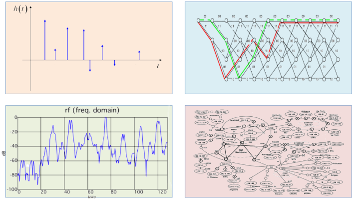
Medium Access Control (MAC) Protocols

6.02 Fall 2013 Lecture 18



INTRODUCTION TO EECS II

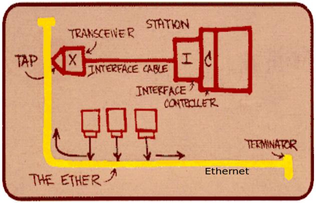
DIGITAL COMMUNICATION SYSTEMS

Medium Access Control (MAC) Protocols

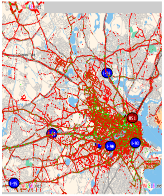
- Shared Medium Model
- Shared Medium Performance
- Time Division Multiplexing
- Contention Protocols: Aloha

Shared Media

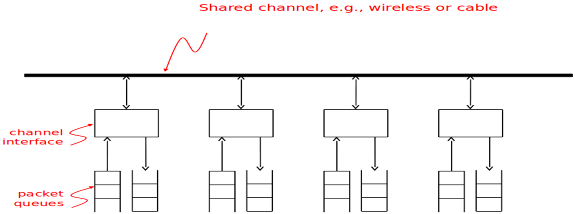
Shared Media



Wireless LANs



Shared Media: An **Abstraction**



- **nodes** transmit information divided into **packets**
- time is divided into equal **slots**
- single packet transmission takes an integer number of slots
- when two (or more) nodes use same time slot to transmit, a **collision** occurs, and all packets involved are lost
- nodes can detect collisions (and re-transmit packets later)

Shared Media Conrol: Performance Objectives

throughput	amount of data transmitted successfully over a period of time (typically depends on the load)
fairness	divide capacity equally among requesters (those nodes that have something to transmit)
bounded wait	maximal wait before successful transmission from a given node (important for voice, video, real time control)
dynamism	accomodate variability in user behavior
scalability	be suitable for a large number of users

These are usually **conflicting** objectives

Fairness And Utilization As Numbers

node throughputs:

x_i - data bits transmitted by the i-th node in T units of time ($i = 0, 1, \ldots, n$)

channel capacity:

C - maximal number of bits transmittable in a unit of time

utilization :

$$U = \frac{x_0 + x_1 + \cdots + x_n}{CT} \qquad (0 \le U \le 1)$$

fairness:

$$F = \frac{(x_0 + x_1 + \cdots + x_n)^2}{n(x_0^2 + x_1^2 + \cdots + x_n^2)} - \frac{1}{n} \qquad (0 \le F \le 1)$$

Example

Question:

A desktop, a printer, and a knitting machine are connected by a single wire to form a network capable of transmitting up to 2 Kb per second. For a 10 second period, all three devices were backlogged (i.e. had data to send). In these 10 seconds, the desktop and the printer sent 5Kb each, while the knitting machine have not managed to send anything. What was utilization and fairness in the network during this period?

Answer:

$$U = \frac{5+5}{2 \cdot 10} = \frac{1}{2},$$

$$F = \frac{(5+5)^2}{2 \cdot (25+25)} - \frac{1}{2} = \frac{1}{2}.$$

Channel Sharing Protocols

Sharing Protocol: rules of engagement for good performance, known as media access control (MAC)

Means of Separation:

- frequency division
- time division
- some other orthogonality

Assignment Prnciples:

- static centralized (as FCC to radio stations)
- dynamic centralized assignment (as cell tower to cell phones)
- decentralized/contention (as between Ethernet nodes)

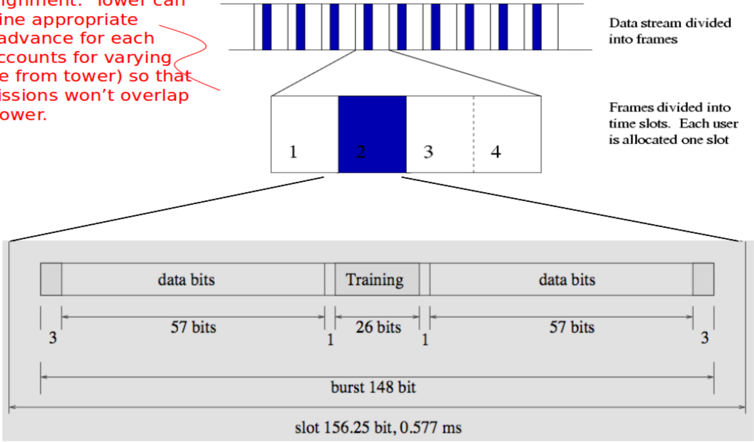
Time Division Multiple Access (TDMA)

- use a centralized resource allocator/synchronizer between the nodes (e.g., a cellular base station)
- give each of n nodes a unique index $i \in \{0, 1, \ldots, n-1\}$
- node i gets to transmit in time slots i, $i+n$, $i+2n$, ..., $i+kn$

No packet collisions! But unused time slots are wasted, lowering utilization. Poor when nodes send data in bursts or have different offered loads.

TDMA for GSM Phones

First slot is used in cell phones to contact tower for slot assignment. Tower can determine appropriate timing advance for each user (accounts for varying distance from tower) so that transmissions won't overlap at the tower.



http://en.wikipedia.org/wiki/Time_division_multiple_access

Example: TDMA Analysis For n Nodes

Fairness when all nodes backlogged:

$$F = \frac{(nx)^2}{(n-1)nx^2} - \frac{1}{n-1} = \frac{n}{n-1} - \frac{1}{n-1} = 1.$$

Utilization when k (out of n) nodes backlogged:

$$U = \frac{kC}{nC} = \frac{k}{n}$$

(when capacity is C per time slot)

Example: TDMA Statistical Analysis For Two Nodes

Assumptions:

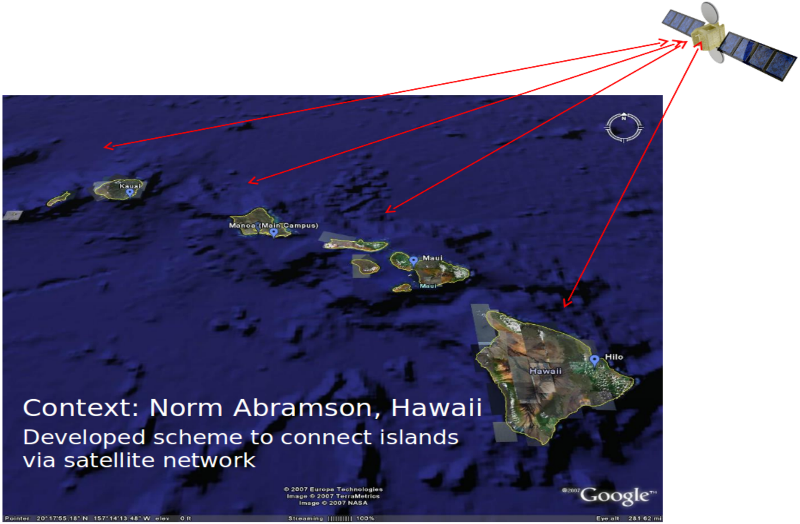
- one data packet takes one time slot to transmit
- each time slot, node 0 has a new packet to send with probability 1/4
- each time slot, node 1 has a new packet to send with probability 2/3

Utilization:

$$U = \frac{T/2 + T}{2T} = \frac{3}{4}$$

(Over $2T$ slots, node 0 needs to send approximately $(1/4) \cdot (2T) = T/2$ packets, and has T time slots to do this, while node 1 needs to send approximately $(2/3) * (2T) = 4T/3$ packets, and has T time slots to do this.)

The Aloha Protocol



Aloha Context

- Alohanet was a satellite-based data network connecting computers on the Hawaiian islands.
- One frequency was used to send data to the satellite, which rebroadcast it on a different frequency to be received by all stations.
- Stations could only hear the satellite, so had to decide independently when it was their turn to transmit.

Contention Procotols: Aloha (Simplest Example)

- assume it takes one time slot to send one data packet
- each backlogged node sends a packet with probability p

Decentralization via Randomization!

When pn is not large (where n is the number of backlogged nodes), we hope that the probability of successful transmission in a given time slot will be large enough.

Aloha (Simplest Example): Statistical Analysis

- $\mathbf{P}(\text{given node success}) = p(1-p)^{n-1}$
- $\mathbf{P}(\text{ success}) = np(1-p)^{n-1}$
- utilization: $U = \mathbf{P}(\text{ success}) = np(1-p)^{n-1}$

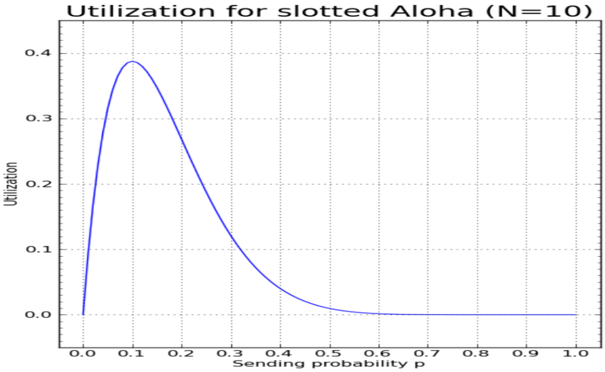
maximizing utilization: $U(p) = np(1-p)^{n-1} \to \max_{p \in [0,1]}$

$$\frac{dU}{dp} = n(1-p)^{n-1} - n(n-1)(1-p)^{n-2} = n(1-p)^{n-2}(1-np).$$

The function $U = U(p)$ has positive derivative when $0 \le p < 1/n$, negative derivative when $1/n < p \le 1$. Hence it achieves maximum at $p = 1/n$.

This Magic Number, 0.37

$$U_{\max} = \frac{n}{n}\left(1 - \frac{1}{n}\right)^{n-1} \rightarrow \frac{1}{e} \approx 0.37 \quad \text{as} \quad n \rightarrow \infty$$



Stabilization: Selecting The Right p

The Issue:

- setting $p = 1/n$, where n is the number of backlogged nodes, maximizes utilization
- in many applications, the number of backlogged nodes is constantly varying
- how to dynamically adjust p to achieve maximum utilization?

The Solution:

- detect collisions by listening, or by missing acknowledgement
- each node maintains its own dynamically changing p
- if collision detected, hence too much traffic, so decrease p
- if success, maybe more traffic possible, so increase local p

Stabilization: the process of ensuring operation at, or near, a desired operating point. Stabilizing Aloha means finding a p that maximizes utilization as loading changes.

Stabilization by Exponential Back-Off

Select parameters $\alpha, \beta, p_{\text{min}}, p_{\text{max}}$ such that

$$0 < \alpha < 1, \qquad \beta > 1, \qquad 0 < p_{\text{min}} < p_{\text{max}} < 1$$

Decreasing p on collision:

$$p_{\text{next}} = \max\{\alpha p, p_{\text{min}}\}$$

Increasing p on success:

$$p_{\text{next}} = \min\{\beta p, p_{\text{max}}\}$$

Example: Ethernet Media Access Control

- the network is monitored for transmissions ("carrier sense")
- if an active carrier is detected, transmission is deferred
- if active carrier is not detected, begin frame transmission
- while transmitting, monitor for a collision
- if a collision is detected, transmit "jam sequence"
- wait a random period of time before re-starting transmission
- on repeated collisions, increase random delay
- on success, clear the collision counter used for backoff

(from http://www.techfest.com/networking/lan/ethernet3.htm)

Analysis Of Stabilization Algorithms

- simulation (e.g., PS7)
- Markov Chains (see 6.041)