Channel Allocation Problem
Mathematical Preliminaries
Multiple Access Protocols
Ethernet
Medium Access Control Sublayer
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Outline

1. Channel Allocation Problem
2. Mathematical Preliminaries
   - Probability Distributions
   - Poisson Distribution
3. Multiple Access Protocols
   - ALOHA
   - Slotted ALOHA
   - CSMA
4. Ethernet
   - CSMA-CD in Ethernet
   - Binary Exponential Backoff
   - Ethernet Performance
   - Ethernet - IEEE 802.3
   - Wireless Ethernet (WLAN)

Channel Allocation

- When multiple users want to use the same channel, we need to regulate channel use
- TDM, FDM
- How do we handle bursty traffic?
- Static allocations are very inefficient

Dynamic Channel Allocation

- \( n \) terminals or stations sharing a channel
- Contention for channel access
- Collision occurs when packets from any two stations overlap
- Packet start times can be continuous or slotted
- Carrier sensing - sensing the medium to check if it is in use
- Packets generated by the network layer of stations
- Generated packets are transmitted
- Some packets collide - so need to be retransmitted
- Number of transmitted packets are more than generated packets.

Continuous Probability Distributions

- Probability density function \( p(x) \), \( -\infty \leq x \leq \infty \)
- \( \int_{-\infty}^{\infty} p(x)dx = 1 \)
- Example, Gaussian distribution
  - \( p(x) = \frac{1}{\sqrt{2\pi} \sigma} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \)
  - Mean (or expectation) \( \mu = \int_{-\infty}^{\infty} xp(x)dx \)
  - Variance \( \sigma^2 = \int_{-\infty}^{\infty} (x-\mu)^2 p(x)dx \)

Discrete Probability Distributions

- Probability mass function \( p(k) \)
- \( k \) takes only discrete values
- \( \sum_{k=-\infty}^{\infty} p(k) = 1 \)
- Example, result of a coin toss or dice throw
  - \( p(k) = \frac{1}{6} \), \( x = \{1, 2, 3, 4, 5, 6\} \)
  - Mean \( \mu = \sum_{k=-\infty}^{\infty} kp(k) \).
Some Useful Infinite Series

\[ e^x = 1 + x + \frac{x^2}{2!} + \cdots = \sum_{k=0}^{\infty} \frac{x^k}{k!} \]

\[ e^x = \sum_{k=1}^{\infty} \frac{x^{k-1}}{k!} \]

\[ \sum_{k=0}^{\infty} x^k = \frac{1}{1-x}, 0 \leq x < 1 \]

\[ \sum_{k=1}^{\infty} kx^{k-1} = \frac{1}{(1-x)^2}, 0 \leq x < 1 \]

Poisson Distribution

- Model for generation of packets by network layers in stations
- The mean and variance of a poisson distribution are the same
- A poisson distribution with mean \( \lambda \) (and variance \( \lambda \)) represented by
  \[ \Pr \{ k \} = \frac{\lambda^k e^{-\lambda}}{k!} \]
- \( \Pr \{ k \} \) is the probability of exactly \( k \) occurrences in an unit interval
- For example, \( \Pr \{ 0 \} = e^{-\lambda}, \Pr \{ 1 \} = \lambda e^{-\lambda} \)

Poisson Distribution Properties

\[ \sum_{k=0}^{\infty} \Pr \{ k \} = \sum_{k=0}^{\infty} \frac{\lambda^k e^{-\lambda}}{k!} = e^{-\lambda} \sum_{k=0}^{\infty} \frac{\lambda^k}{k!} = e^{-\lambda} e^\lambda = 1 \]

Expected number of occurrences per unit interval (mean) is

\[ \mu = \sum_{k=0}^{\infty} k \Pr \{ k \} = \sum_{k=0}^{\infty} \frac{k \lambda^k e^{-\lambda}}{k!} = e^{-\lambda} \sum_{k=0}^{\infty} \frac{k \lambda^{k-1}}{k!} \]

\[ \mu = \lambda e^{-\lambda} \lambda = \lambda \]

ALOHA

- \( n \) stations share a medium
- Stations transmit whenever they have a packet that needs to be transmitted
- If collision occurs, it can be detected
- If a collision is detected, the stations wait for a random amount of time and then retransmit.
- All packets are of the same duration (say unit interval).

ALOHA - Some Assumptions

- Packet creation by network layers (of all stations together) is Poisson distributed with mean \( N \) or \( \Pr_N \{ k \} = \frac{N^k e^{-N}}{k!} \) (an average of \( N \) packets generated during each unit interval)
- Obviously for efficient channel usage \( N \leq 1! \)
- Average number of packets transmitted in a unit interval is \( G \). As some packets will be retransmitted, \( G \geq N \). Also Poisson distributed with mean \( G \). \( \Pr_G \{ k \} = \frac{G^k e^{-G}}{k!} \)
- Collision occurs when 2 or more frames occupy the same channel at the same time.
### Channel Allocation Problem

**Mathematical Preliminaries**

**Multiple Access Protocols**

**Ethernet**

**ALOHA**

**Slotted ALOHA**

**CSMA**

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### Efficiency of ALOHA

- Vulnerable period is 2 intervals
- Assume \( n \to \infty \)
- When a station transmits a packet, the packet will be successfully transmitted if no other packets are generated for two consecutive intervals
- Probability \( \Pr_C(0) = e^{-G} \) for one interval
- Probability of no other packet in the vulnerable period is \( \Pr_C(0) \times \Pr_C(0) = e^{-2G} \)
- Throughput (for each interval) \( S = Ge^{-2G} \) (\( G \) attempts, but only a fraction \( e^{-2G} \) is successful).

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### Slotted ALOHA

- Assumption - existence of some mechanism for synchronizing different stations
- Station will transmit only at the beginning of slot intervals.
- Vulnerable period is only one interval - not 2
- Throughput \( S = Ge^{-G} \)
- Maximized when \( \frac{dS}{dG} = 0 \to G = 1, S = \frac{1}{2} \approx 0.368 \)
- Maximum efficiency less than 37%
- Twice as efficient as pure ALOHA

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### Average Number of Attempts for Successful Delivery

Expected value of number of attempts (or average number of attempts for successful delivery) is

\[
E = \sum_{k=1}^{\infty} k p_k = \sum_{k=1}^{\infty} k e^{-G} (1 - e^{-G})^{k-1} = e^G
\]

We know

\[
\sum_{k=0}^{\infty} y^k = \frac{1}{1 - y}
\]

With \( x = e^{-G} \) and \( y = 1 - x \), we have

\[
\sum_{k=1}^{\infty} k(1-x)^k = \sum_{k=1}^{\infty} ky^{k-1} - y \sum_{k=1}^{\infty} ky^{k-1} = \frac{1 - y}{(1-y)^2} = \frac{1}{x} = e^G.
\]

Number of attempts increases exponentially with \( G \)
**Channel Allocation Problem**

**Mathematical Preliminaries**

**Multiple Access Protocols**

- Ethernet
- ALOHA
- Slotted ALOHA
- CSMA
- Carrier Sense Multiple Access Protocols

**Channel Utilization With ALOHA**

Slotted ALOHA: 
\[ S = Ge^{-G} \]

Pure ALOHA: 
\[ S = Ge^{-2G} \]

- **Slotted ALOHA:**
  - Listens first. If no one is currently using the channel, then transmit.
  - Collisions can still occur.
  - Propagation delay ($B$ has started transmission, but $A$ does not know that yet).
  - $A$ and $B$ wait for $C$ (which is currently transmitting) to finish and start at the same time.

- **Persistent and nonpersistent CSMA**
  - 1-persistent - if busy keep sensing the line till it becomes available and start transmitting immediately.
  - $p$-persistent (for slotted channels):
    - If busy keep sensing the channel.
    - If free, transmit at the next slot - but with probability $p$.
    - Probability $q = 1 - p$ that a station will yield.
    - Process continues till the packet has been transmitted or another station takes over the channel.

**Nonpersistent CSMA**

1. If channel is free transmit.
2. If not stop sensing and wait (for a random time)
3. If the channel is free now, transmit
4. If not, back to 2 (stop sensing and wait)

**Carrier Sense Multiple Access Protocols**

- Listen first. If no one is currently using the channel, then transmit.
- Collisions can still occur.
  - Propagation delay ($B$ has started transmission, but $A$ does not know that yet).
  - $A$ and $B$ wait for $C$ (which is currently transmitting) to finish and start at the same time.
- Persistent and nonpersistent CSMA

**CSMA With Collision Detection (CSMA-CD)**

- “Plain” CSMA also detects collisions - but does not do anything about it! (except for trying again)
- What if nodes stop transmitting as soon as a collision is detected?
- Colliding packets will now use up only a *small* fraction of the time.
- As usual stations sense channel, and transmit only if the channel is free.
- If collision is detected - stop sending the packet (only part of a packet may be sent).
Seizing the Channel with CSMA-CD

- After a station starts transmission of a packet, it should be able to detect within a period \( \tau_d \) that no collision is going to occur for that packet.
- If \( \tau \) is the maximum delay between any two stations in the channel \( \tau_d < 2\tau \). Why?
- After time \( \tau_d \), the station is sure that it has “seized” the channel
- \( \tau_d \) is the contention period.
- CSMA-CD is employed in ethernet

Restrictions On Packet Size

- With CSMA-CD there is also a restriction on minimum packet duration!
- What happens if packet duration is less than \( 2\tau \)?
- It is possible that \( A \) completes the entire packet before it sensed the collision.
- So \( A \) does not even know that a collision occurred!
- Packet sizes have to be chosen such that the packet duration is greater than \( 2\tau \)
- For example, for 10Mbps LAN, with maximum distance od 2500m between two stations round trip time \( (2r) \) is nearly 50µs
- Smallest packet size is 500 bits - Ethernet prescribes 64 bytes (512 bits) as the minimum packet size.

Binary Exponential Backoff in Ethernet

- After a collision is sensed, stations divide time into discrete slots - each slot with a duration \( 2\tau \).
- Let us assume that two nodes were involved in the collision
- After first collision, each node waits 0 or 1 slot (picked randomly)
- If both pick 0 or both pick 1, a second collision will occur (probability of second collision is 0.5).
- After second collision is sensed, both nodes pick one of four slots 0,1,2 or 3.
- If a third collision occurs (probability 0.25) for the next attempt the nodes will choose randomly from 1 of 8 slots ...
- and so on
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Binary Exponential Backoff vs Slotted ALOHA

- The contention periods in Ethernet are in some ways similar to slotted ALOHA
- For slotted ALOHA, with $n$ users contenting for channel use, the best we can do is if each user transmits with probability $1/n$ (which will result in, on an average, $G = 1$, which is the best “operating point” for slotted ALOHA)
- The number of contending users (stations) may vary
- So difficult to ascribe a probability (we do not know apriori how many stations are going to contend!)
- Exponential backoff “kind of” caters for this dynamics
- When slotted ALOHA is operating efficiently, the probability that a slot is used effectively by some node (or there are no collisions) is $\frac{1}{e}

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Ethernet Efficiency

- Exact analysis is very complicated
- We shall make some simplifying assumptions
- Contention period for ethernet can be likened to slotted ALOHA
- Best we can do with slotted ALOHA - the probability that some node can “grab” a slot is $\frac{1}{e}$
- Lets assume that with ethernet too, (because the exponential backoff caters for the dynamics in $n$), the probability that any of the $n$ nodes in contention, “grab” a slot successfully is $A = \frac{1}{e}$

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Ethernet Efficiency

- $F$ - frame size (in bits)
- $B$ - data rate (bits per sec)
- $P = F/n$
- $c$ - velocity of propagation
- $L$ - maximum length of ethernet cable (maximum separation between two stations)
- $\tau = \frac{L}{c}$

$$\nu = \frac{P}{P+2re} = \frac{1}{1+2BLc/cF}$$

- Larger frame sizes results in increased efficiency
- Need to control $BL$ product - higher bandwidth lines have to be shorter than lower bandwidth lines
- 100 Mbps lines of some length $L$ does not have 10 times the capacity of a 10Mbps line of length $L$
Manchester Encoding

![Manchester Encoding Diagram](image)

Unambiguous detection of start of each bit. Each bit period divided into two intervals. Twice the bandwidth. Every bit period has a transition in the middle.

Ethernet Families

- Based on speed:
  - 10Base5 (thick coax), 10Base2 (thin coax), 10Base-T (Twisted Pair), 10Base-F (Fiber optics)
  - Fast ethernet (802.3u), 100Base-T4 (category 3 UTP), 100Base-TX (category 5), 100Base-FX (Fiber)
- No changes in protocol - just better wires (and better technology for ethernet cards)
- Backward compatibility
- Maximum length reduced (otherwise we need to increase minimum frame size!)

Gigabit ethernet (802.3z)

- Once again backward compatible
- Need to reduce length further - unacceptable
  - Carrier extension - Padding to extend frame to 512 bytes.
  - Frame bursting - concatenated sequence of frames.

Collision-Free Protocols

- Bit-map protocol
- Binary Countdown

Bit Map Protocol

![Bit Map Protocol Diagram](image)
Binary Countdown

- Bit time
  - 0 1 2 3
- 0 0 1 0
- 0 1 0 0
- 1 0 0 1
- 1 0 1 0

Result: 1 0 1 0

Stations 0010 and 0100 see this 1 and give up.
Station 1001 sees this 1 and gives up.

MACA

- Multiple Access with Collision Avoidance (MACA)
- Rx should send a short frame to indicate that it is ready to receive from a source.
- Other stations hearing the Rx will yield.
- RTS (Request to Send) and CTS (Clear to Send) packets.

MACAW - MACA for Wireless

- Some enhancements to MACA
- MAC layer acknowledgements
- CSMA for transmitting RTS
- Backoff algorithm for each source-destination pair instead of for each station.
- Additional information exchange about congestion.

Hidden / Exposed Station Problem

- Case 1: \( A \to B \). \( C \) senses medium but does not hear \( A \)'s transmission as \( C \) is out of range. If \( C \) transmits to \( B \) we have collision.
- Hidden Station Problem. \( A \) is hidden from \( C \)
- Case 2: \( B \to A \). \( C \) needs to transmit to \( D \). \( C \) senses medium and assumes that it cannot transmit. Actually it can as \( A \)'s reception will not be affected.
- Exposed Station Problem.
- What is needed? Interference at the Rx is the problem - not the interference at the transmitter!
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802.11 Modes

- DCF - Distributed Coordination Function
  - Each node determine what to do next
- PCF - Point Coordination Function
  - Base station broadcasts beacon frames (10-100 times per sec)
  - Could provide QOS guarantees
  - Coordinator can even request nodes to go to “sleep”

802.11 Frame Structure

Bytes 2 2 6 6 6 6 2 6 0-2312 4

Bits 2 2 4 5 1 1 1 1 1 1 1 1 1 Frame control

Version Type Subtype
2Bits 2 4
To DS
From DS
MF
Retry
Pwr
More
W
O
Frame control

11 subfields!
- Version, Data type (data, control, management), subtype (RTS, CTS)
- To DS, From DS - for interoperability with 802.3
- MF - more fragments
- Retry - retransmission (ABP 0)
- Power management (sleep)
- More - additional frames to be sent
- W - WEP in use
- O - strict processing

Duration (includes duration of ACK) - for managing NAV
- Address 3 and 4 - to handle handover for intercell traffic
- Sequence - frame number

SIFS - Short IFS, PIFS - PCF IFS, DIFS - DCF IFS, EIFS - Extended IFS

Extended IFS
SIFS - Short IFS, PIFS - PCF IFS, DIFS - DCF IFS, EIFS -

PCF - DCF Coordination

Frame Control

802.11 Protocol Stack

Logical link control

Upper layers

Data link layer

Physical layer

MAC sublayer

802.11 Infrared
802.11 FHSS
802.11 DSSS
802.11a OFDM
802.11b HR-DSSS
802.11g OFDM
Hides difference between different IEEE 802.x protocol families to network layer
LLC can provide three types of services (unreliable datagram, acknowledged datagram, connection oriented)
Three fields in LLC header - Source access point, destination access point, control

Bridges interconnect LANs
Need for bridges
- LANs might have sprouted independently
- Sometimes (geographically well distributed) cheaper to connect different segments with a bridge than run a single cable
- Controlling load in each LAN
- Very large physical distances (greater than 2500 m)
- Reliability
- Security

Hash tables are empty at first
If route to destination not known - flood!
If dest and source are on the same LAN discard packet
If dest and source are on different LANs, forward
Backward learning - operate in promiscuous mode
Inspect source address of each packet seen to get some knowledge of the topology

Should the frame be forwarded? To whom?
Hash tables

Repeaters, Hubs, Bridges, Switches, Routers, Gateways
Hub, Bridge, Switch