Link Layer

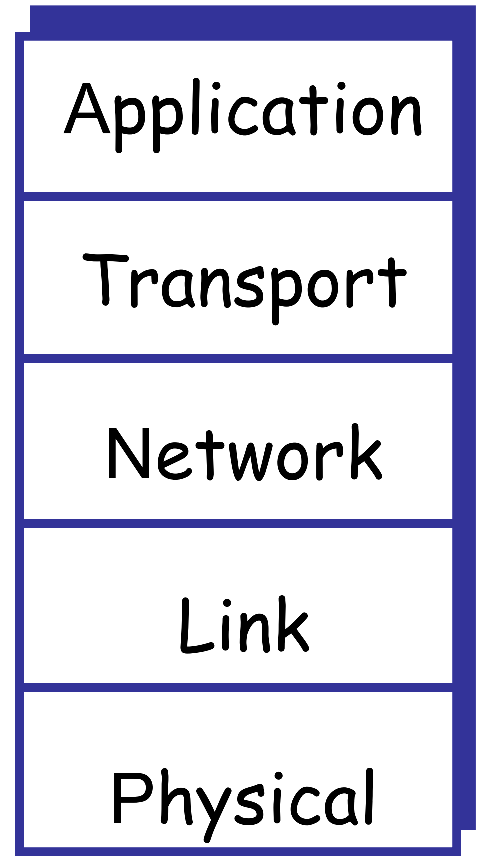
Lecture 19

- Principles behind data link layer services
- Framing
- Multiple access protocols
- ALOHA

**The slides are adapted from ppt slides (in substantially unaltered form) available from "Computer Networking: A Top-Down Approach," 6th edition, by Jim Kurose and Keith Ross, Pearson, 2013.*

Internet protocol stack

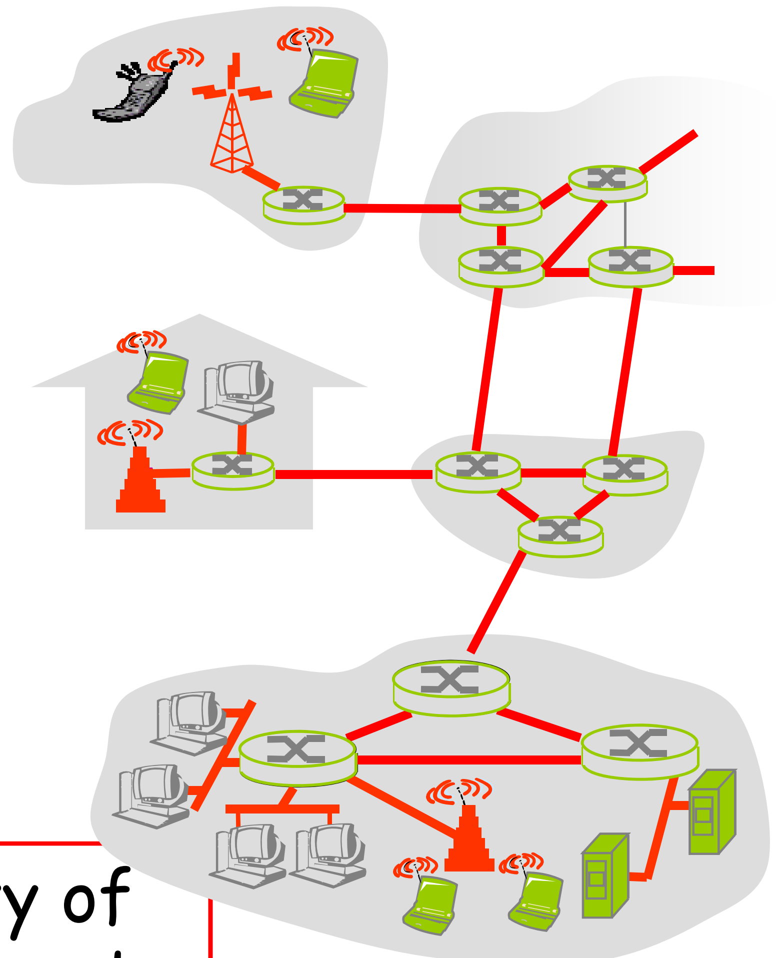
- application: supporting network applications
  - HTTP, SMTP, FTP, DNS
- transport: process-process data transfer
  - TCP, UDP
- network: routing of datagrams from source to destination
  - IP, routing protocols
- link: data transfer between neighboring network elements
  - 802.11, Ethernet
- physical: bits "on the wire"



Link Layer: Introduction

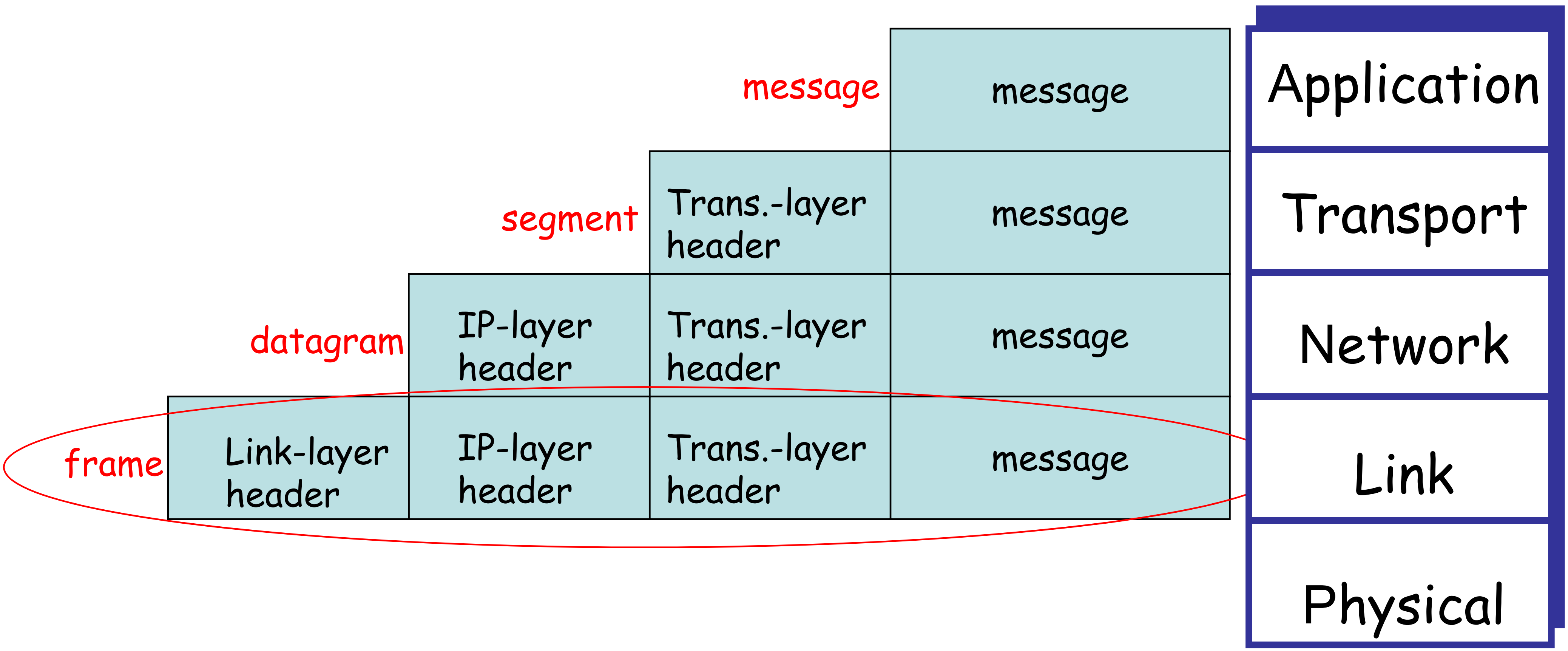
Some terminology:

- hosts and routers are **nodes**
- communication channels that connect adjacent nodes along communication path are **links**
  - wired links
  - wireless links
  - LANs
- layer-2 packet is a **frame**, encapsulates datagram



data-link layer has responsibility of transferring datagram from one node to adjacent node over a link

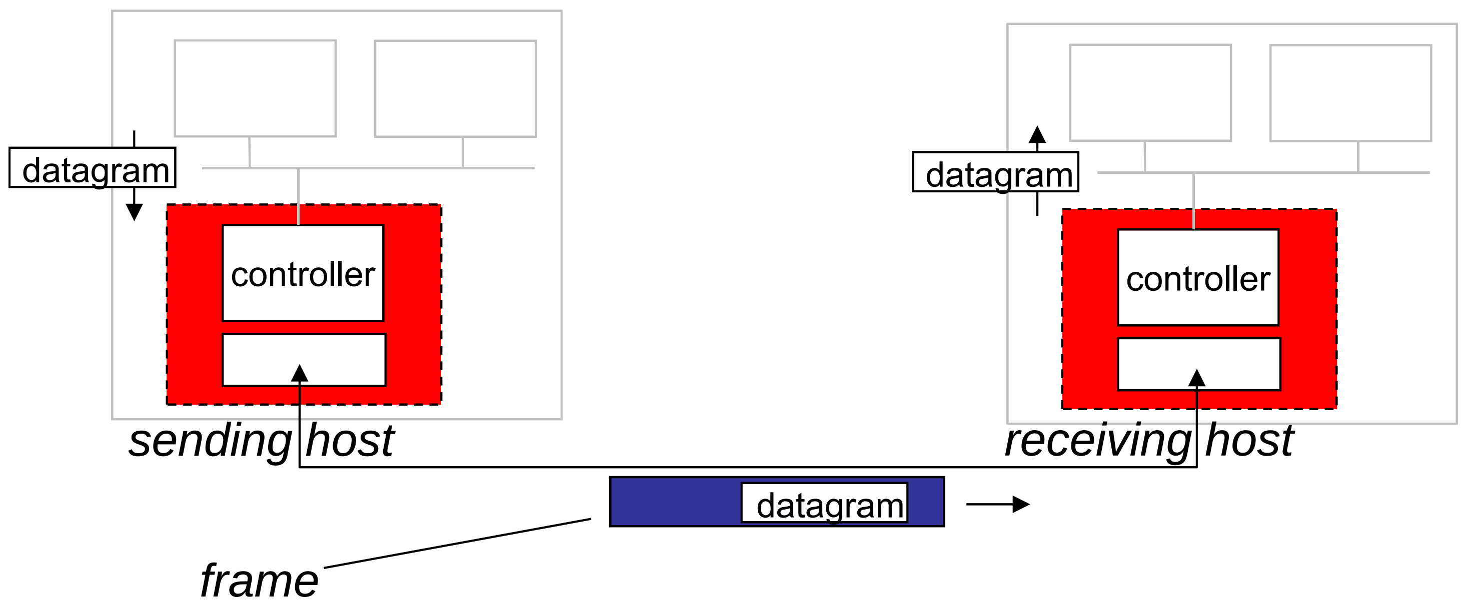
Packet Names



Link Layer Services

- *framing, link access:*
  - encapsulate datagram into frame, adding header, trailer
  - channel access if shared medium
  - "MAC" addresses used in frame headers to identify source, dest
    - different from IP address!
- *error detection*:
  - errors caused by signal attenuation, noise.
  - receiver detects presence of errors:
    - signals sender for retransmission or drops frame
- *error correction:*
  - receiver identifies *and corrects* bit error(s) without resorting to retransmission

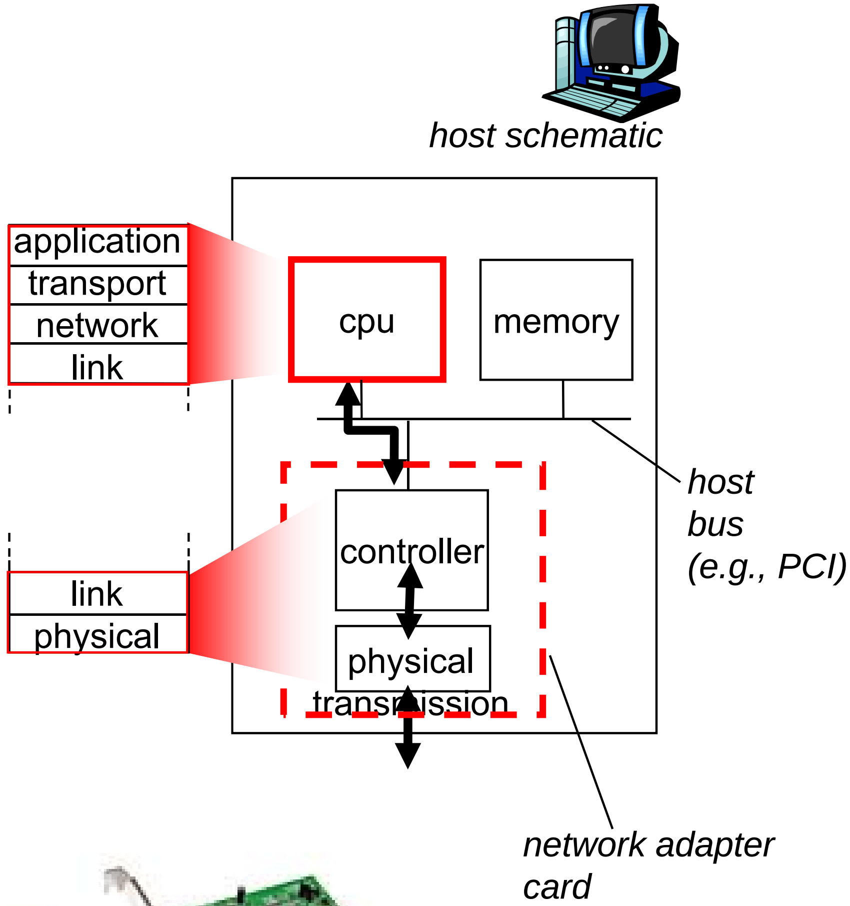
Adaptors Communicating

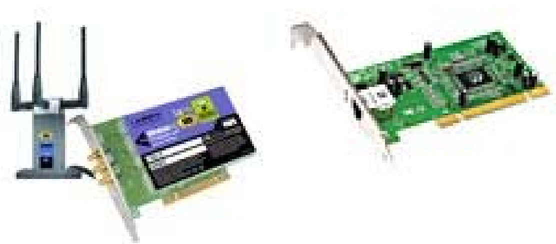


- sending side:
  - encapsulates datagram in frame
  - adds error checking bits, and other link-layer headers, etc.
- receiving side
  - looks for errors, etc
  - extracts datagram, passes to upper layer at receiving side

Where is the link layer implemented?

- in each and every host
- link layer implemented in "adaptor" (aka *network interface card* NIC)
  - Ethernet card, 802.11 card
  - implements link, physical layer
- attaches into host's system buses
- combination of hardware, software, firmware

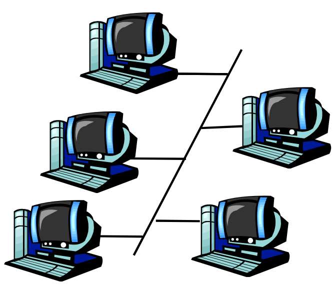




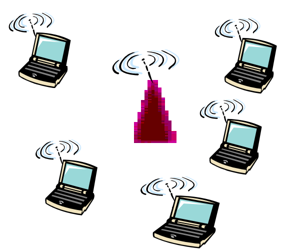
Multiple Access Links and Protocols

Two types of "links":

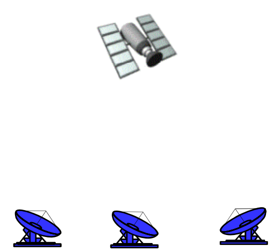
- point-to-point
  - PPP for dial-up access
  - point-to-point link between Ethernet switch and host
- broadcast (shared wire or medium)
  - old-fashioned Ethernet
  - upstream HFC
  - 802.11 wireless LAN



shared wire (e.g., cabled Ethernet)



shared RF (e.g., 802.11 WiFi)



shared RF (satellite)

humans at a cocktail party (shared air, acoustical)

Multiple Access protocols

- single shared broadcast channel
- two or more simultaneous transmissions by nodes: interference
  - collision if node receives two or more signals at the same time

multiple access protocol

- distributed algorithm that determines how nodes share channel, i.e., determine when node can transmit
- communication about channel sharing must use channel itself!
  - no out-of-band channel for coordination

Ideal Multiple Access Protocol

<u>Broadcast channel of rate R bps</u>

1. when one node wants to transmit, it can send at rate R.
2. when M nodes want to transmit, each can send at average rate R/M
3. fully decentralized:
   - no special node to coordinate transmissions
   - no synchronization of clocks, slots
4. simple

Multiple Access Control (MAC) Protocols: a classification

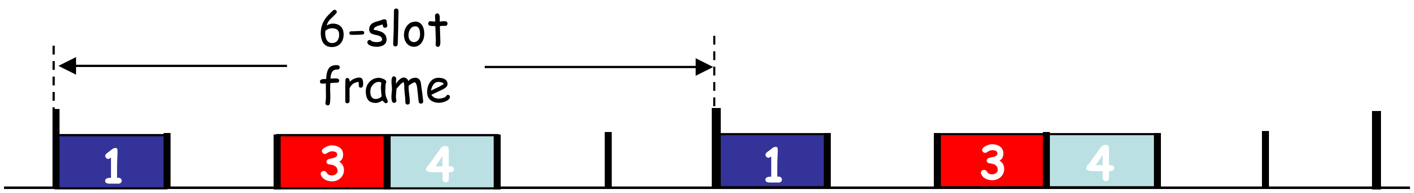
Three broad classes:

- Channel Partitioning
  - divide channel into smaller "pieces" (time slots, frequency, code)
- Random Access
  - channel not divided, allow collisions
- "Taking turns"
  - nodes take turns, but nodes with more to send can take longer turns

Channel Partitioning MAC protocols: TDMA

TDMA: time division multiple access

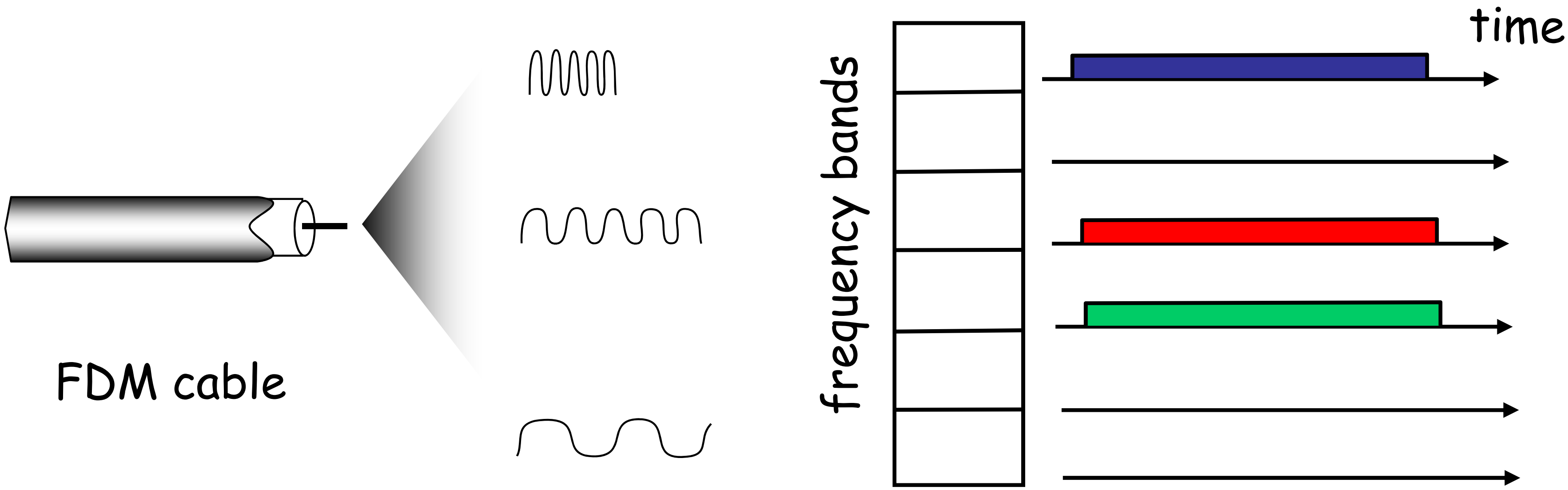
- access to channel in "rounds"
- each station gets fixed-length slot (length = packet transmission time) in each round
- unused slots go idle
- example: 6-station LAN, 1,3,4 have packet, slots 2,5,6 idle



Channel Partitioning MAC protocols: FDMA

FDMA: frequency division multiple access

- channel spectrum divided into frequency bands
- each station assigned fixed frequency band
- unused transmission time in frequency bands go idle
- example: 6-station LAN, 1,3,4 have packet, frequency bands 2,5,6 idle

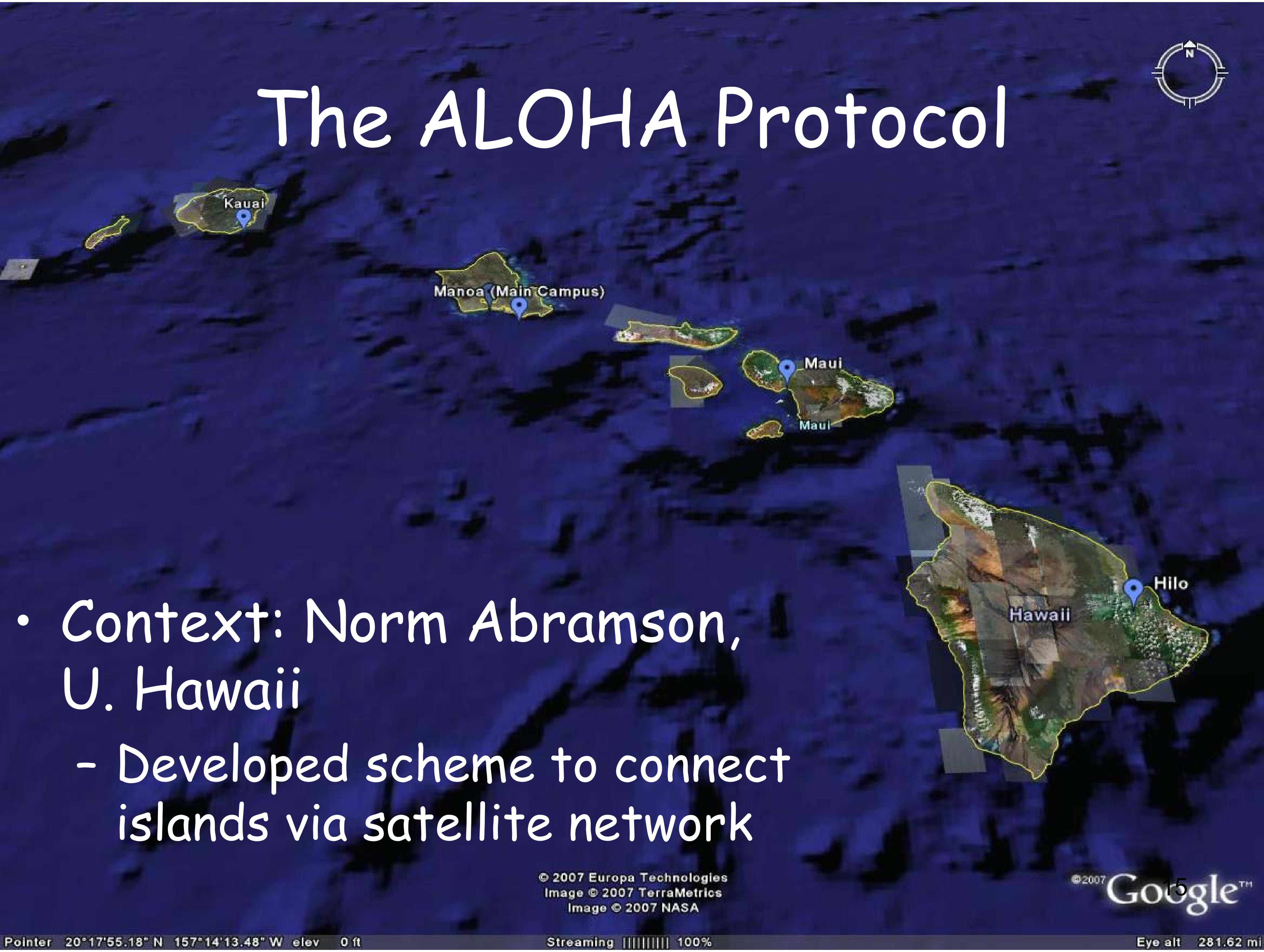


Random Access Protocols

- When node has packet to send
  - transmit at full channel data rate R.
  - no *a priori* coordination among nodes
- two or more transmitting nodes ➜ "collision",
- random access MAC protocol specifies:
  - how to detect collisions
  - how to recover from collisions (e.g., via delayed retransmissions)
- Examples of random access MAC protocols:
  - Slotted ALOHA
  - Pure ALOHA
  - CSMA, CSMA/CD, CSMA/CA

The ALOHA Protocol

- Context: Norm Abramson, U. Hawaii
  - Developed scheme to connect islands via satellite network



Slotted ALOHA

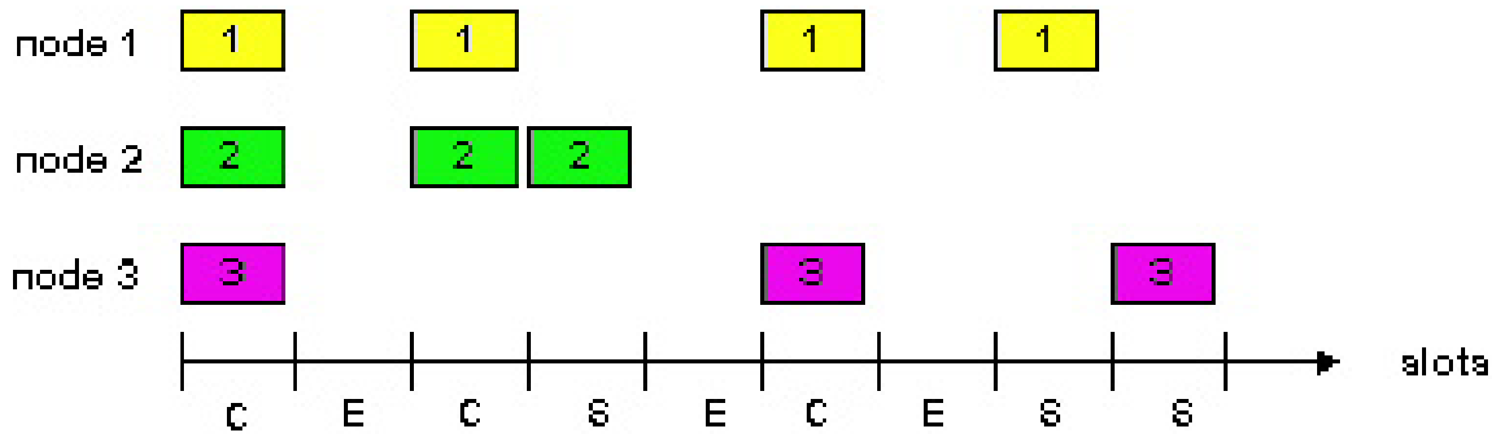
Assumptions:

- all frames same size
- time divided into equal size slots (time to transmit 1 frame)
- nodes start to transmit only at slot beginning
- nodes are synchronized
- if 2 or more nodes transmit in a slot, all nodes detect collision

Operation:

- when node obtains fresh frame, transmits in next slot
  - *if no collision:* node can send new frame in next slot
  - *if collision:* node retransmits frame in each subsequent slot with prob. p until success

Slotted ALOHA



Pros

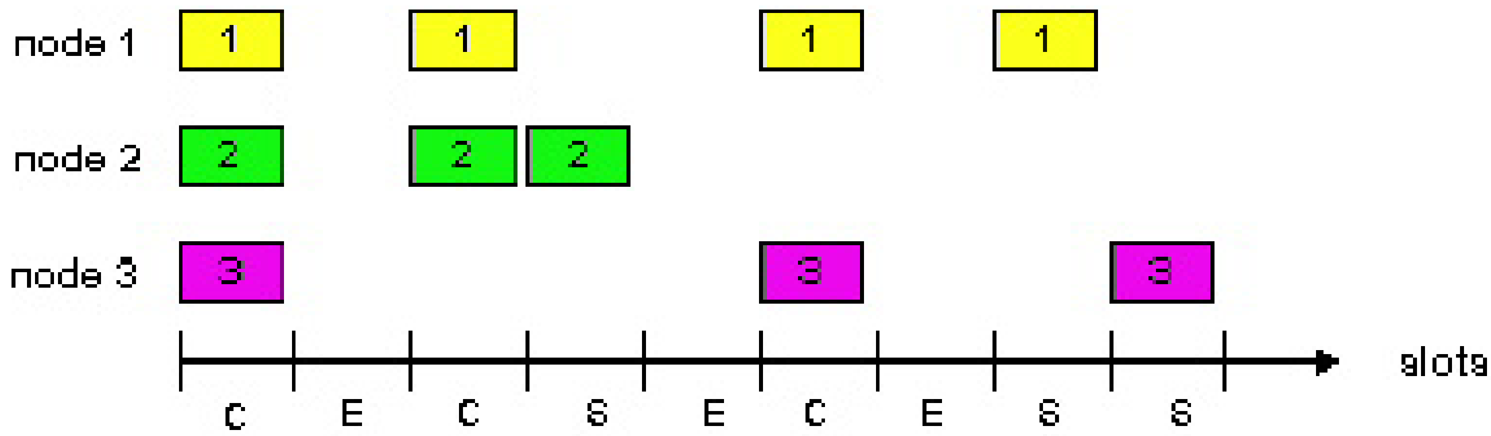
- single active node can continuously transmit at full rate of channel
- highly decentralized
- simple

Cons

- collisions, wasting slots
- idle slots
- once collision happens, entire slot is wasted
- clock synchronization

Analysis of Collisions

- A *collision* occurs when multiple transmissions overlap in time



- **Throughput S**: total number of successful frames per slot
- **Offered load G**: total number of frames transmitted per slot

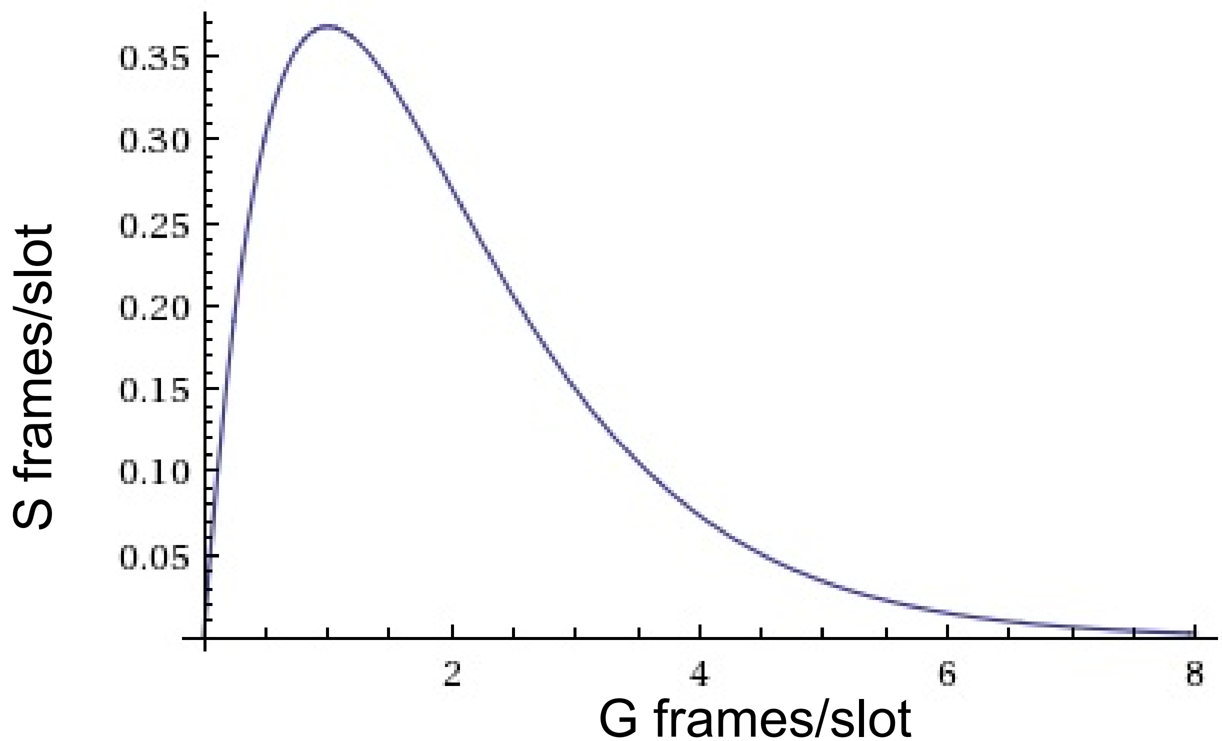
Slotted ALOHA efficiency

Efficiency : long-run fraction of successful slots (equivalent to throughput measured per slot)

- *Suppose:* N nodes with many frames to send, each transmits in a slot with probability p
- The average offered traffic is therefore G=Np in frames/slot
- Need to calculate the average amount of offered traffic that gets successfully received and this is known as throughput S in frames/slot
- Prob that a node is successful in a slot $= p(1-p)^{N-1}$
- Prob that *any* node is successful $= Np(1-p)^{N-1}$ or $G(1-G/N)^{N-1}$ and is the throughput S in frames/slot

Slotted ALOHA efficiency

- Let N become large and tend to infinity
- We can then write S= $G(1-G/N)^N$
- Also remember that $\lim_{n\to\infty}\left(1-\frac{x}{n}\right)^n = e^{-x}$
- Therefore when N is large S= Ge^{-G}

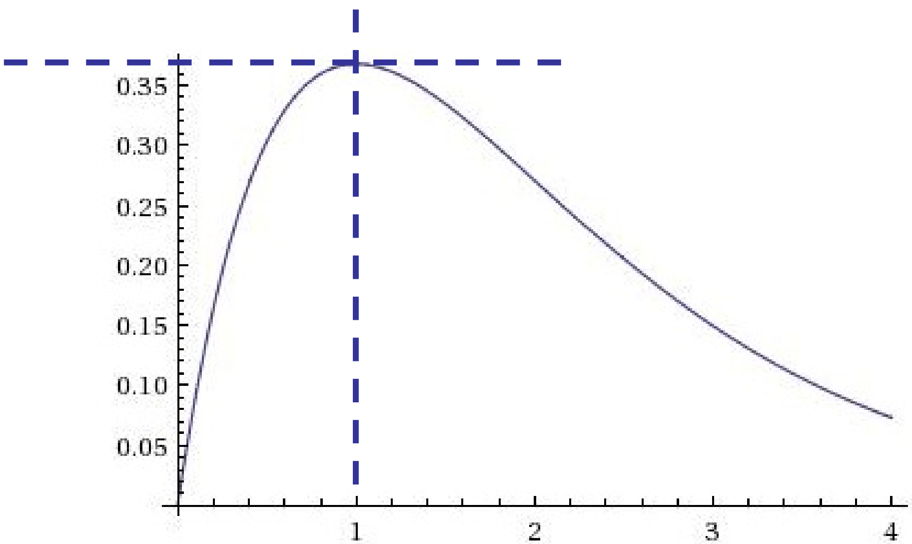


Slotted ALOHA efficiency

- At what G is the throughput maximum?
- Maximum is when derivative is zero (slope is flat)

$$\frac{dS}{dG} = e^{-G} - Ge^{-G} = e^{-G}(1 - G)$$

- Derivative is zero when G=1 so this is where maximum throughput occurs
- Maximum S is therefore S= $e^{-1} = 0.37$

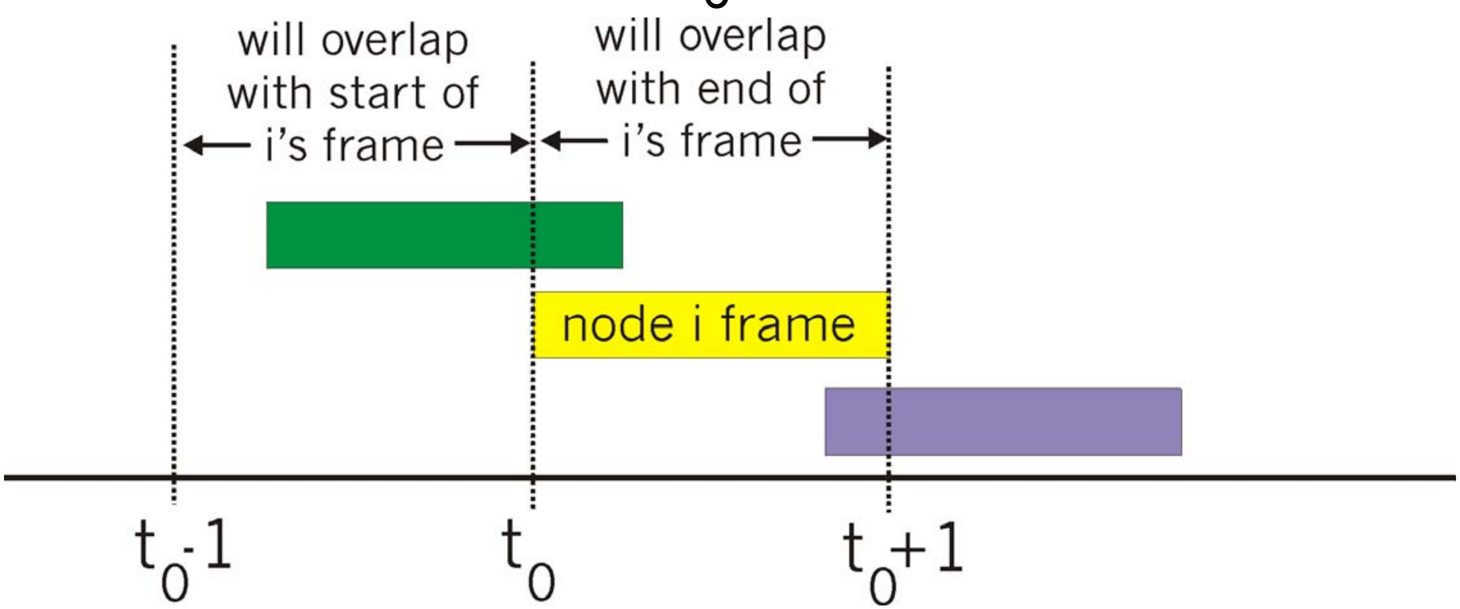


At best: channel used for useful transmissions 37% of time!

!

Pure (unslotted) ALOHA

- unslotted Aloha: simpler, no synchronization
- when frame first arrives
  - transmit immediately
- increase collision probability:
  - frame sent at t_0 collides with other frames sent in $[t_0-1,t_0+1]$



Pure Aloha efficiency

P(a node is successful) = P(the node transmits) ·

P(no node transmits in $(t_0-1,t_0]$)·

P(no other node transmits in $[t_0,t_0+1)$)

$= p \cdot (1-p)^N \cdot (1-p)^{N-1}$

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

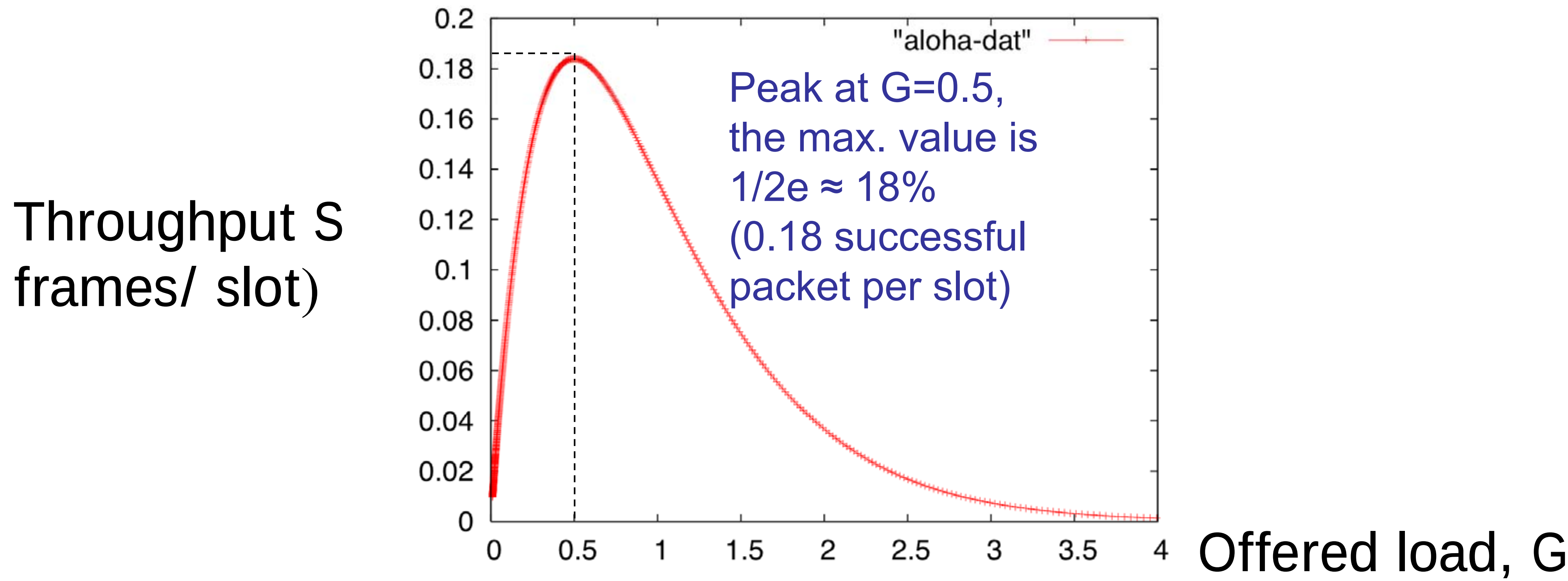
Therefore $G(1-G/N)^{2N-1}$ or when N is large $S = Ge^{-2G}$

Maximum efficiency = 1/(2e) = .18

even worse than slotted Aloha!

Throughput vs. Offered Load

- Throughput = G exp(-2G)



Throughput S: number of successful frames per slot

Offered load G: total number of frames transmitted per slot

Summary

- Link layer functions
- Link layer helps share a channel
  - Many ways to share a channel
  - Channel partitioning (FDMA, TDMA)
  - Random access (ALOHA)
  - Taking turns
- Simple analysis for ALOHA collisions and throughput
  - Slotted ALOHA
  - Pure ALOHA