MODELING MEDIUM ACCESS CONTROL PROTOCOLS

Multiaccess Media

- The received signal at one node depends on the transmitted signal at two or more other nodes.
  - Local area networks (LAN)
  - Metropolitan area networks (MAN)
  - Satellite systems
  - Radio/Wireless systems
- Medium access control (MAC) sublayer (between the data link control layer and the physical layer)

Medium Access Control

- Each node has a queue of packets to be transmitted
- The multi-access channel is a common server
- The knowledge about the state of the queue is *distributed*

Medium Access Control Protocols

1. Pure ALOHA
2. Slotted ALOHA
3. IEEE Standard 802.3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD)
4. Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)

Modeling Medium Access Protocols

6. IEEE Standard 802.4 (Token Bus) & 802.5 (Token Ring)
7. IEEE Standard 802.6: Distributed Queue Dual Bus (DQDB)
8. IEEE Standard 802.11: Wireless LANs using the distributed coordination function (DCF) and Wireless LANs using the point coordination function (PCF)

ALOHA

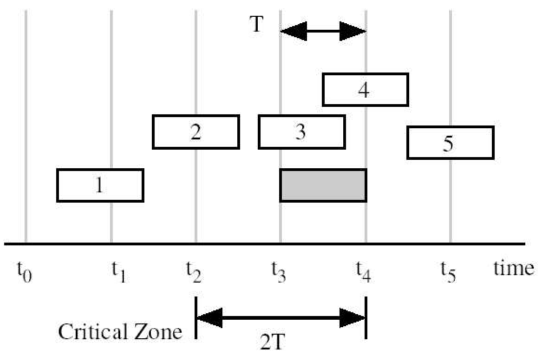
ALOHA

- ALOHA was developed by N. Abramson in the 1970's at the University of Hawaii to allow several computers spread over a wide geographical area to communicate using a broadcast wireless channel.
- The technique chosen was simple and applies to any system where several users attempt to access a shared resource without the help of a central controller. ALOHA did not require global time synchronization and this impacted its performance.

ALOHA

- In ALOHA network, a user that has a frame to transmit does so without waiting to see if the channel is busy or not.
- When two users transmit at the same time both colliding frames will be received in error due to interference.
- The collision phenomenon that occurs in a shared medium is also known as **contention or collision**.
- The sender knows that contention has occurred through the feedback channel – explicit or implicit ACK.
- If errors are detected, the sender retransmits the frame after waiting for a random amount of time.

ALOHA



ALOHA contention problem. Illustrating all possible conflict situations encountered by the transmitted frame (shaded rectangle).

Modeling ALOHA

We make the following assumptions for our analysis of ALOHA

1. The states of the Markov chain represent the status of the wireless channel.
2. There are N users in the system.
3. Users can transmit any time they want.

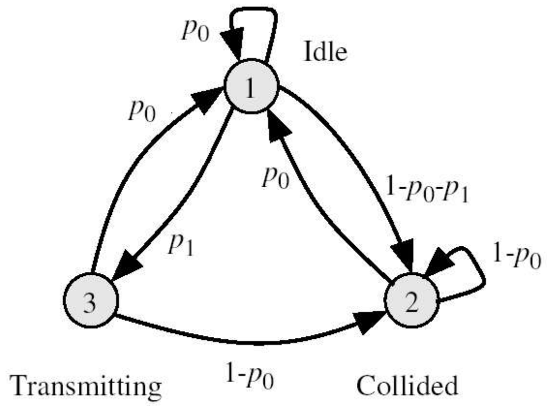
Modeling ALOHA

4. The time step is chosen equal to the frame time T.
5. The propagation delay between any pair of users is lesser than the frame time T.
6. The probability that a user transmits a frame in one time step is a.

Modeling ALOHA

7. All frames have equal lengths and the duration of each frame is T.
8. Contention occurs if a frame is sent at time t and there are transmissions during the time period $T - t$ to $t + T$.
9. A user retransmits a corrupted frame after waiting a random amount of time.

Modeling ALOHA



Transition diagram for the ALOHA network.

Aloha Performance

The probability that k users request access during a time step is given by binomial statistics

$$p_k = \binom{N}{k} a^k (1-a)^{N-k}$$

The transition matrix of the system is

$$\mathbf{P} = \begin{bmatrix} p_0 & p_0 & p_0 \\ 1-p_0-p_1 & 1-p_0 & 1-p_0 \\ p_1 & 0 & 0 \end{bmatrix}$$

ALOHA Performance

At equilibrium the distribution vector is obtained by solving the two equations

$$\begin{aligned} \mathbf{P\,s} &= \mathbf{s} \\ s_1 + s_2 + s_3 &= 1 \end{aligned}$$

The solution to the above two equations is simple:

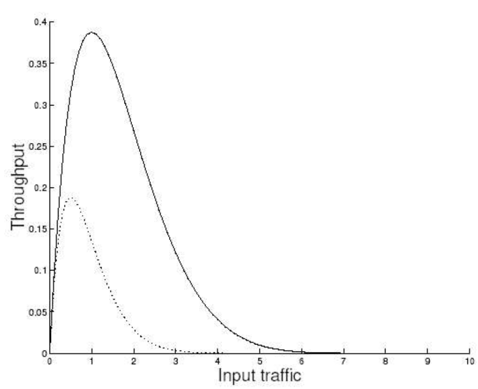
$$\begin{aligned} s_1 &= p_0 \\ s_2 &= 1 - p_0 - p_0\, p_1 \\ s_3 &= p_0\, p_1 \end{aligned}$$

ALOHA Performance

We are interested in the throughput of ALOHA which is given by

$$\begin{aligned} Th &= s_3 \\ &= p_0\, p_1 \\ &= N\, a\, (1-a)^{2N-1} \end{aligned}$$

ALOHA Throughput



The throughput for ALOHA versus the average number of requests per time step for the case $N = 10$. Dotted line is for ALOHA and Solid line is for slotted ALOHA.

ALOHA Performance

The input traffic is found from the binomial distribution

$$N_a(in) = N\, a$$

ALOHA Performance

Assume that the number of stations is fixed, in that case we can vary the arrival probability a and investigate how the throughput varies. The maximum throughput occurs when

$$\frac{d\,Th}{d\,a} = 0$$

where

$$Th = N\,a\,(1-a)^{2N-1}$$

ALOHA Performance

Maximum throughput for ALOHA occurs when

$$a_0 = \frac{1}{2\,N}$$

Thus, the maximum throughput is theoretically equal to

$$Th(\max) = \frac{1}{2}\left(1 - \frac{1}{2N}\right)^{2N-1}$$

ALOHA Performance

A simple expression is obtained when the user population is very large $N \to \infty$:

$$\begin{aligned} Th(\max) &= \frac{1}{2\,e} \\ &= 18.394\% \end{aligned}$$

ALOHA Performance

In summary, maximum throughput occurs when $N \to \infty$ and we would have

$$\begin{aligned} Th &= 0.18394 && \text{frames/time step} \\ N_a(in) &= 0.5 && \text{frames/time step} \\ a_0 &= 1/(2N) \\ \eta &= Th/N_a(in) = 0.367 \end{aligned}$$

ALOHA Performance

The probability of a transmission be successful is

$p = (1\text{-}a)^{2N-1}$

and the probability of failure is $q = 1 - p$.

ALOHA Performance

probability that the user successfully transmits a frame after a delay of n unsuccessful attempts is

$$p(n) = q^n\,p$$

ALOHA Performance

The average number of attempts before a successful transmission is

$$n_a = \sum_{n=0}^{\infty} n\, q^n\, p$$

ALOHA Performance

This evaluates to

$n_a = q/p$

$= (1-p)/p$

$= [1-(1-a)^{2N-1}] / (1-a)^{2N-1}$

ALOHA Performance

If the average duration of the random wait period is τ (in seconds), then the average wait for a frame before successful transmission is

$W = n_a \quad = \quad (1-p)/p \quad$ seconds

Example

Assume an ALOHA network supporting $N = 20$ users and each user issues a request per time step with probability $a = 0.01$. Find:

(a) The throughput

(b) The average number of time steps before successful transmission

(c) The maximum throughput

(d) The value for a for maximum throughput

The performance figures are as follows

$Th = s_3 = p_0 p_1$

$p = (1-a)^{2N-1}$

$n_a = (1-p)/p$

$Th(max) = 0.5\,(1-N/2)^{2N-1}$

$a_0 = 1/(2N)$

Slotted Aloha

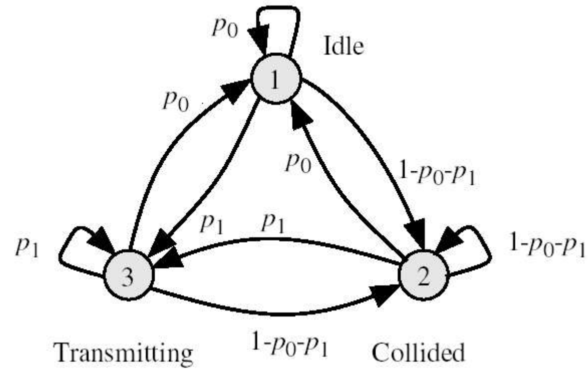
Slotted Aloha

- As the name implies, time in slotted ALOHA is divided into slots and the value of one time slot equals the frame time T.
- Users know about the start of a new slot through a synchronizing signal that is transmitted by a source.
- A user with data to send is only permitted to transmit at the start of a time slot only.
- This improves the efficiency as we shall see below.

Modeling the Slotted ALOHA Network

- We employ the same assumptions that we used to model ALOHA with the only exception that users are allowed to transmit only at the start of a time slot and not at any time as before.

Modeling the Slotted ALOHA Network



Transition diagram for the slotted ALOHA network.

Modeling the Slotted ALOHA Network

The probability that k users request access during a time step is given as before by binomial statistics

$$p_k = \binom{N}{k} a^k (1-a)^{N-k}$$

The transition matrix of the system is

$$\mathbf{P} = \begin{bmatrix} p_0 & p_0 & p_0 \\ 1-p_0-p_1 & 1-p_0-p_1 & 1-p_0-p_1 \\ p_1 & p_1 & p_1 \end{bmatrix}$$

Modeling the Slotted ALOHA Network

At equilibrium the distribution vector is obtained by solving the two equations

$$\mathbf{P\,s} = \mathbf{s}$$

$$s_1 + s_2 + s_3 = 1$$

Modeling the Slotted ALOHA Network

The solution to the above two equations is simple:

$$s_1 = p_0$$

$$s_2 = 1 - p_0 - p_1$$

$$s_3 = p_1$$

ALOHA Versus Slotted ALOHA

- We can draw the following conclusions based on equations we obtained.

1. Pure ALOHA and slotted ALOHA channels have the same probability of being in state S_1 (the idle state).
2. Slotted ALOHA has a **lower** probability of being in state S_2 (the collided state) compared to pure ALOHA.
3. Slotted ALOHA has a **higher** probability of being in state S_3 (the transmitting state) compared to pure ALOHA.

Slotted ALOHA Performance

We are interested in the throughput of slotted ALOHA which is given by

$$Th = s_3 = p_1 = N\, a\, (1-a)^{N-1}$$

ALOHA vs. Slotted ALOHA Throughput

We obtained the following expressions for throughputs of pure ALOHA and slotted ALOHA

$$Th(\text{pure ALOHA}) = N\, a\, (1-a)^{2N-1}$$

$$Th(\text{ slotted ALOHA}) = N\, a\, (1-a)^{N-1}$$

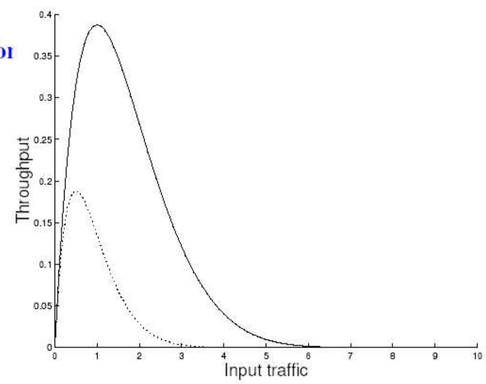
ALOHA vs. Slotted ALOHA Throughput

Slotted ALOHA has higher throughput compared to ALOHA by a factor of $p_0^{-1} = (1-a)^{-N}$.

We expect the two network to perform almost the same for very low traffic conditions ($a \ll 1$).

Slotted ALOHA will outperform ALOHA by **orders of magnitude** for high values of traffic ($a \approx 1$) especially for systems with many users ($N \gg 1$).

Slotted ALOHA Perfor



The throughput for ALOHA (dotted line) and Slotted ALOHA (solid line) versus the average number of requests per time step for the case $N = 10$.

Maximum Throughput for Slotted ALOHA

The maximum throughput occurs when

$$\frac{d\,Th}{d\,a} = 0$$

where

$$Th = N\, a\, (1-a)^{N-1}$$

Maximum Throughput for Slotted ALOHA

Maximum throughput for slotted ALOHA occurs when

$$a_0 = \frac{1}{N}$$

Thus, the maximum throughput is theoretically equal to

$$Th(\max) = \left(1 - \frac{1}{N}\right)^{N-1}$$

A simple expression is obtained when the user population is very large $N \to \infty$:

$$Th(\max) = \frac{1}{e}$$

$$= 36.788$$

Example

Assume a slotted ALOHA network supporting ***N=20*** **users and each user issues a request per time step with probability** ***a=0.01*****. Find:**

(a)The throughput

(a)The maximum throughput and the value of ***a*** **to maximize throughput**

$$Th = p_1 = Na(1-a)^{N-1} = 0.165$$

$$\frac{dTh}{da} = 0$$

$$a = 1/N = 0.05$$

$$Th_{\max} = (1-1/N)^{N-1} = 0.95^{19} = 0.377$$

- What are the advantages with ALOHA and slotted ALOHA?
  - Simplicity
  - Latency when traffic load is small
- What are the problems with ALOHA and slotted ALOHA?
  - Efficiency
  - Stability