>N, and traffic is often 'bursty'.

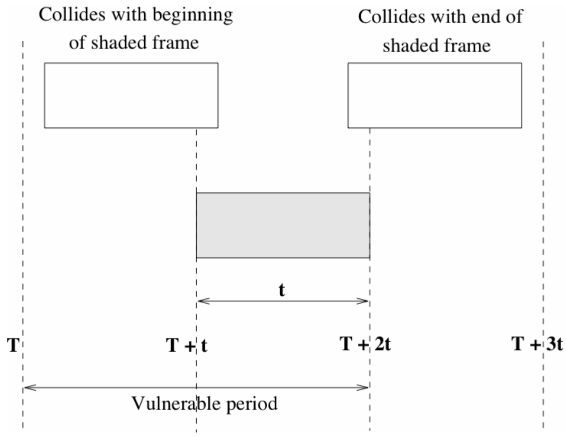
Pure ALOHA

In 1970 Norman Abramson devised the ALOHA network at the University of Hawaii.

Pure ALOHA uses a *contention based* protocol:

- Users transmit whenever they wish.
- Users detect their own collisions.
- After a collision, a user 'backs-off' for a random time period and then retransmits.





What are our expectations for throughput of this approach?

- Infinite number of users each thinking and sending.
- Generation of packets is a *Poisson* distribution, with mean S. Here, S = number of packets generated per packet time.

If S > 1 we have chaos.
If 0 < S < 1 we get acceptable throughput.

Analysis can show the **best possible** utilization of 18.38%.

Slotted ALOHA (1972)

The *slotted Aloha* mechanism makes an obvious improvement to improve expected throughput:

- the satellite generates a *timing pulse*.
- users then only transmit when they get this pulse.

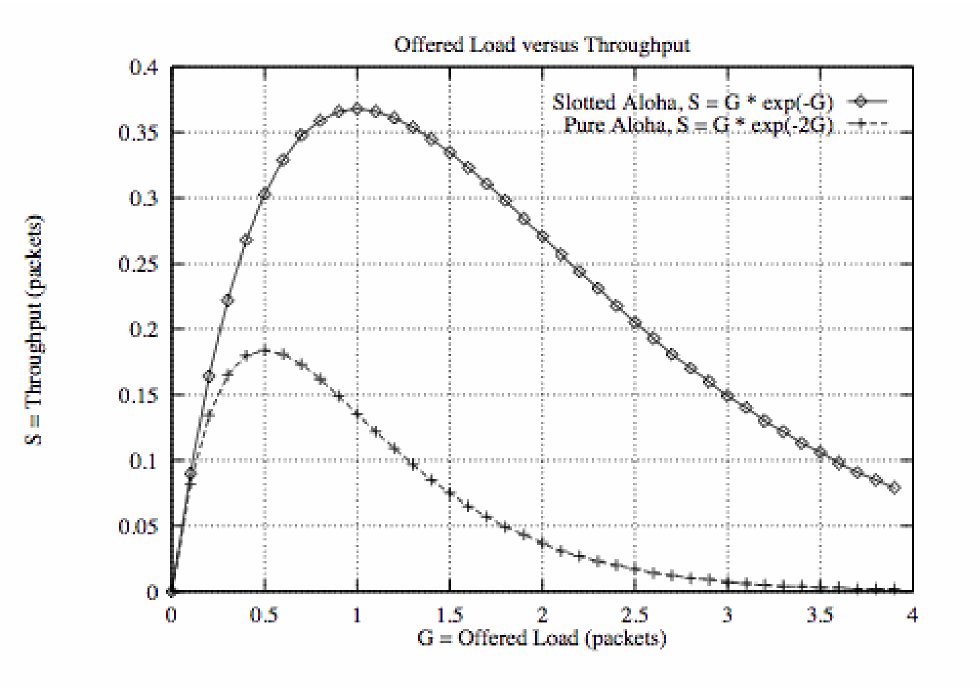
This quantization of time reduces the vulnerability period by half (now to a single packet transmission time).
Hence :

$$S = G * e^{-G}$$

Maximum throughput is now achieved when G = 1,

giving $S = 1 / e$

or a **best possible** utilization of 36.79%.
Note that small increases in G dramatically reduce performance.



Local Area Networks

Let's use an informal definition to characterize our next topic of study, local area networks:

Activity	Separation	Bit rate
Wide area networks, WANs	> 10km	< 100.0 Mbps
Local area networks, LANs	10 → 0.1km	100.0 → 10,000Mbps
Multiprocessors	<< 0.1km	> 1Gbps

In particular, for local area networks:

- Machines connect to a (logically) single cable within a 1km radius (often the same building or campus).
- Total data rate > 10Mbps (short round trip time, simple data link layer with, say, a one bit sliding window)
- Single organization ownership (no political domains to traverse).
- Usually use broadcasting (no routing problems, but everyone sees all frames).

One general definition, often cited, is:

> *"A LAN is a routerless network, using the same protocol stack for each device, and using only a uniform, local, networking media."*

Carrier Sense Networks

- All stations can *sense* the electrical carrier before sending.
- This is possible because of the use of high speed cables over short distances.

We will be concerned with *carrier-sense multiple-access* (CSMA) protocols.

Factors Affecting CSMA LANs

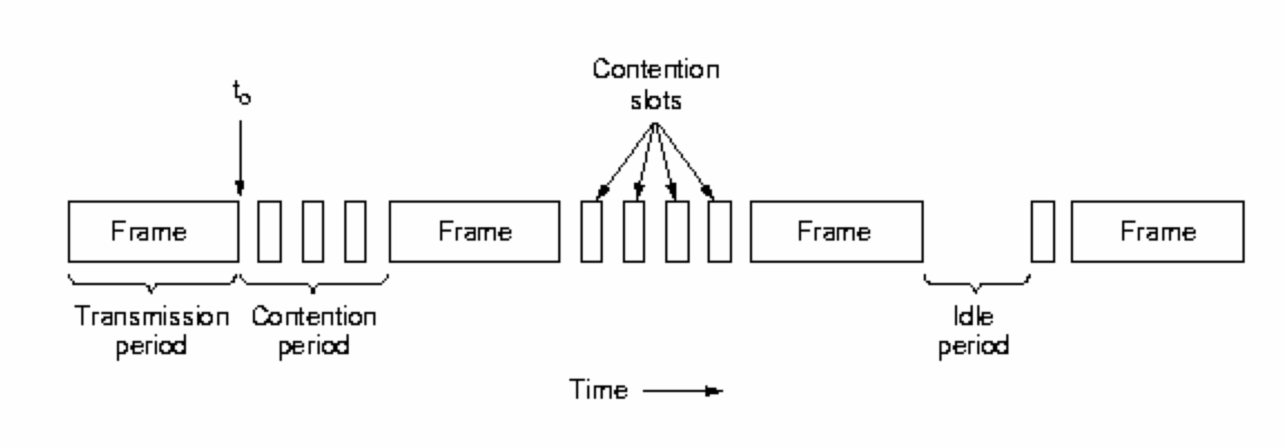
1. All frames are of constant (or small, bounded) length.
2. There are no transmission errors, other than those of collisions.
3. There is no capture effect.
4. The random delay after a collision is uniformly distributed and large compared to the frames' transmission time.
5. Frame generation attempts (OLD and NEW) form a Poisson process with mean G frames per time.
6. A station may not transmit and receive simultaneously.
7. Each station can sense the transmission of other stations.
8. Sensing of the channel state can be performed at the same time as transmitting.
9. The propagation delay is small compared to the frames' transmission time, and identical for all stations.

Persistent CSMA Protocols

Using *1-persistent CSMA protocols*, each station first senses the activity on the channel.

If two stations A and B are waiting for C to finish, they just pause for a period, and when they sense that the channel is free, transmit with a probability of `1` (pretty persistent eh?).

This, naturally, results in a good chance of a collision.



The longer a propagation delay on a LAN the more collisions there will be and, hence, the worse will be the performance.

`1`-persistence is no good for satellite broadcasting because :

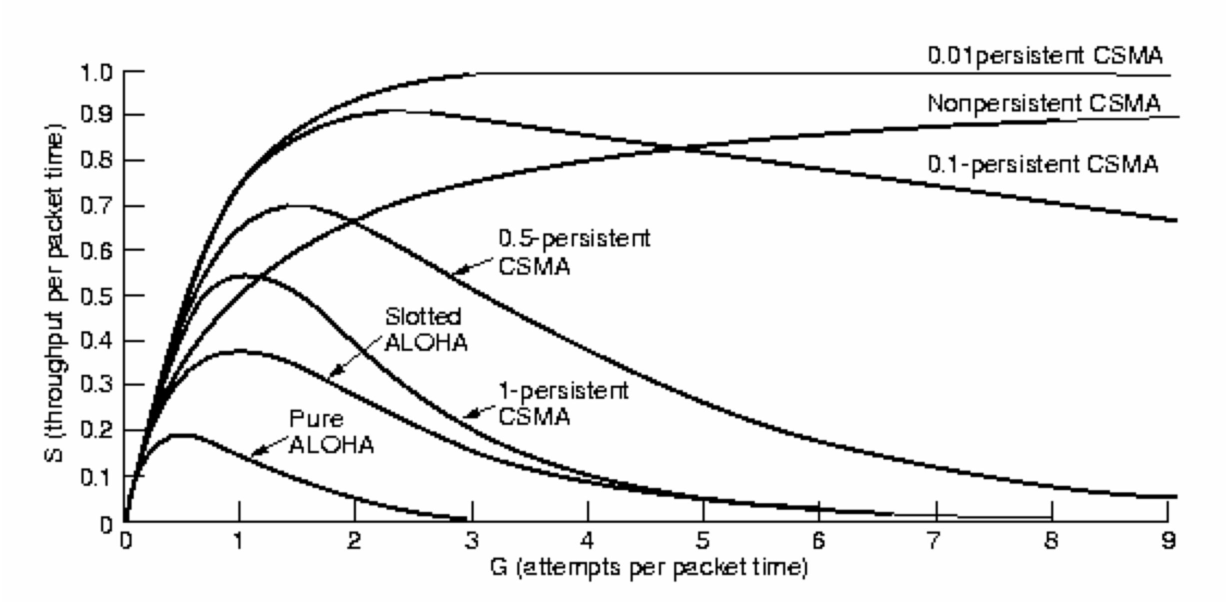
> each station hears what was happening at least *270msec ago*!

Non- and p-persistent CSMA Protocols

In *non-persistent* and *p-persistent* protocols, each station may *again* sense a busy channel.

If the channel is found too busy, contending stations 'back-off' for various intervals.

- Non-persistent stations back-off for random intervals.
- p-persistent stations 'jump in' *with a probability* `p` (or back-off for a constant amount of time *with a probability* `q=1-p`



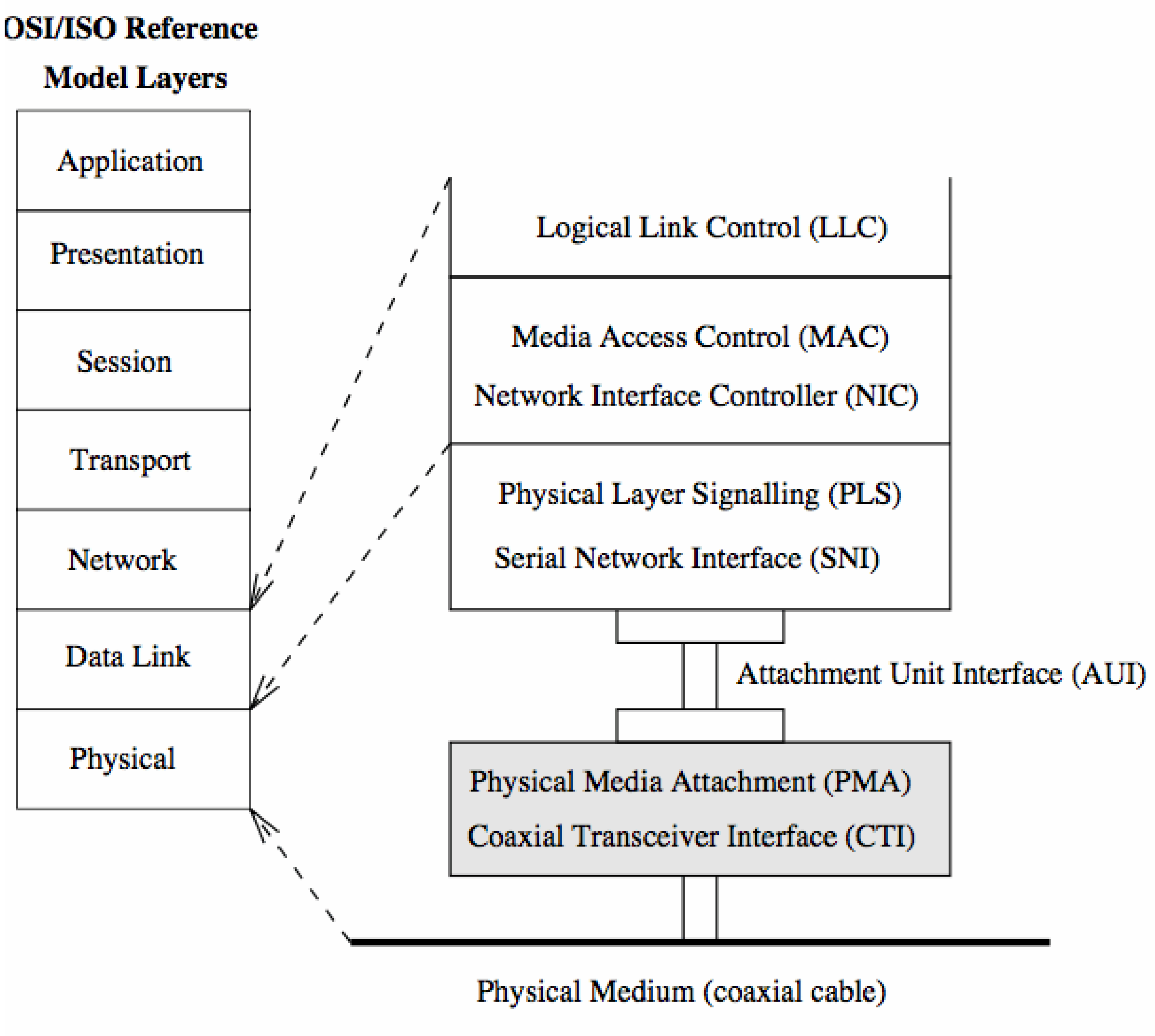
Obviously, the lower the value of `p` the fewer collisions there will be (each station is almost 'chicken' to transmit).

Even though the channel utilization can approach its maximum, each station can be waiting a long time.

IEEE-802.x LAN Standards - The Ethernet System

Devised by Metcalfe and Boggs (1976) from Xerox Parc, (CACM, July 1976, pp395-404).

The 'Ethernet' system is a member of the IEEE-802 family of protocols for local area networks (it is 802.3). 802.3 uses a 1-persistent Carrier-Sense Multiple-Access with Collision Detection (CSMA/CD) method.



See:

- Ethernet: Distributed Packet Switching for Local Computer Networks
- Ethernet Systems on Personal Computers

Physical Properties

The original 'standard' Ethernet proposal was for a 3Mbps network, connecting up to 256 stations (1975).
The IEEE-802.3 standard has since been introduced which at first supported up to 1024 stations at 10Mbps over a total length not exceeding 2.5km.

Type	Cable	Max. Segment	Nodes/seg.	Advantages
10Base5	Thick coax	500m	100	Used for backbones
10Base2	Thin coax	185m	30	Cheaper
10Base-T	Twisted pair	100m	1024	Easy maintenance
10Base-FX	Fiber optic	2000m	1024	Best between buildings

- Each packet must be at least 64 bytes long to provide some reasonable chance of detecting collisions over long-ish propagation times.
- Due to power losses within the Ethernet cables, each segment cannot exceed 500m, so *repeaters* were used to connect up to 5 segments in a single LAN.
- Later additions to the 802.3 standard support increasingly faster twisted pair speeds: 100Base-T, 1000Base-T, and recently 10GBase-T.
- Similarly, fiber optic speeds and segment lengths have increased: 10GBase-ER (extended range) allows 40km. 100Gbps is in the works.

More recently, there has been an 'explosion' in wired Ethernet categories:

- Standard: 10Base5, 10Base2, 10BaseT, 10BaseFX
- Fast: 100BaseTX, 100BaseT4, 100BaseFX
- Gigabit: 1000BaseT, 1000BaseLX
- 10-Gigabit: 10000BaseT, 10000BaseLR

Ethernet's Contention Algorithm

Each station wanting to transmit, listens to the ether and on finding it silent begins transmission.

On detecting a collision a station:

- 'backs-off' for a random period which is a multiple of the 802.3 slot time. (This time is chosen based on the longest allowable path being 2.5km, and is set at 51.2microseconds).
- After the first collision each station backs-off for `0` or `1` slot times before trying again.

  If there is a second collision, a station backs-off for `0`, `1`, `2` or `3` slot times.
- In general, a station will back-off from `0` to 2^{i-1} slot times after the i^{th} collision.

  This continues for a maximum of `10` collisions (`1023` back-offs), after which the station stays at `1023` for `6` more collisions.
- After `16` collisions the station considers the 'ether' severed and reports back to the Networking Layer.

This method, termed *binary exponential back-off*, ensures a short delay for each station when a small number of stations collide and a reasonable delay when many stations collide.

Ethernet Addressing Schemes

Each 802.3 packet contains the source and destination address, each of 6 bytes (48 bits).

Preamble	SFD	Destination	Source	Length	Data	CRC
62 bits	2 bits	6 bytes	6 bytes	2 bytes	46 - 1500 bytes	4 bytes

1010...1011

- If all 48 destination bits are set to 1, the packet is a *broadcast* address destined for all stations on a LAN.
- The high-order bit (bit 47) is used to indicate addressing domains, 0 being for individual addresses and 1 being for *multicast* addresses (to deliver packets to a group of stations).
- Bit 46 (high-order less one) indicates whether the address is for the current LAN or for a more global station on another LAN.
- Using 2^{46} bits ($7 * 10^{13}$ stations) each device in the world can have a unique Ethernet card number (assigned by the IEEE).

Of course it is up to the Network Layer to determine how to get to other stations not on your LAN.

Packet Transport Mechanisms

Each station connects to the ether with a transceiver. 'The design of the transceiver must be an exercise in paranoia'. In particular, failures of the transceiver must not pollute the ether, power failure must not 'cloud' the ether and disconnection must not be noticed by other stations.

802.3 uses *five* significant mechanisms to reduce the probability and cost of losing a packet.

- carrier detection.
  Ethernet uses the carrier sense mechanism of *phase encoding* which guarantees that there is at least one phase transition on the ether during each bit time.

  The Aloha scheme does not use carrier detection and subsequently suffers a higher collision frequency.

  (Use of *deference* and *acquisition*).

- packet error detection (initially 2-byte CCITT-16, now 4-byte CRC-32).

Packet Transport Mechanisms, *continued*

- interference detection.
  Each transceiver has an interference detector; a station can detect interference because what it is receiving is not what it is transmitting.

  Interference detection has three advantages:

  1. A station can detect collisions and re-schedule transmission (no need to wait for a lack of acknowledgement).
  2. Interference is detected within the propagation time (with Aloha a whole packet was transmitted and then examined for a collision).
  3. The frequency of collisions is immediately used to dynamically change the back-off times.

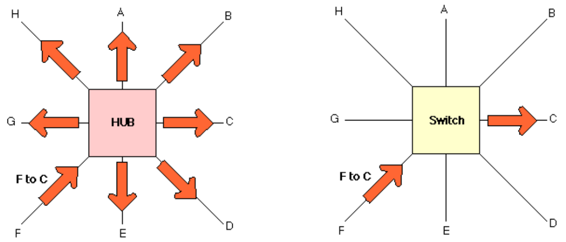
- truncated packet filtering.
  Interference detection and deference cause most collisions to result in *truncated packets* of only a few bits. To reduce the overhead of obviously damaged packets, the *hardware* is able to filter them out.

- collision consensus enforcement.
  Whenever a station detects a collision of its own transmission it deliberately *jams* the ether to ensure that other colliding stations hear the collision as quickly as possible and then to stop transmitting.

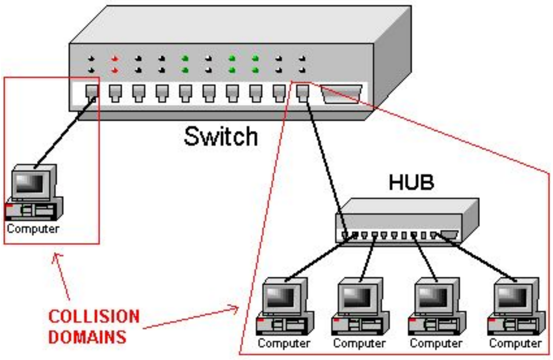
Hubs, Switches, and Collision Domains

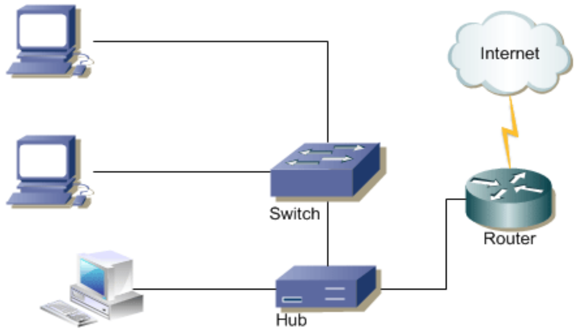
A *collision* now occurs when a device or LAN-segment receives two or more signals simultaneously. Obviously our goal is to reduce collisions by either resolving them quickly, or reducing the likelihood of them occuring at all.

The following diagram highlights the difference between a *hub* and a *switch*, when node F is transmitting to node C. The hub will retransmit the frame to *all* of its outgoing ports, whereas the switch will more 'intelligently' retransmit the signal to the ports known to be wanting the frame:



A *collision domain* is the set of devices (potentially) receiving a frame collision. Today, it is very difficult to purchase a hub, as switches have become so inexpensive, but hubs can still play a role in Ethernet traffic monitoring.



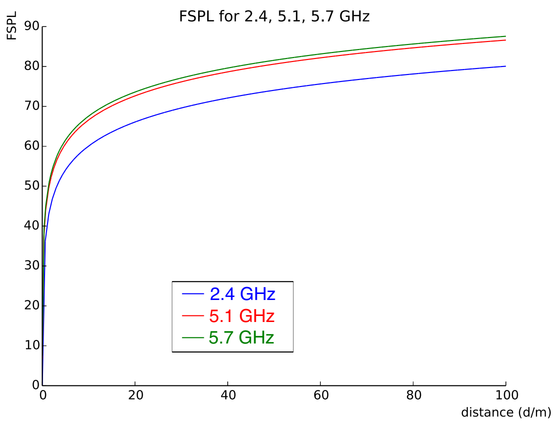


The IEEE-802.11 Wireless LAN protocol

We'll next examine devices implementing the IEEE-802.11 family of wireless networking protocols, and get an appreciation of some of the security challenges.

TABLE 1: IEEE 802.11 COMMON WIFI STANDARDS BREAKDOWN

Standard	Frequency Band	Bandwidth	Modulation Scheme	Channel Arch.	Maximum Data Rate	Range	Max Transmit Power
802.11	2.4 GHz	20 MHz	BPSK to 256-QAM	DSSS, FHSS	2 Mbps	20 m	100 mW
b	2.4 GHz	21 MHz	BPSK to 256-QAM	CCK, DSSS	11 Mbps	35 m	100 mW
a	5 GHz	22 MHz	BPSK to 256-QAM	OFDM	54 Mbps	35 m	100 mW
g	2.4 GHz	23 MHz	BPSK to 256-QAM	DSSS, OFDM	54 Mbps	70 m	100 mW
n	2.4 GHz, 5 GHz	24 MHz and 40 MHz	BPSK to 256-QAM	OFDM	600 Mbps	70 m	100 mW
ac	5 GHz	20, 40, 80, 80+80= 160 MHz	BPSK to 256-QAM	OFDM	6.93 Gbps	35 m	160 mW
ad	60 GHz	2.16 GHz	BPSK to 64-QAM	SC, OFDM	6.76 Gbps	10 m	10 mW
af	54-790 MHz	6, 7, and 8 MHz	BPSK to 256-QAM	SC, OFDM	26.7 Mbps	>1km ?	100 mW
ah	900 MHz	1, 2, 4, 8, and 16 MHz	BPSK to 256-QAM	SC, OFDM	40 Mbps	1 km	100 mW



Often of interest is not simply the maximum possible transmission rate, but the distance over which WiFi may operate.

We need an understanding of the transmission power, propagation, and signal loss over distance and through objects.

The unit **dBm** is defined as power ratio in decibel (dB) referenced to one milliwatt (mW). It is an abbreviation for dB with respect to 1 mW and the "m" in dBm stands for milliwatt. dBm is different from dB. dBm represents absolute power, whereas dB is a ratio of two values and is used to represent gain or attenuation. For example, 3 dBm means 2 mW, and 3 dB means a gain of 2. Similarly, -3 dBm means 0.5 mW, whereas -3 dB means attenuation of 2.

A WiFi access point (AP) will typically transmit at up to 100mW, and a receiving device will typically be able to discern arriving signal from noise until -90dBm.

mW	dBm
100	20
10	10
1	0
0.1	-10
0.01	-20
0.001	-30
0.0001	-40
0.00001	-50
0.000001	-60
0.0000001	-70
0.00000001	-80
0.000000001	-90
0.0000000001	-100

Material	Attenuation @ 900 MHz
Glass 0.25" (6 mm)	0.8 dB
Glass 0.5" (13 mm)	2 dB
Lumber 3" (76 mm)	2.8 dB
Brick 3.5" (89 mm)	3.5 dB
Brick 7" (178 mm)	5 dB
Brick 10.5" (267 mm)	7 dB
Concrete 4" (102 mm)	12 dB
Masonry Block 8" (203 mm)	12 dB
Brick faced concrete 7.5 " (192 mm)	14 dB
Masonry Block 16" (406 mm)	17 dB
Concrete 8" (203 mm)	23 dB
Reinforced Concrete 3.5" (203 mm)	27 dB
Masonry Block 24" (610 mm)	28 dB
Concrete 12" (305 mm)	35 dB

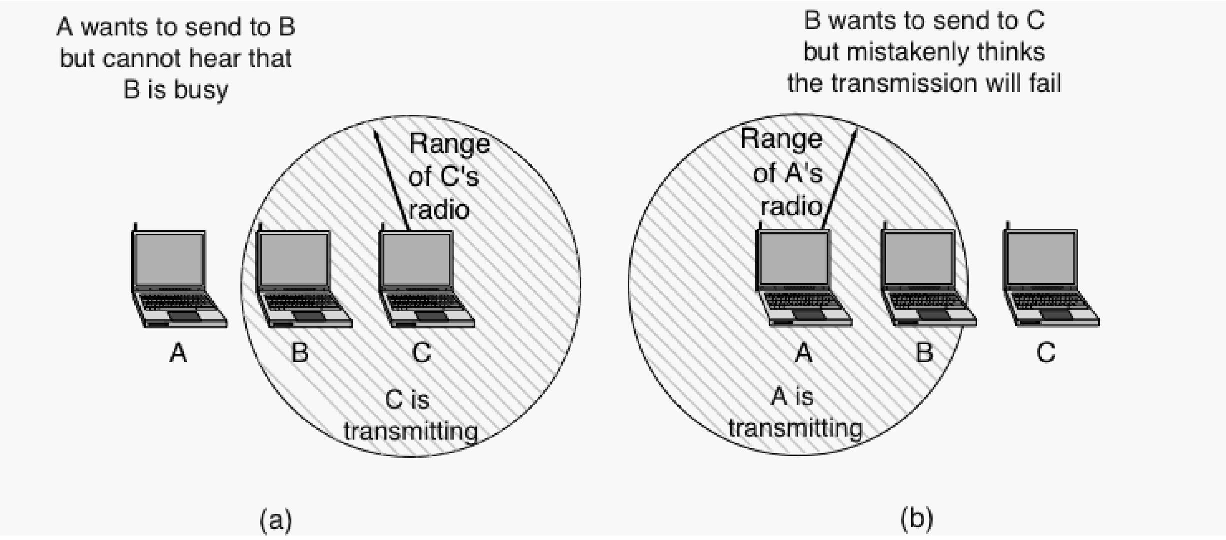
Table 2.

Hidden Node, ~~Crouching Dragon~~ Exposed Node

As a first guess, it would appear that the standard (wired) Ethernet protocol should also work for wireless networks - simply wait until the medium (airwaves) becomes clear, transmit, and then retransmit if a collision occurs.

However, this simple approach will not work, primarily because not all nodes are within range of each other.

Consider these two typical situations:



- (a) A wishes to send a frame to B, but A cannot 'hear' that B is busy receiving a message from C. If A transmits after detecting an idle medium, a collision may result near B. This is described as the *hidden terminal* or the *hidden node* problem. C is hidden from A, but their communications can interfere.
- (b) B wishes to transmit to C, but hears that A is transmitting (possibly to someone to the left of A). B incorrectly concludes that it cannot transmit to C, for fear of causing a collision. This is described as the *exposed terminal* or the *exposed node* problem.

802.11 Collision Avoidance

A further problem is that most wireless cards are unable to both transmit and receive at the same time, on the same frequency - they employ *half-duplex* transmissions.

This means that while collisions do occur, they generally cannot be detected (while transmitting).

Unlike their 802.3 wired counterparts, 802.11 wireless LANs do not employ the Carrier Sense Multiple Access with Collision Detection protocol (CSMA/CD). (pedantically, it is incorrect to call 802.11 as being 'wireless Ethernet', but everyone does).

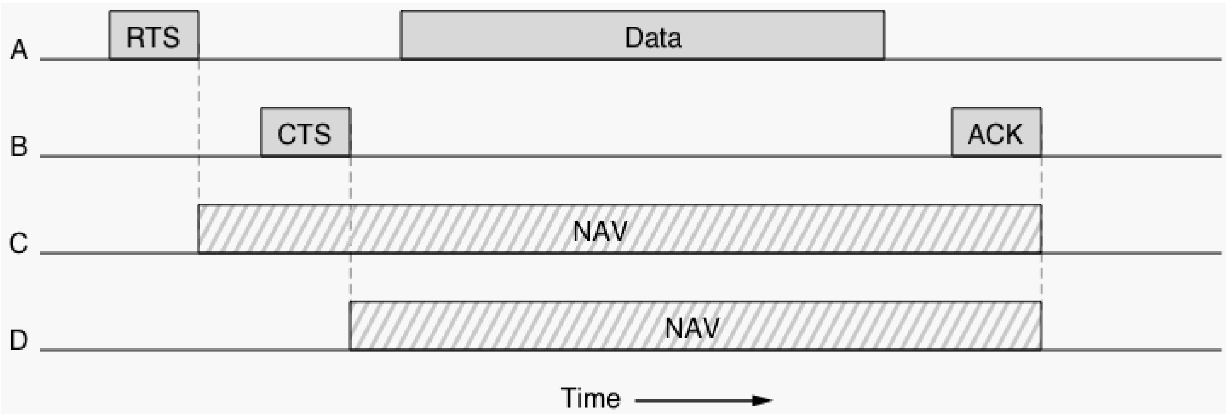
Instead, 802.11 employs *collision avoidance* to reduce (but not eliminate) the likelihood of collisions occurring. The algorithm is termed Multiple Access with Collision Avoidance (MACA), or CSMA/CA, in which both *physical channel* sensing and *virtual channel* sensing are employed.

The basic idea is that before transmitting data frames, the sender and receiver must first exchange additional control frames before the 'true' data frames. The succcess or failure of this initial exchange either *reserves* the medium for communication between A and B, or directs how A, B, and *all other listening nodes* should act.

802.11 Collision Avoidance, *continued*

Consider the situation of 4 nodes. You can imagine that we have 4 nodes left-to-right, named C, A, B, D.

- A wishes to communicate with B,
- C can hear only A, and
- D can hear only B.



- A observes an idle medium, and initially sends a *Request to Send* (RTS) frame to B. This frame includes a field indicating how long (in microseconds) the actual data frame will be, i.e. how long the sender wishes to *hold* the medium.

- When B receives the RTS it replies with a *Clear to Send* (CTS) frame, also carrying the length of the data frame.

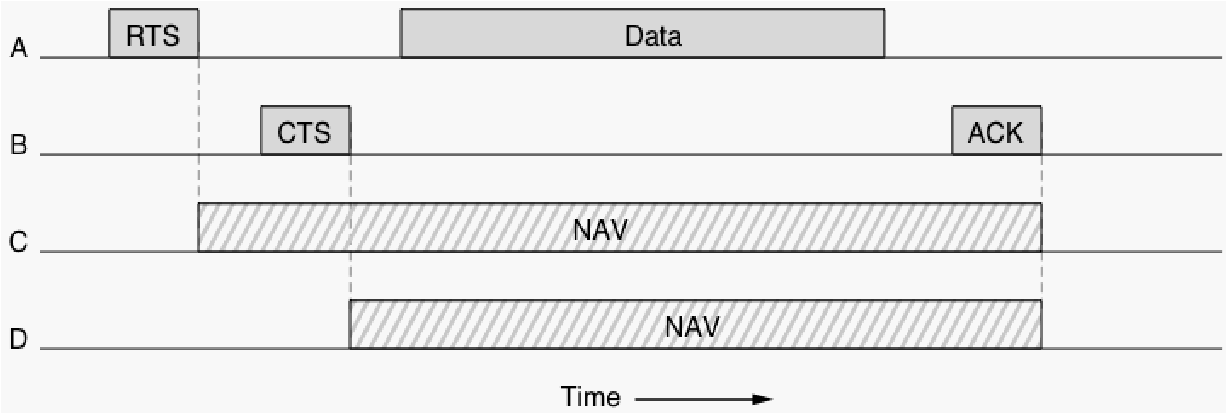
- Any other node hearing the RTS frame (e.g. C) knows that A is making a request, and should not itself transmit until the indicated length/time has elapsed.

- Any node hearing the CTS frame (e.g. D) must be close to the receiver (B) and therefore should also not transmit for the indicated length of time.

- Any node that hears the RTS frame, but not the CTS frame, knows that it is not close enough to the receiver to interfere, and so is free to transmit (but must first transmit its own RTS...).

802.11 Collision Avoidance, *continued*

There are two final considerations -



- When the receiver (B) successfully receives a data frame, it must reply with an ACK frame. All other nodes must wait for this ACK frame before they can transmit their own RTS frames.

  The additional ACK frames were not defined in the early MACA protocols, but added to the *Wireless* MACA -> MACAW protocol used today.

- What if two nodes simultaneously issue an RTS? If they are not in range, there is little problem, we can have two transmission sequences in the same medium. If the two RTS frames collide, then any receivers will not be able to guess what they were, and no CTS frame will be issued.

  When no CTS arrives at the senders, they *assume* a collision and undergo the standard 802.3 *binary exponential backoff* algorithm.

Access-Point Association

Although two mobile nodes can communicate directly, the more usual approach is for all communication to be through fixed *access-points*.

We say that a mobile node *associates* with a single access-point if all of its communications are via that point, and all such related nodes form a *cell*.

Communication between nodes in different cells requires two access-points connected via a *distribution system*.

The mechanism employed by a mobile node to select an access-point is termed *active scanning*:

1. the mobile client node sends *Probe* frames,
2. all access-points within range reply (if they have capacity) with a *Probe Response* frame,
3. the mobile node selects an access-point and sends an *Association Request* frame, and
4. the access-point responds with an *Association Response* frame.

An alternative is for an access-point to use *passive scanning*:

1. the access-point periodically sends *Beacon* frames advertising its existence and abilities (e.g. supported bandwidths),
2. the mobile node may choose to switch to this new access-point using *Disassociation* and *Reassociation* frames.

When a node selects a new access-point, the new access-point is expected to inform the old access-point using the distribution system.