Networks and Systems Security

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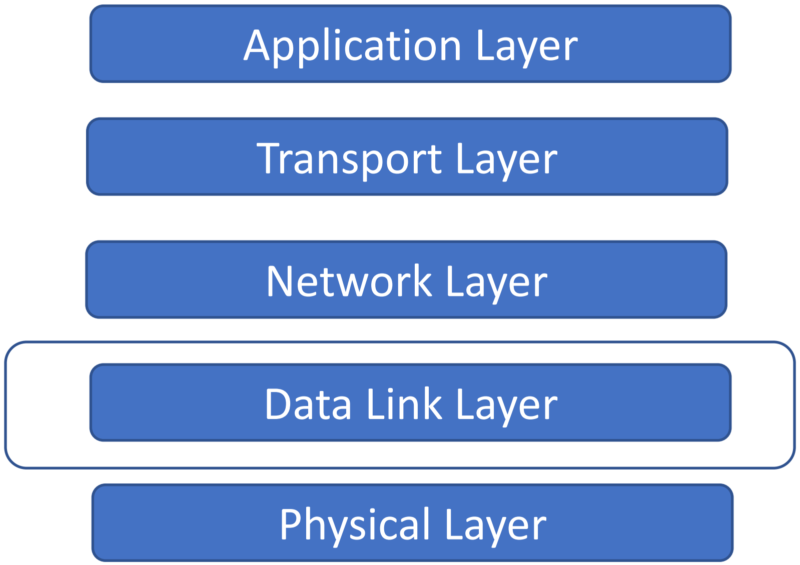
Data Link Layer / MAC Layer issues



- Addressing of source station as well as the destination station, or groups of destination stations.
- **Multiple access resolutions** when more than one data frame is to be transmitted.
- Determines the channel access methods for transmission.
- Collision resolution and initiating retransmission in case of collisions.
- Frame check sequences and thus contributes to protection against transmission errors.

Connection with Physical Layer -

- **Functionality** provided by the **Physical Layer:**
- **Transmission** of ***analog/digital*** **data** using ***analog/digit al*** **signals**

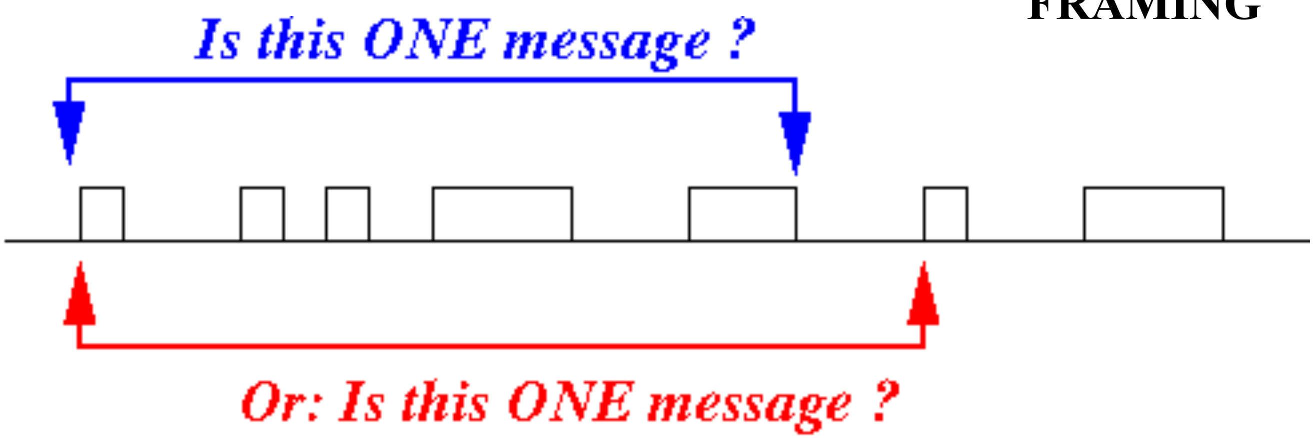
- Errors

Framing

- We can **transmit *bits*** using ***analog/digital* signals**

•**How** can you ***tell*** the **start** and **end** of a **message** ?

This problem is called: FRAMING



- A **frame** = a ***unit*** **("atom") of data** ***transmitted*** and ***received*** by the **Data Link layer**
- The **Data Link layer** will:
- **Receive** ***one*** **entire frame** (if the **frame** is **deemed error-free**) **or**
- **Reject** ***one*** **entire frame** (if the **frame** is **deemed** contain **bit errors**)

•The **Data Link layer** will ***never*** **receive/reject** a ***portion*** of a **frame**

Functions provided by the Datalink Layer

- **Framing**

> •A **protocol (= agreement)** on ***how*** to **group** a **series of bits** into **logical unit (= frame)**

- **Error** ***detection*** **and** ***recovery*****:**
- **Check** if a **received frame** is ***correct***
- If **frame** contains **bit errors**: ***Recover*** the **correct frame**
- ***Further*** **conditions** on **correctness**:
- **Each frame must** be **received exactly** ***once***:
-

> •***Duplicate*** **reception** (that you **cannot tell**) of the ***same*** **frame** is **in fact** a **communication** ***error*** !!!

Other functions …

Frames must be ***received*** in
the ***same* order** as ***transmitted***

Flow control:

•***Pace*** the **transmission rate** of the **sender** in accordance with the **processing speed** of the **receiver**

•The **flow control function** is ***desirable*** but is **not *necessary*** in the **Data Link layer**

Framing (glimpse…)

- **Framing: how to tell when a frame *begin* and when it *ends***
- Read **these bits** from **left to right**:
-

  01010001111110000000110100101001001111101111101111011011111101010101

•Can you tell ***where*** a **frame starts** and **where** it **ends** ???

Framing (Glimpse …)

- You **cannot** find the **start** and the **end** because:
-

•You **do *not* know** the ***protocol*** **(= agreement)**.....

If its given that –
A **frame *starts*** and ***ends*** with
this **pattern**: 01111110

Framing (Glimpse …)

- Can
  you **now** tell ***where*** a **frame starts** and **where** it **ends**:
-

01010001111110000000110100101001001111101111101111011011111101010101

01010001111110000000110100101001001111101111101111011011111101010101

Frame

Framing (Glimpse …)

- **Types of framing methods**

- ***Byte*-oriented** protocols:
-

•Used in ***low* speed links**

***Bit*-oriented** protocols

•Used in ***high* speed links**

Transmission and Propagation

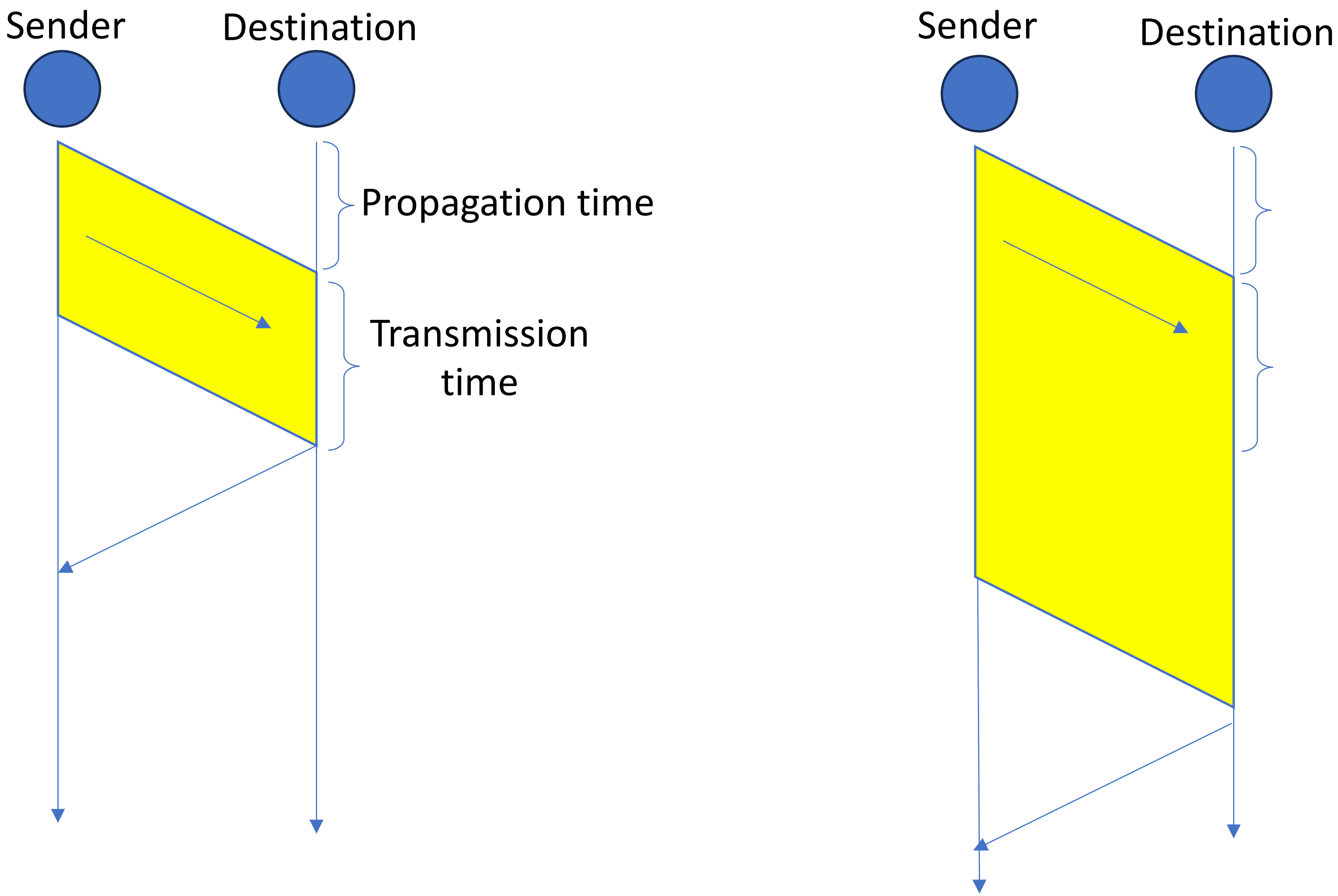
Transmission time: The time taken for the complete packet to get transmitted by the underlying hardware radio or NIC

It depends on the modulation strategy, bandwidth or bit rate

Propagation: The time taken for a signal to propagate from one end of the link to the other end

It depends on the speed of light – 3×10^8 m/s

Transmission and Propagation



Propagation and **transmission** time

- Consider a 1000-bit packets transmitted over a channel operating at a speed of 100 kbits/s.
- The transmission time of the packet is then **10** ms. [**How?** 100000 bits take 1 second – so 1000 bits take 1/100 second = 10 ms]
- If the maximum distance between the source and the destination is 10 meter, then the (speed of light = 3 X 10^8 m/s) packet propagation delay is about 33 *microsecond.*
- Thus the propagation delay constitutes only a very small fraction *(33/10000 = 0.0033)* of the transmission time of a packet.
- However, for **satellite channel** the propagation delay is a relatively large multiple of the packet transmission time

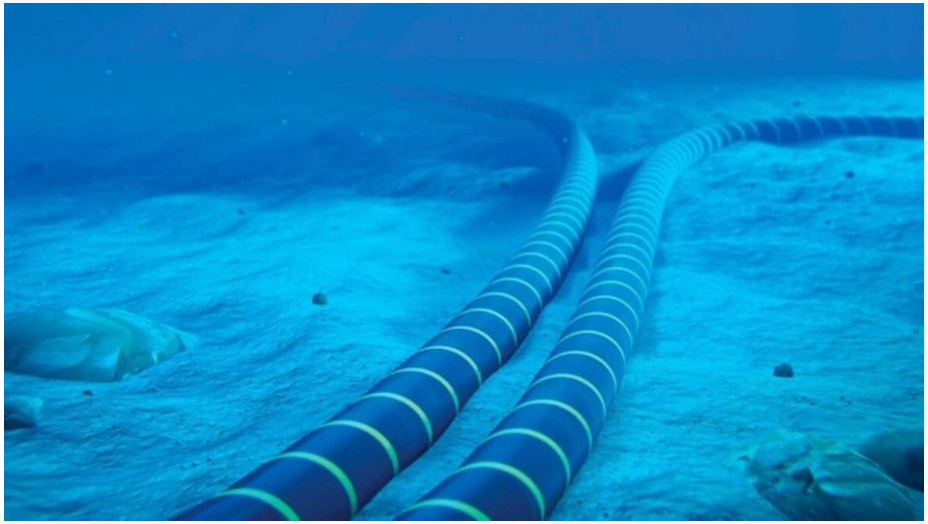
The Datalink Layer for *Broadcast* Links

- **Point-to-point link vs. broadcast links**

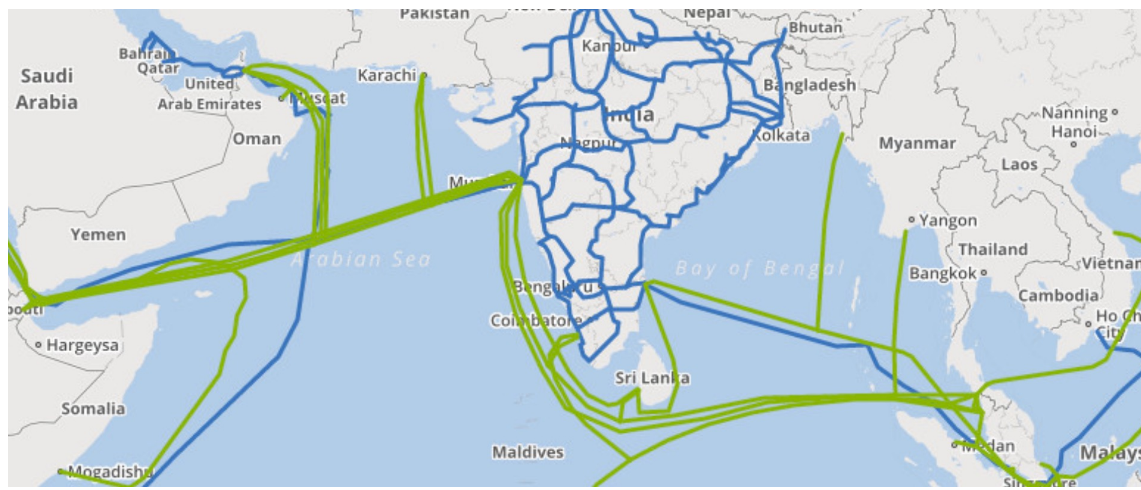
- **Point-to-point links** ===> **switched networks**

- Point to point links –
  - These links **typically** spans ***large*** **geographical distances** (across continents)
  - Due to the **length**: **Transmission errors (bit errors)** may happen
  - Typical: 1 bit in ~10,000 bit for copper and 1 in ~10,000,000 in optical fiber

Undersea cables



Undersea cables connecting different countries



The Datalink Layer for *Broadcast* Links

- The **datalink layer** for **point-to-point link** deals **primarily** with:

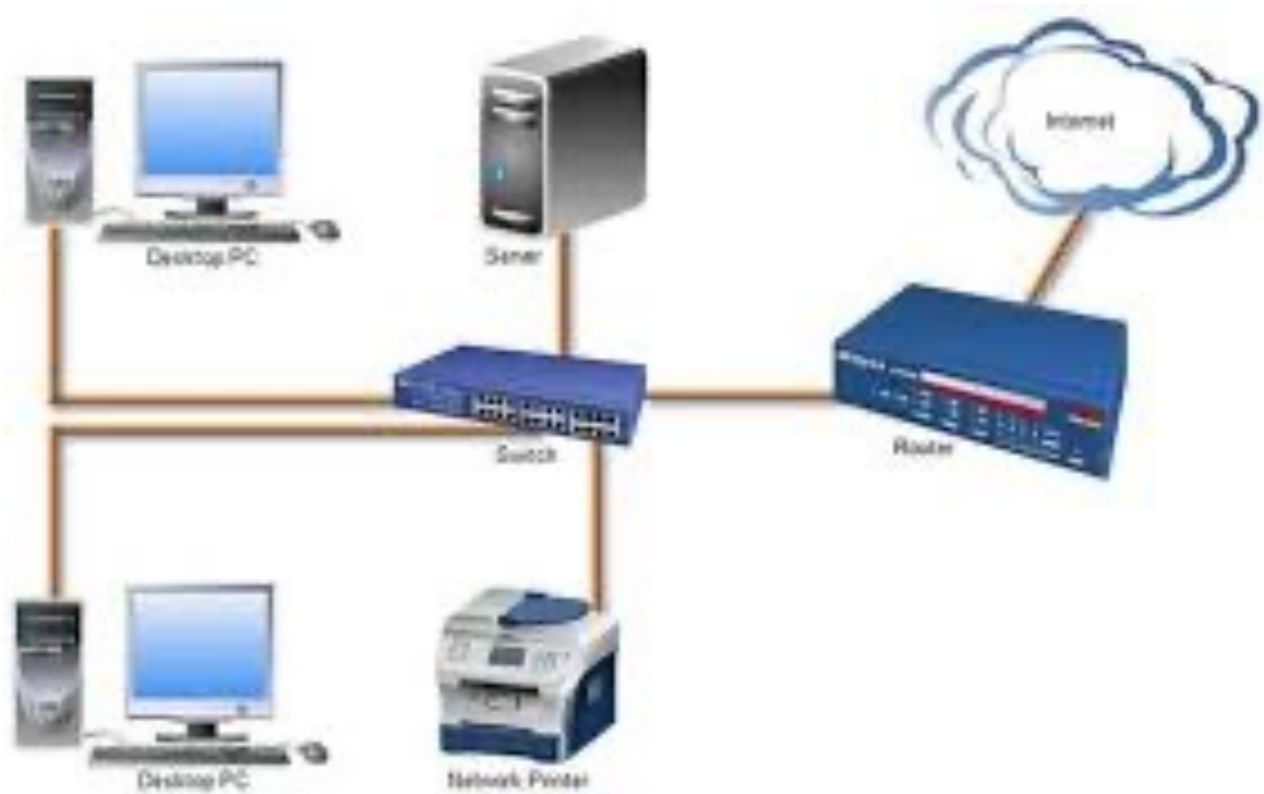
•***Reliable*** **transmission** using **Sliding Windows** protocol (in addition to framing)

•Examples -

- **HDLC** is used in **switched networks**
- It uses ***Go-Back-N*** for **reliability**)

The Datalink Layer for *Broadcast* Links

- **Broadcast links =======> *very short* distances (*local* area network)**



The Datalink Layer for *Broadcast* Links

- **Transmissions** over **short distance** are **very reliable**

- The **data link layer** of **broadcast network** does **not** implement any ***reliable*** **communication protocol**

- **The MAIN Problem** solve by the **Datalink layer** of **broadcast networks**:

- How to ***share*** the **broadcast network** ***efficiently***

Transmission on a broadcast network

- **Property** of a **broadcast network**:

- A **transmission** on a ***broadcast*** **network** will be **received** by ***all*** **nodes** on the ***broadcast*** **network**

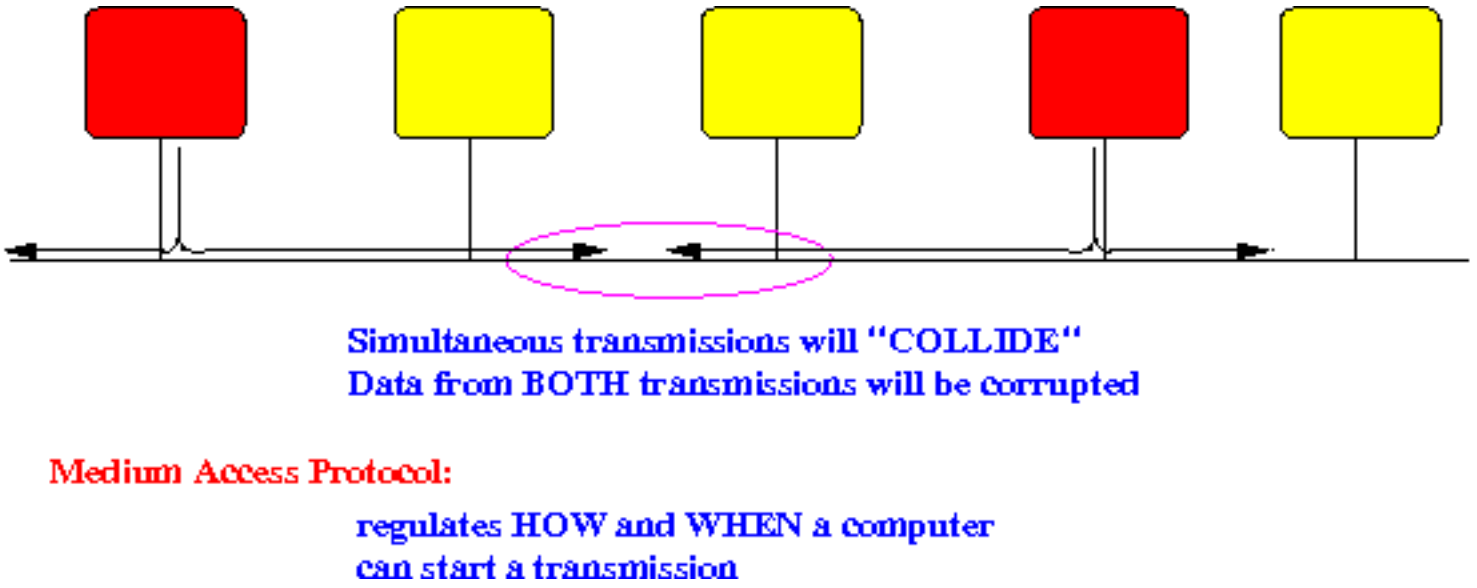
- **Example – RF , Radio**

- When ***multiple*** **nodes transmit** at the ***same*** **time**:
- ***All*** **transmitted frames** will be **lost** !!!

- **Collision** = ***multiple*** **simultaneous transmission** on a **broadcast network**
- The ***simultaneous*** **transmission** have ***collided***

Medium Access Control (MAC):

- **Medium Access Control (Protocol)** =
- A **protocol (procedure)** that **nodes** on a **broadcast network** must follow ***when*** the **node** wants to **transmit** a **frame**



Types of MAC protocols used in broadcast networks

- There are **2 types** of **Medium Access Control protocols**:

- **Contention-based protocols**
- **Contention-free protocols**

Contention-based MAC protocols

- Properties

- **Nodes** in a **contention-based network** will **compete** to be the ***winner***

- The **winner node** will
  be **able** to **transmit** its **message** on the **network** !!

Contention-based MAC protocols

- Operations –
- **Nodes** that **want to transmit** a **message** will **compete** to be the ***first*** **node** to ***start*** **transmitting** its **message**

- The ***first*** **transmitting node** will **succeed** in **completing** its **transmission**

- When ***other*** **(= not first) nodes** ***hear*** the **transmission** of the ***first*** **node**:

- They will ***refrain*** from **transmitting**(Until the **transmission** of the **first node** is **complete**)

Contention-based MAC protocols

- When the ***first*** **node finishes**:

- **All active nodes** (= nodes that **want to transmit** a **message**) will **compete *again***

- **Another name**: ***Multiple Access*** **protocols** – Why ?

Competing for **access** to the **network** can **result** in: ***Simultaneous* transmissions**

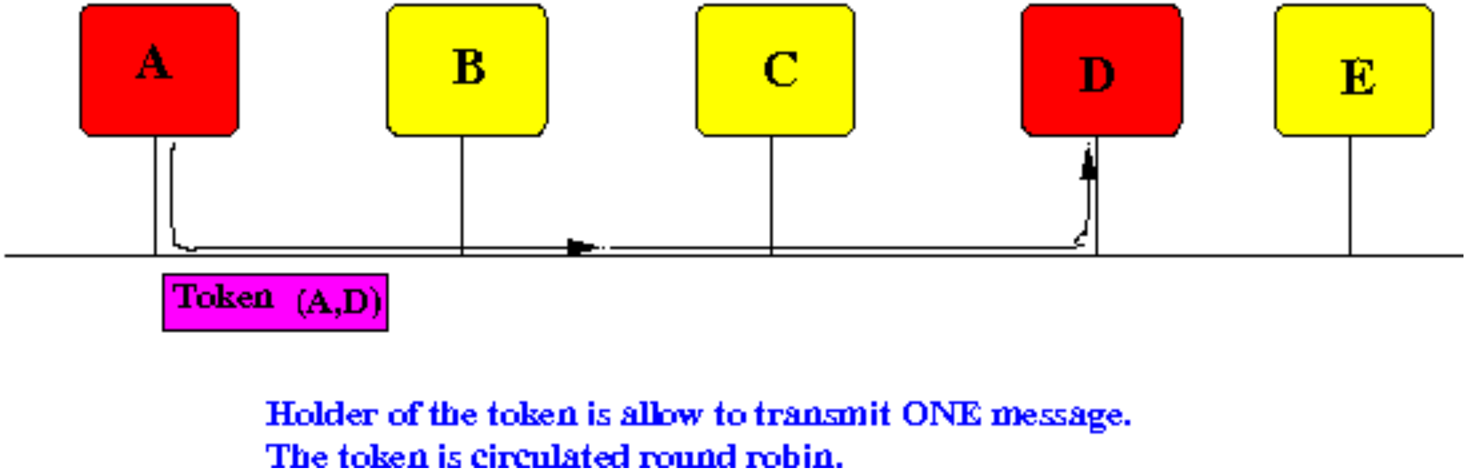
- ***Simultaneous* transmissions** are **transmission "collisions"**

Result of a ***collisions*** :

- **All colliding transmissions** from **nodes** will be **lost** !!!
- **Nodes** involved in a **collision** will need to **transmit** the **frame *again***:
- **N**odes need ***multiple* attempts** before they will be **successful** in transmitting
- That's why – C**ontention-based MAC protocols** are **also** called: MULTIPLE ACCESS PROTOCOLS

Contention-free MAC Protocols

- **Contention-free Medium Access Protocols** ***regulate*** the **network access** using a ***special*** **message** called **token**:
-



Contention-free MAC Protocols

- **Operation** of **content-free MAC networks**:

- A **node** is **given** the **turn** to **transmit a message** when
  The **node receives** a ***special*** **message** called: **"token" message**.

- When a **node** receives a **token**:

  - **If** the **node** has some **message** to **transmit**:

  - The **node** transmits ***one*** **message** and

  - The **node must "pass" (= send)** the **token** to the ***next*** **node**.

  - **If** the **node** does **not** have **any message** to **transmit**:

  - The **node must "pass" (= send)** the **token** to the ***next*** **node**

Some **problems** that **contention-*free* protocols** must **resolve**:

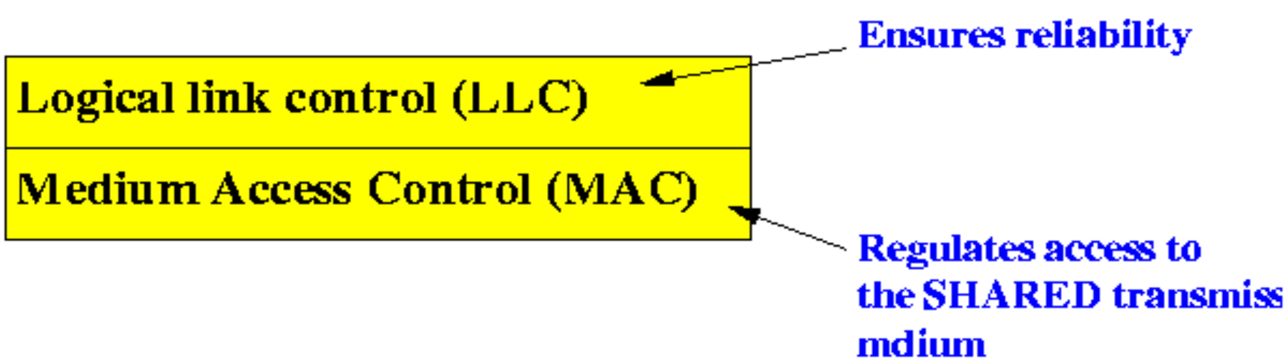
- **Maintain (= keep track of)** the ***complete*** **list** of **nodes**:
- **How to add** a **new node** to the **network**
- The ***new*** **node** does **not "get"** the **token** without being ***added*** !!
- **How to remove** a **node** from the **network**
- If **some node** sends the **token (message)** to a **"deleted" node**, the **token (message)** will be ***lost*** !!!
- Then the ***whole*** **network** will **stop** working --- like a **broken traffic light**

Structure of the Datalink layer for broadcast links

- The **datalink layer for *broadcast* links** consists of ***two* functional layers**:

  - **Logical Link Control** that **provides *reliable communication (sliding etc)***

  - **Medium Access Control (MAC)** that **provides functions** to ***access* (= share)** the **broadcast network**



Logical Link Control

- Provide **reliability functionality - Sliding window** and **ACK scheme**

- **Real-life datalink layers** (e.g.: **Ethernet**, **Token ring**) for **broadcast networks** do **not implement** the **Logical Link control layer (function)**

- ***How*** to **recover** from **transmission errors**:

  - The **error control function** is ***also*** implemented in a ***higher*** **layer**: Transport Layer

  - The **Ethernet/Token Ring protocol datalink layer relies (= depends)** on the **Transport Layer (TCP !!!)** to **recover** any **lost messages** !!!
(The **TCP layer does implement** the **reliability function**)

Medium Access Control

- The **MAC layer** implements **functions** to

Regulate *orderly* and *fair* access to the ***shared* (broadcast) transmission medium**.

We will see from the perspective of wireless communication mostly…

Some technologies

Example of short-range wireless communication technologies

- Bluetooth mesh networking
- Light-Fidelity (Li-Fi)
- Near-field communication (NFC) –within a 4 cm range.
- Radio-frequency identification (RFID) –
- Wi-Fi – Technology for local area networking based on the IEEE 802.11 standard, where devices may communicate through a shared access point or directly between individual devices.
- Zigbee – Communication protocols for personal area networking based on the IEEE 802.15.4 standard, providing low power consumption, low data rate, low cost, and high throughput.
- Z-Wave – Wireless communications protocol used primarily for home automation and security applications

Some Technologies

Medium-range wireless

•LTE-Advanced – High-speed communication specification for mobile networks. Provides enhancements to the LTE standard with extended coverage, higher throughput, and lower latency.
•5G - 5G wireless networks can be used to achieve the high communication requirements of the IoT and connect a large number of IoT devices, even when they are on the move.

Long-range wireless

•Low-power wide-area networking (LPWAN) – Wireless networks designed to allow long-range communication at a low data rate, reducing power and cost for transmission. Available LPWAN technologies and protocols:
•LoRaWan, Sigfox, NB-IoT,

Which technology work in which layer

	Physical	Link / MAC	Network	Transport	Application
BLE	✓	✓	✓	✓	✓
IEEE 802.15.4	✓	✓	✗	✗	✗
Zigbee	✗	✗	✓	✓	✓
Ethernet	✓	✓	✗	✗	✗
Wi-Fi	✓	✓	✗	✗	✗

We will see some of the fundamental protocols first to proceed with

Why diversity is important

- High range high energy
- Less life of a node
- Repeated battery change OR node replacement
- Needed for some places when we need more range –

- Low range low energy
- Less / Very replacement of battery
- Low power systems
- Long life

Data Link Layer / MAC Layer Protocols

Application Layer

Transport Layer

Network Layer

Data Link Layer

Physical Layer

- ALOHA
- SLOTTED ALOHA
- CSMA Basics
- CSMA CD
- CSMA CA
- MACA
- MACAW
- RTS/CTS and other details …

ALOHA

Brief History

- Year 1968
- Name of the Researcher
  - **NORMAN ABRAMSON**

A story from Hawaii University –

- Hawaii University is distributed over multiple islands - Manoa, Oahu, Kauai, Maui, and Hawaii… *Multi-Campus university*

- It was necessary to have a good communication among the Campuses - **Wired** is difficult - **Wireless** is the option

The ALOHA System

Target

Link **interactive computer users** and **remote-access input-output devices** away from the main campus to the central computer via UHF radio communication channels

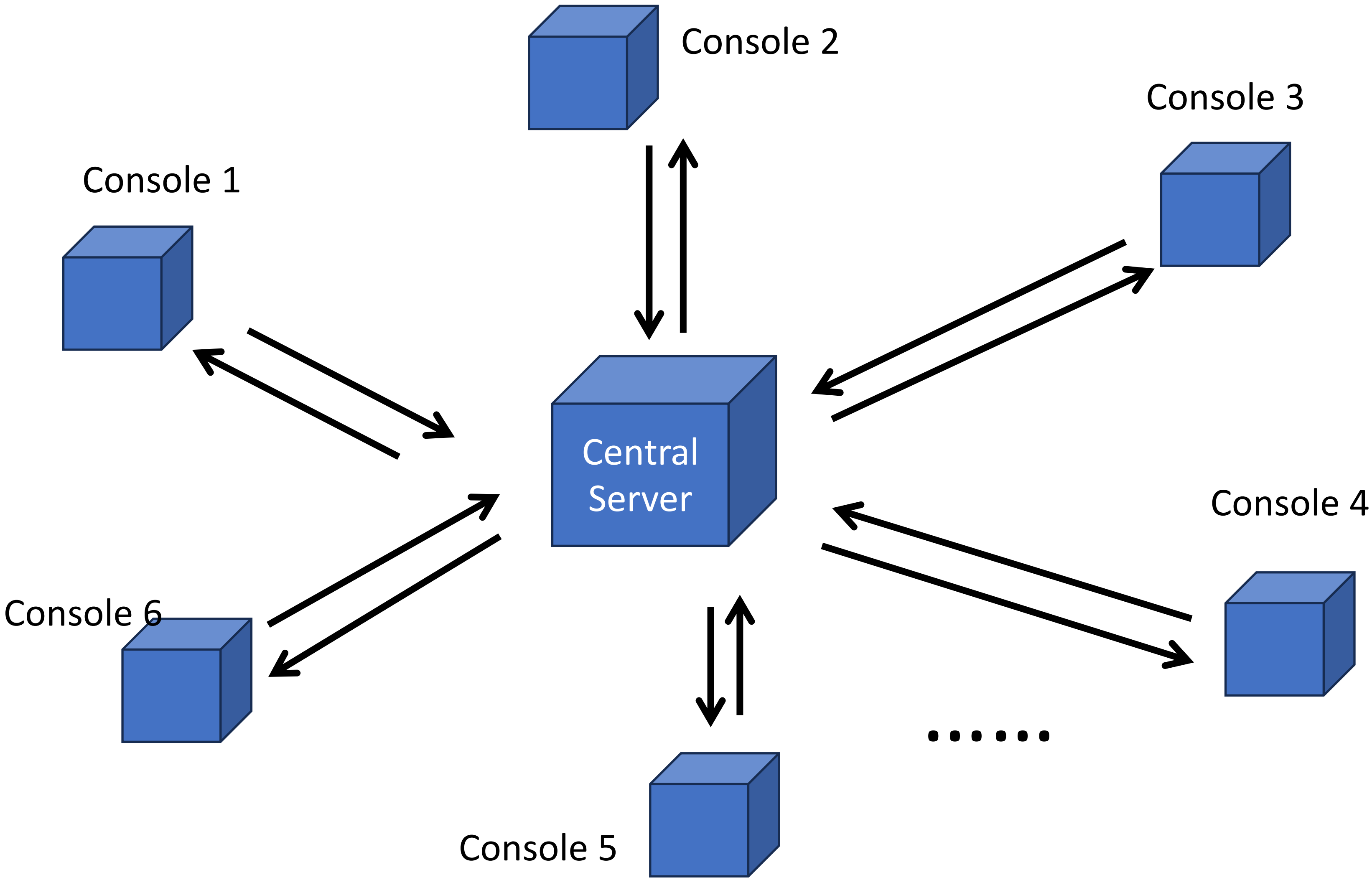
The model of communication

A central server machine in the Main Campus

Many console units in all other islands

All the console units need to communicate with central machine

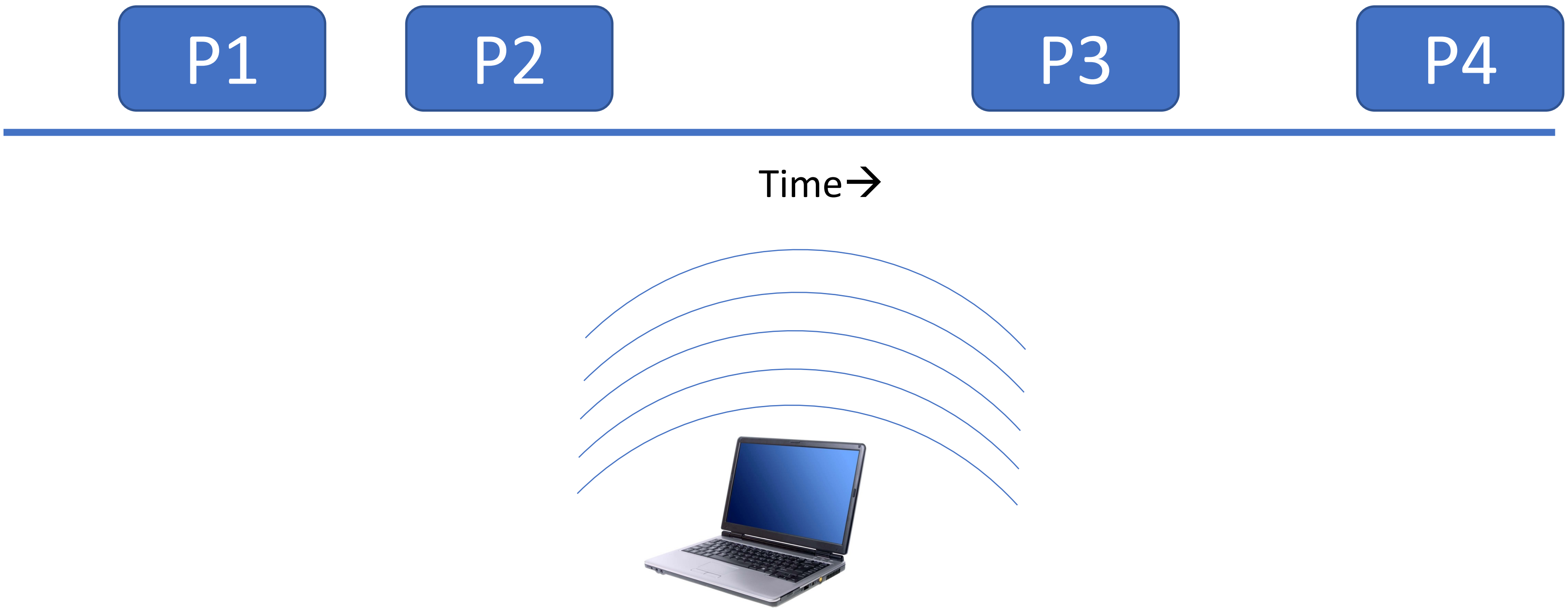
The Model of Communication



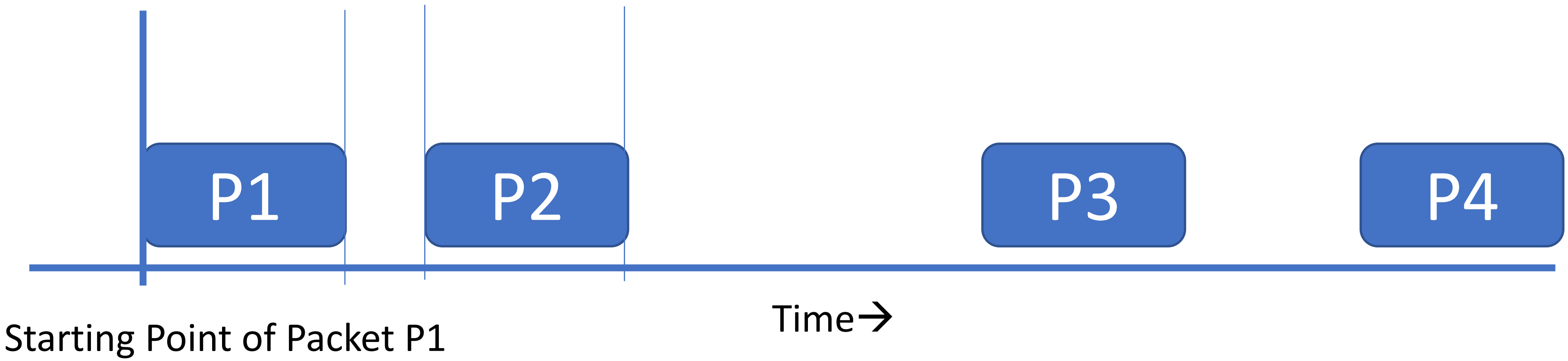
The ALOHA System – Settings

- Information to and from the central server is transmitted in the form of "packets,"
- A single packet will have a fixed length of 80 8-bit characters plus 32 identification and control bits and 32 parity bits
- Each packet will consist of 704 bits and will last for 29 milliseconds
- The random access method employed by THE ALOHA SYSTEM is based on an error detecting code.

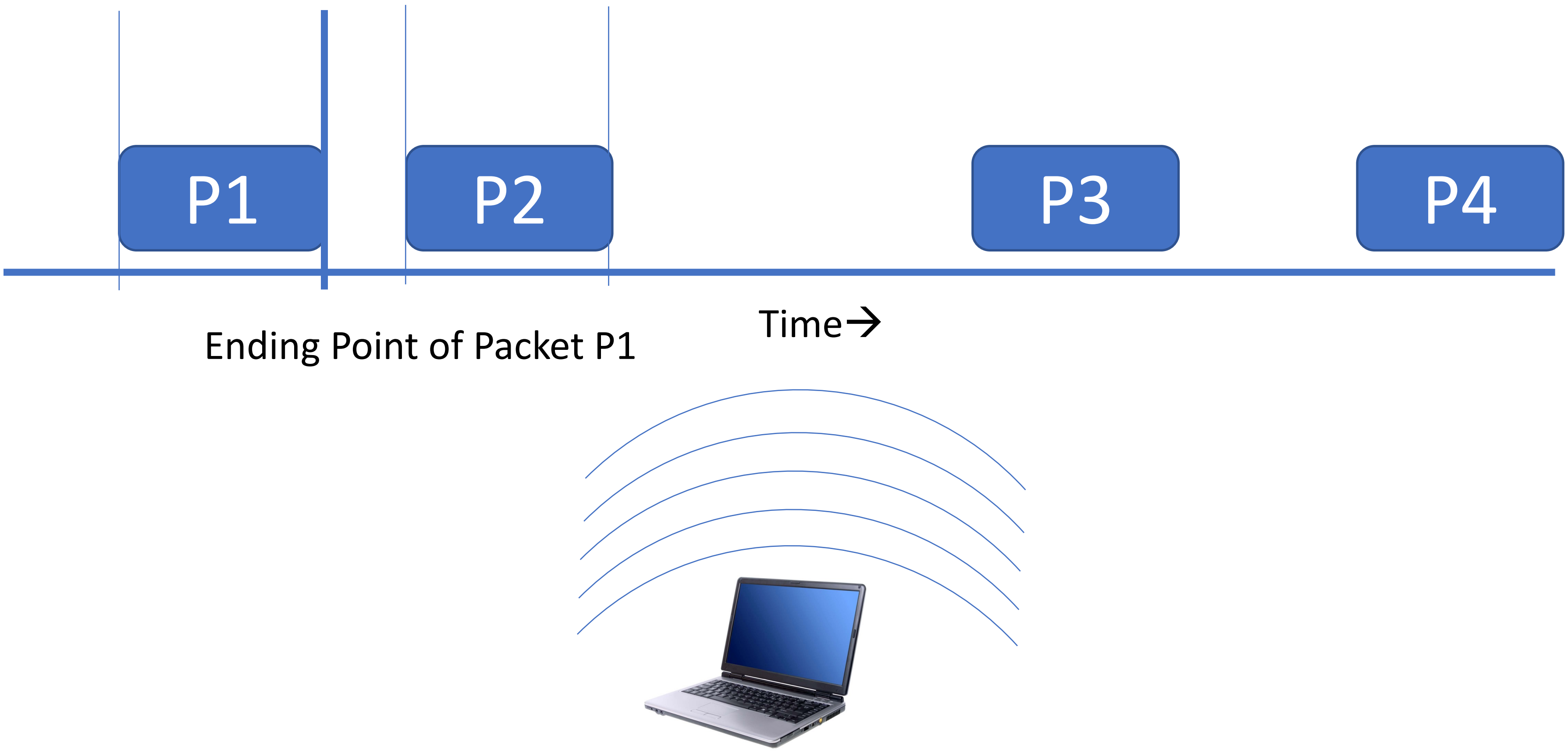
For visualization



For visualization



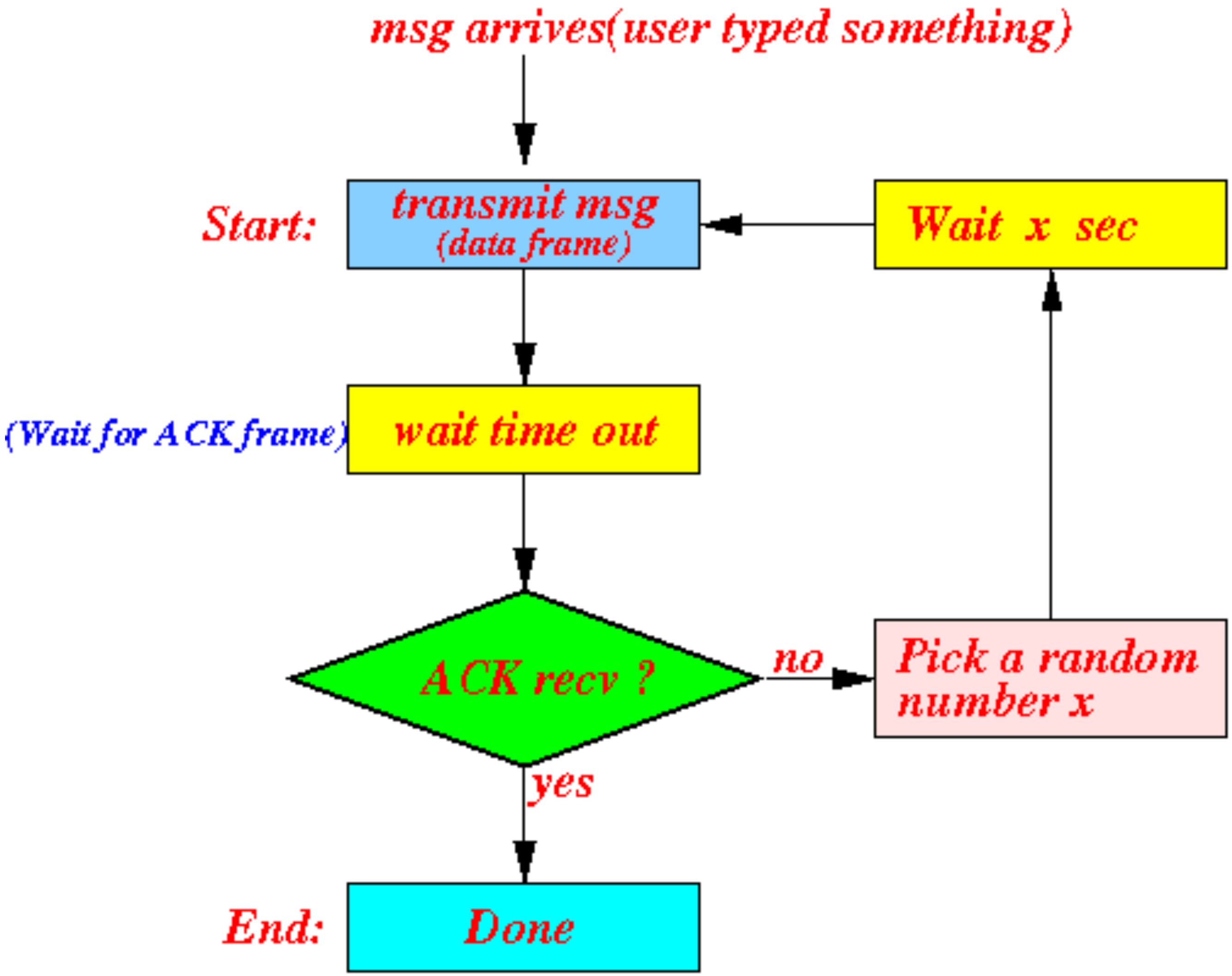
For visualization



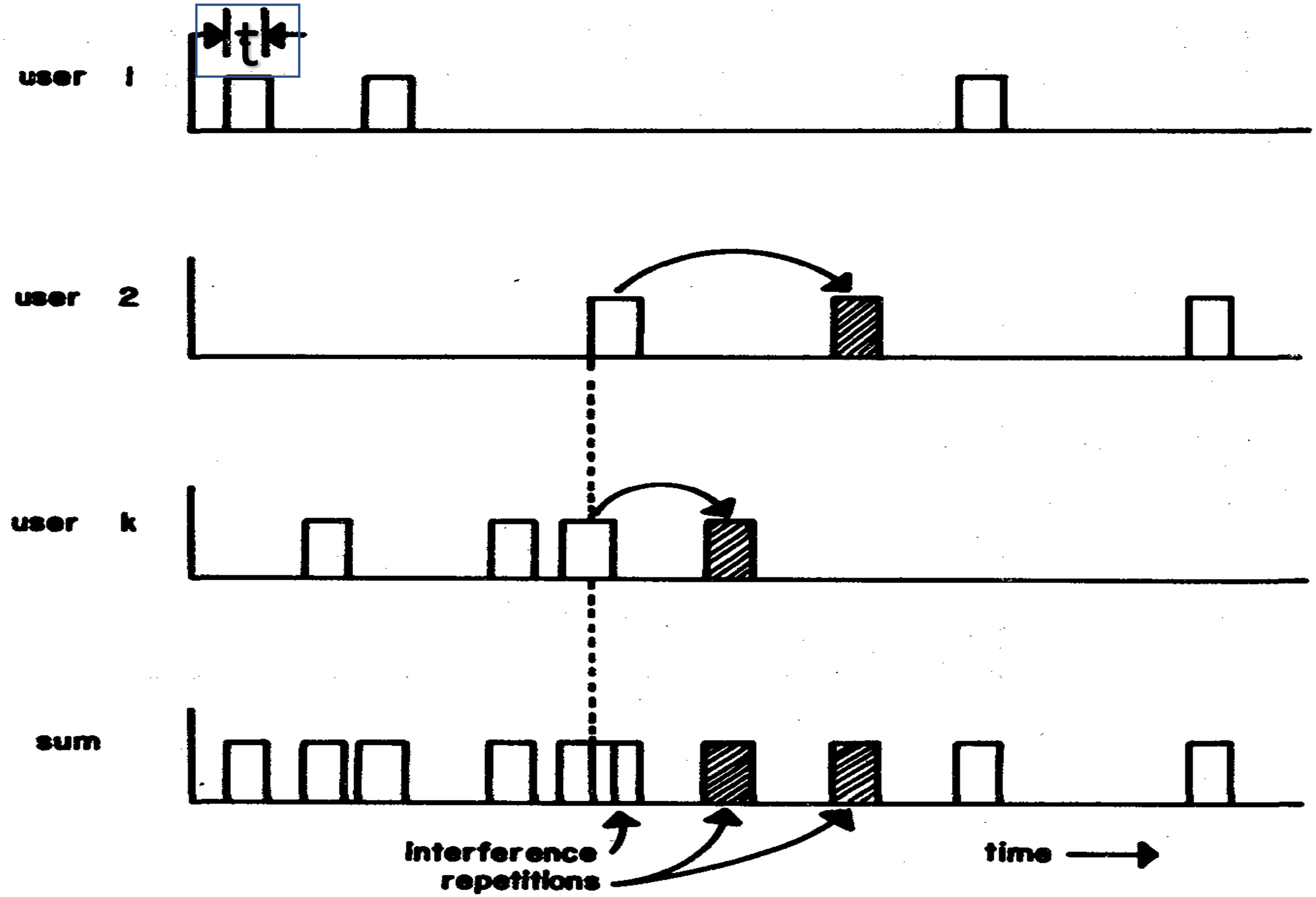
ALOHA - Random Access Protocol

- Each user at a console transmits packets to the **Central System** in a completely unsynchronized manner
- If and only if a packet is **received without error it is acknowledged** by the Central Server
- After transmitting a packet the transmitting **console waits for a given amount of time** for an acknowledgment;
- If none is received the packet is **retransmitted.**
- This process is **repeated until a successful** transmission and acknowledgment occurs or until the process is terminated by the user's console.

Formal description of the **Aloha network protocol**



Example



Possible sources of Error

Possible source of errors –

Random noise errors OR Errors caused by **Interference** with a packet transmitted by another console.

The first type of error is not expected to be a serious problem (compared to the second)

The second type of error, that caused by interference, will be of importance only when a large number of users are trying to use the channel at the same time

Interference errors will limit the number of users and the amount of data which can be transmitted over this random access channel.

ALOHA – What is its Capacity?

- We make the pessimistic assumption
  - When an overlap occurs neither of the packets is received without error – (Received with error)
  - Both packets are therefore retransmitted
- Clearly as the number of active consoles increases –

  The number of interferences and hence the number of re-transmissions increase until the channel clogs up with repeated packets.

- **Question:** What is the average number of active consoles which may be supported by ALOHA?

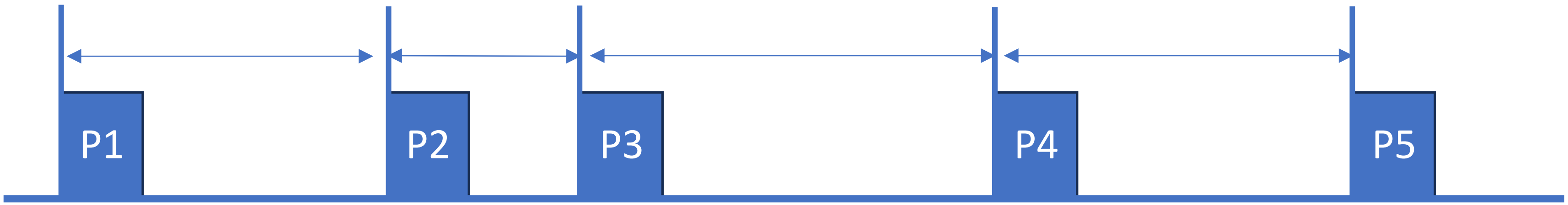
Analysis

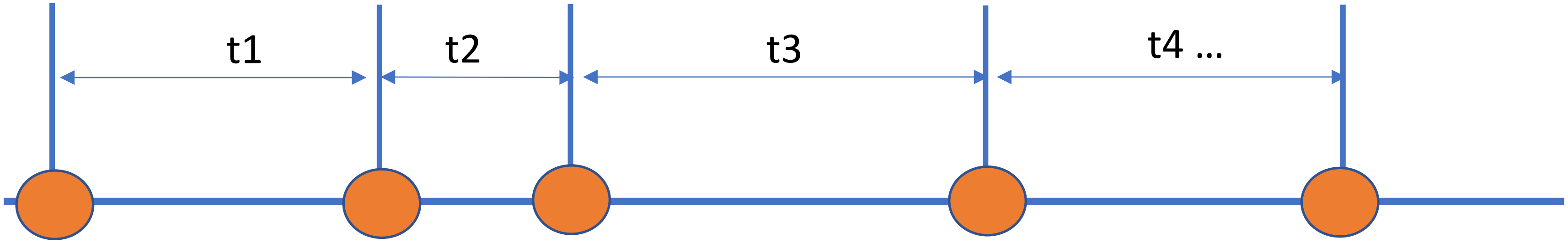
- We define a **Random Point Process** for each of the *k* active users
- Distinguish between two types of packets –
  - Message from a **console** for the first time - ***Message packets***
  - Repetitions of a message - ***Repetitions***

- **Let L be the average rate** (e.g., of a Poisson process) of occurrence of message packets from a single active user and assume this rate is identical from user to user.

- In general the Point Process can be anything and the type of the random process and user to user it may vary – The rate may also vary

The Random Point Process



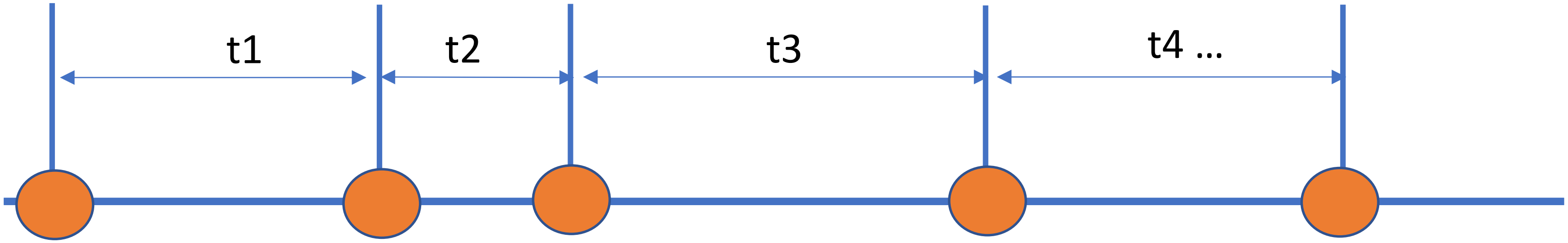


Poisson Distribution / Process

Discrete random variable *X* is said to have a Poisson distribution, with parameter L if it has a probability mass function given by:

$$f(x) = \Pr[\mathbf{X} = x] = (e^{-L} L^x)/x!$$

e, Euler's number 2.71828



Poisson Distribution / Process

- **Poisson Distribution** is a discrete probability distribution that expresses the probability of a given number of events occurring in a fixed interval of time or space if these events occur with a known constant mean rate and independently of the time since the last event

- It is named after French mathematician Siméon Denis Poisson

- The **Poisson** distribution can also be used for the number of events in other specified interval types such as distance, area, or volume.

Poisson Distribution / Process

- **Example – 1:**
- A call-centre receives an average of 180 calls per hour, 24 hours a day.
- The calls are independent: Receiving one does not change the probability of when the next one will arrive.
- **The number of calls received during any minute has a Poisson probability distribution with mean 3:**

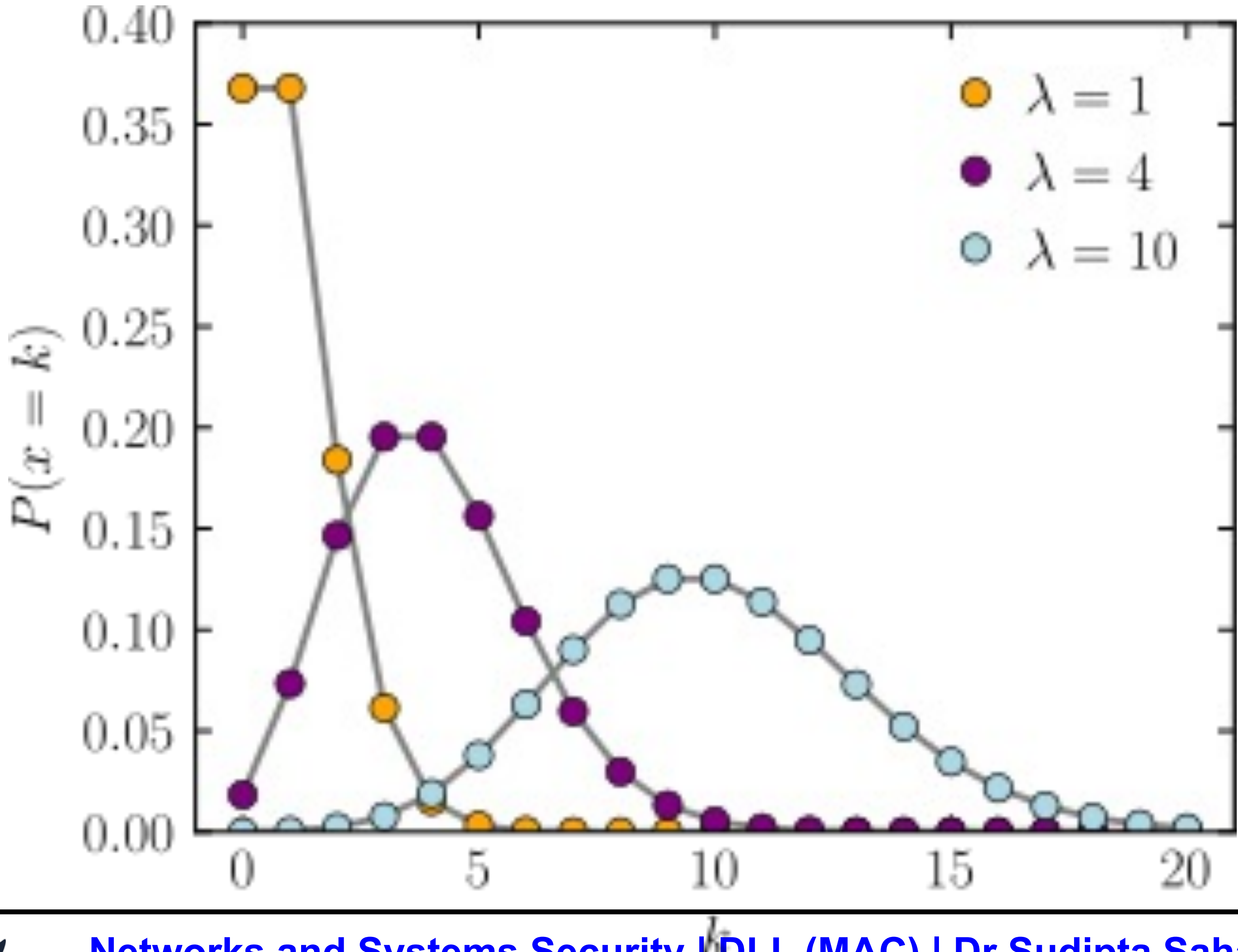
  The most likely numbers are 2 and 3 but 1 and 4 are also likely and there is a small probability of it being as low as zero and a very small probability it could be 10.

Poisson Distribution / Process

- **Example -2:**

- **How many vehicles will cross a specific point over a road within a given interval of time?**

Poisson Distribution



Analysis in the current context …

- Random point process consisting of the starting times of message packets from all the active users has an **Average rate of occurrence** of

r = No of users X Per User Rate = kL

- i.e. - ***r* is the average number of message packets per unit time from the *k* active users.**

- Let **t** be the duration of each packet. [The transmission time of the packets]

- To pack all the channel space with messages perfectly – we need

r.t = 1 **Where r.t is called Channel Utilization**

Analysis

- But intuition is channel utilization can not be that high – There will be a maximum utilization we can achieve – Not beyond that – Because we need to repeat transmissions after collision.

- Questions are –

1) **What is the max value of k for which we get the maximum Channel Utilization ?**
2) **And how much is the utilization?**

- Let us introduce another parameter R as follows –
  - R = (Average number of message packets + Retransmissions) per unit time from all the *k* active users
  - For any retransmissions we will have R > r

Analysis

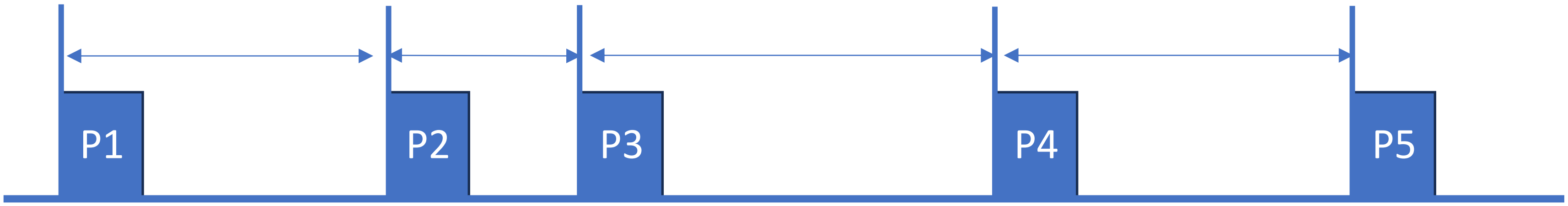
- R.t = **Channel Traffic**

It represents the average number of **message** packets plus **retransmissions** per unit-time multiplied by the duration of each packet or retransmission.

Our target is to calculate R.t as a function of the channel utilization, r.t

Back to the **Random Point Process**

- Inter-arrival times of the point process defined by the start times of all the message packets plus retransmissions are independent and exponential



- This assumption, of course, is only an approximation to the true arrival time distribution

- Under the exponential assumption the probability that there will be **NO EVENT** (i.e. **no start of message packets or retransmission packet**) in a time interval T is

exp(-RT)

Let us try to understand -

- Let us assume that instead of average we are given a rate of events in a Poisson distribution.
- Number of events that occur during a fixed time interval would follow a Poisson distribution.
- The equation needs to be little modified if instead of the average number of events - we are given the average rate at which events occur- e.g. Rt
- [Replace L with R.t]
- Pr [**x number of events in t**] = $(e^{-L} L^x)/x! = [e^{-(Rt)} (Rt)^x]/x!$

Let us try to understand -

- Now put Zero for x
- Pr [**0 number of events in t**] =

$(e^{-L} L^{0})/0! =$

$[e^{-(Rt)} (Rt)^{0}]/0! = e^{-(Rt)} = EXP(-Rt)$

Analysis

- What is the probability that a given message packet or retransmission will need to be retransmitted because of interference with another message packet or retransmission.

  - The first packet will overlap with another packet if there exists at least one other start point T or less seconds before or T or less seconds after the start of the given packet. [Concept of **safe-period**]

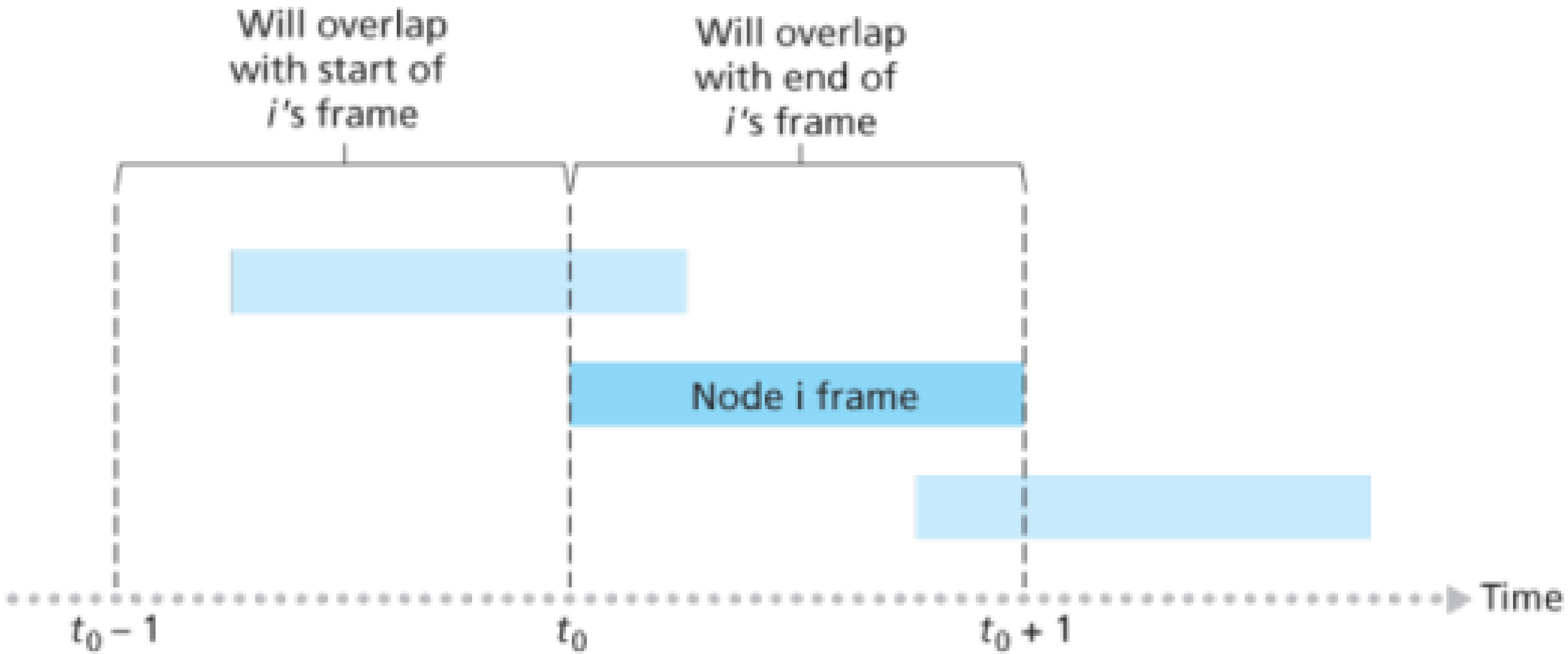
  - Hence the probability that a given message packet or retransmission will be repeated is

$$1- \exp(-2tR)$$

Understanding through an Example

Chance that at least one another node will start transmission in 2t = 1- EXP(-**2**tR)

Where from this 2 comes?



Understanding through an Example

The probability that there is no packet transmission starting in interval **t** is EXP(-tR)

The probability that there is no packet transmission starting by in interval **2t** is EXP(-**2**tR)

The chance that the transmission is going to get repeated = The chance that at least two or more nodes will transmit together in the interval 2t

= 1 - EXP(-2tR)

Relating Channel Traffic and Utilization

- **Our Aim is to relate *R with r***

- Average number of retransmissions per unit time is given by = **Rate of retransmissions = Rate of total transmission X chance of Retransmission**

  i.e., $R[1 - EXP(-2.R.t)]$

  Thus we can relate in the following way –

- Rate of all transmissions = Rate of message transmission + **Rate of retransmissions**
- $R = r + R[1 - EXP(-2.R.t)]$

Channel Utilization VS Traffic

- $R = r + R[1 – \exp(- 2.R.t)]$

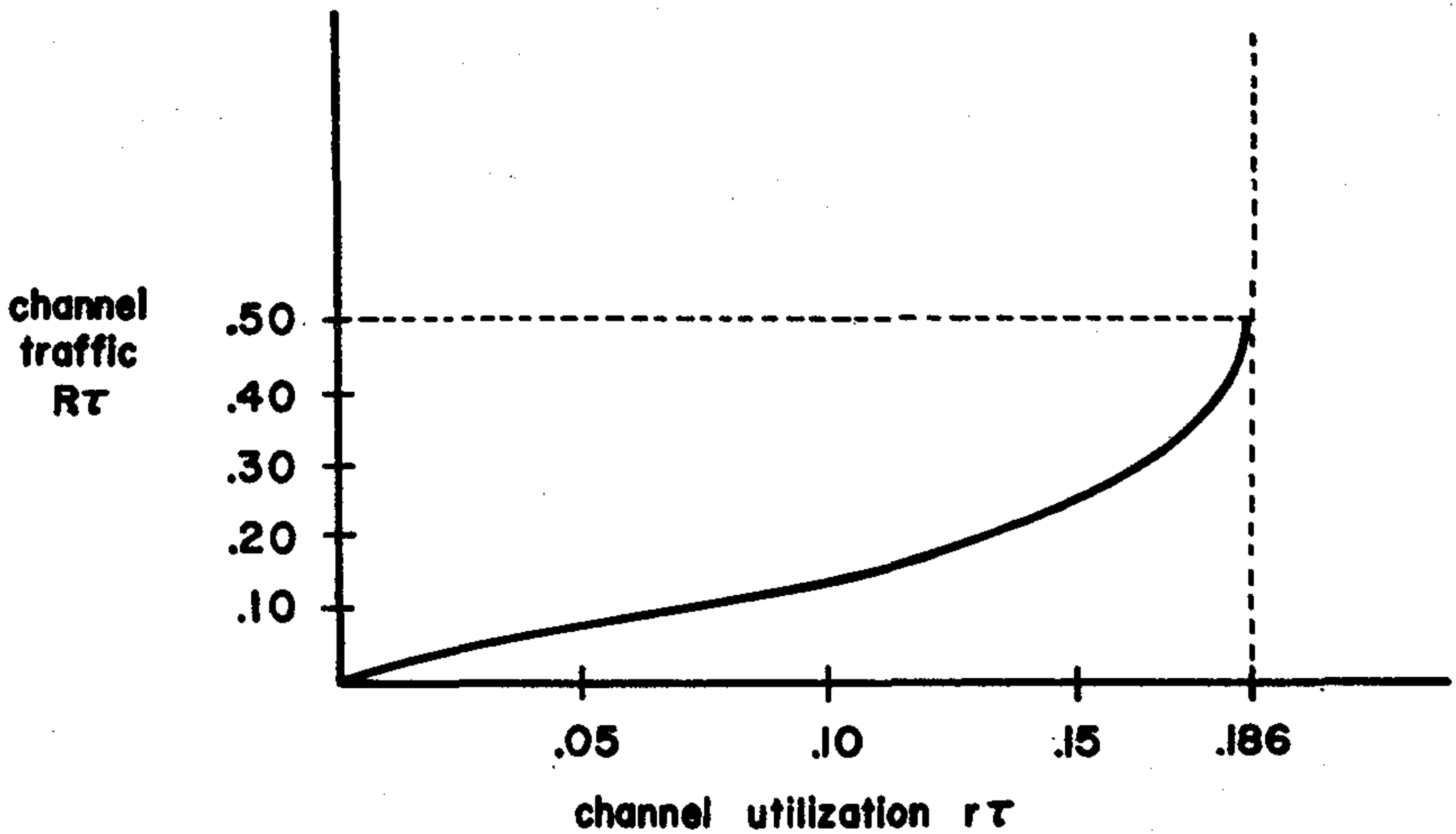
- Can be simplified to –

$$r = R.Exp(-2Rt)$$

$$OR,\ r.t = R.t\ .\ EXP\ (-2R.t)$$

Channel Utilization =
Channel Traffic X EXP (-2Rt)

Channel Utilization VS Traffic



Channel Utilization VS Traffic

Take derivative with respect to R and get the maxima -

Channel Utilization reaches a maximum value of 1/2e =0.186

For this value of R.t, *i.e.,* the channel traffic is equal to 0.5

The traffic on the channel becomes unstable at r.t = 1/2e and the average number of retransmissions becomes unbounded.

Channel utilization is actually the *capacity* of this random access data channel.

Channel Utilization VS Traffic

In ALOHA Channel capacity is reduced to roughly one sixth of its value if we were able to fill the channel with a continuous stream of uninterrupted data -

Who is responsible for this ?

Random Access Mechanism in ALOHA

Channel Utilization VS Traffic

- **For THE ALOHA SYSTEM** we may use this result to calculate the maximum number of interactive users the system can support.

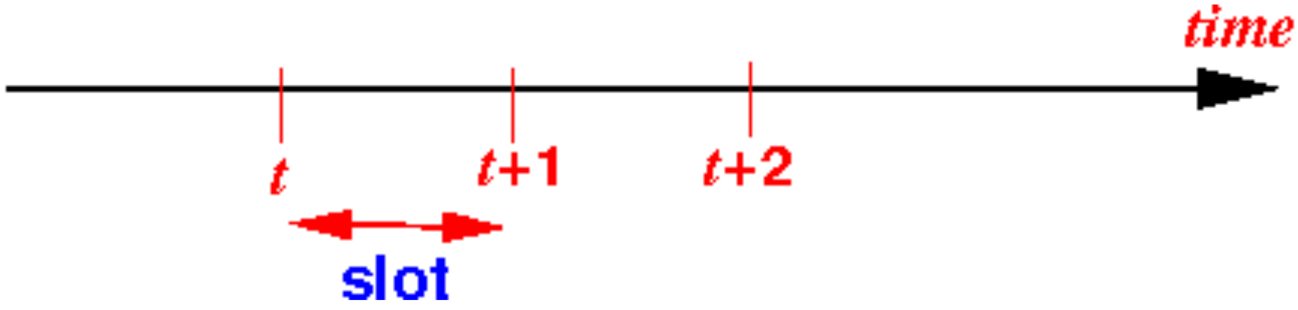
- Let **$r.t = k.\ L.\ t = 1 / 2e$**

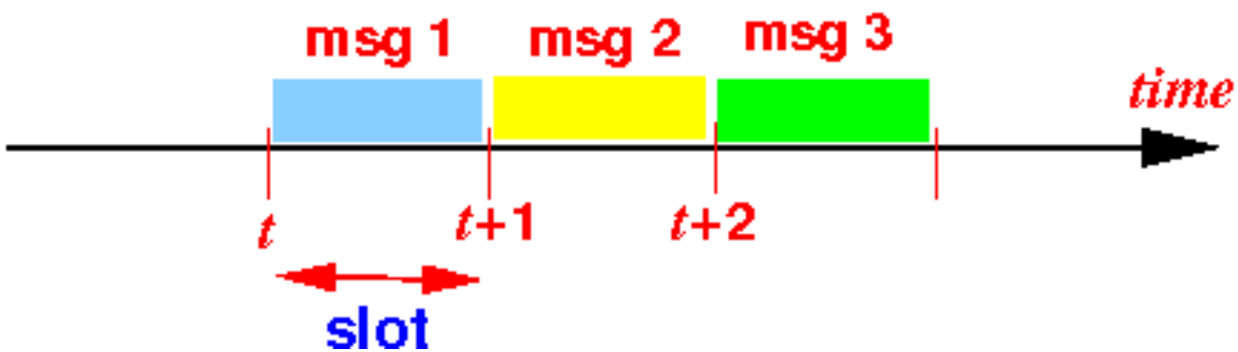
- $K_{max} = 1/(2eLt)$

- A conservative estimate of L would be 1/[60 (seconds)],
- This corresponds to → Each active user sending a message packet at an average rate of one in every 60 seconds.
- With t equal to 34 milliseconds we get Kmax = 324.

Slotted and *unslotted* transmissions

- **Slot** (time slot) = the **transmission time** is **divided** into *fixed* **size "slots"**

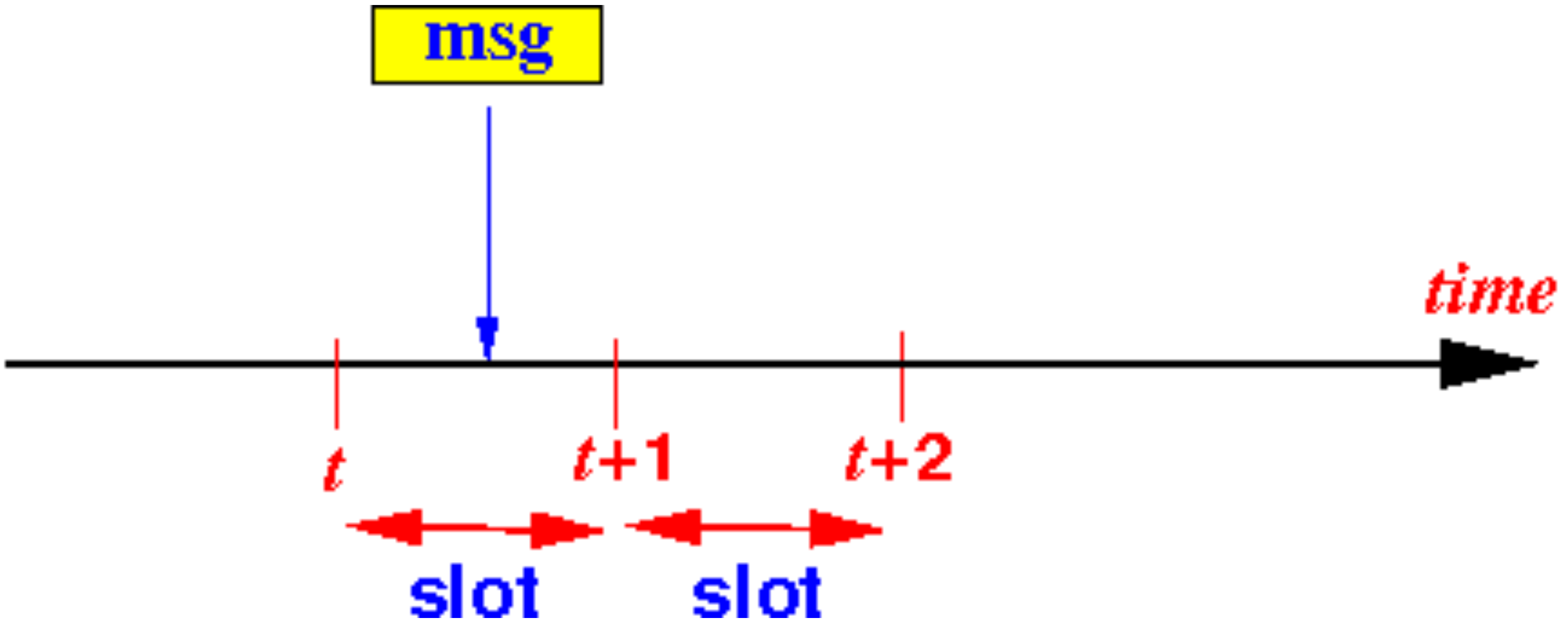


- A **transmission** can *only* start at the **begin** of a **slot**:
- 

Unslotted **transmission**:

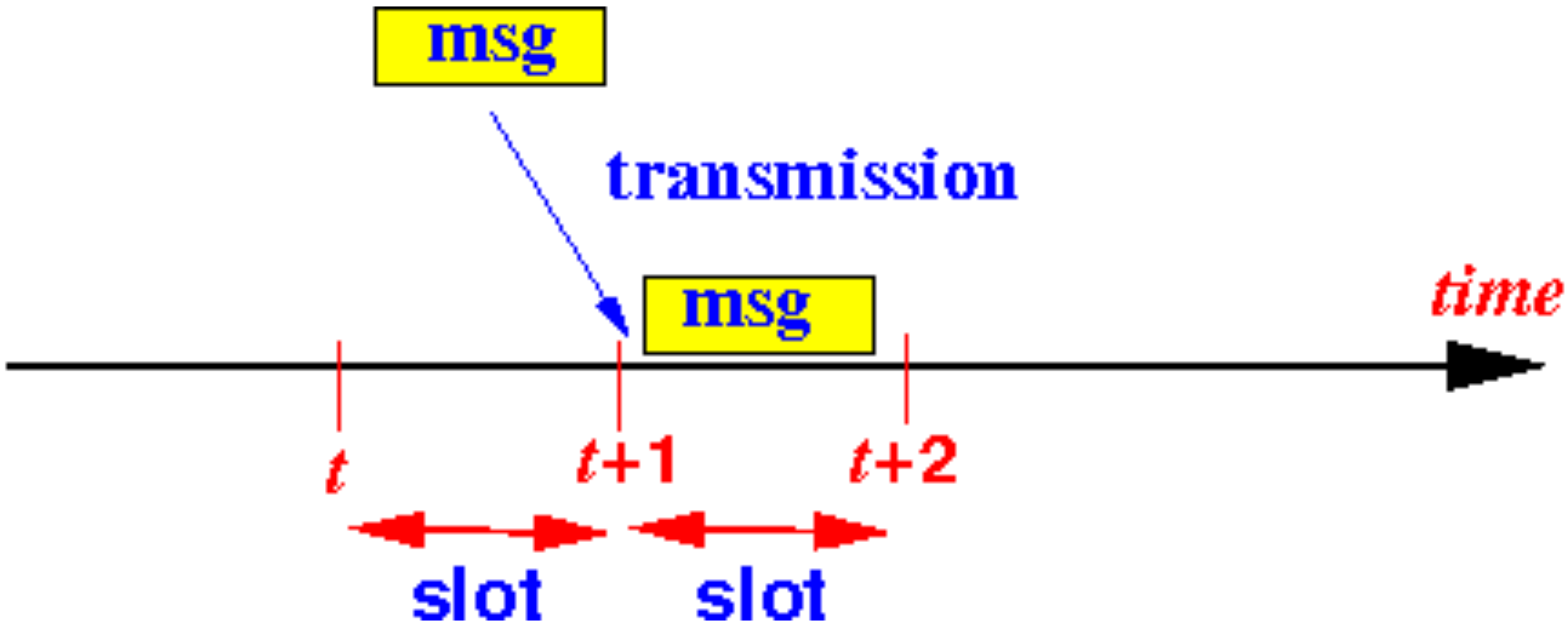
- In ***unslotted*** **transmission**,
  a **transmission** can **start** at ***any*** **moment**:
-

Slotted and unslotted transmission protocols

- A **message** that **arrives** during some **slot** ***t***:
- 

Deferred little bit in slotted transmission

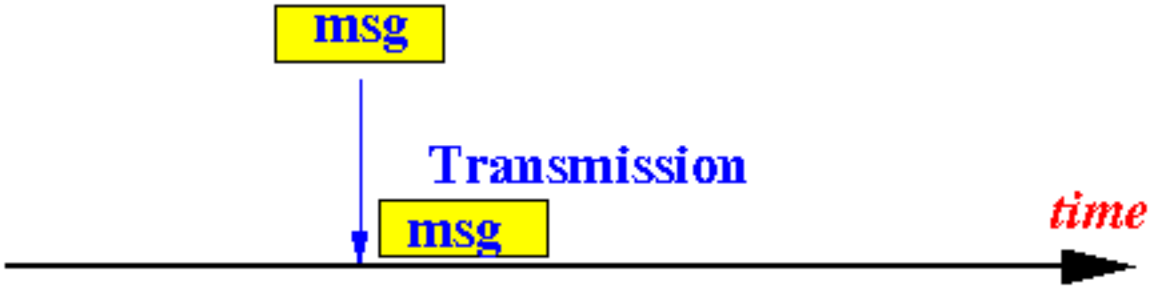
- will be **transmitted** in the **slot** ***t*+1**:
-



Unslotted *transmissions*: Immediate

- A **message** that **arrives**:

- Will be **transmitted** in the *same* **time** as its **arrival moment**:
-



Slotted and Unslotted versions of ALOHA

•**Slotted Aloha** = the **Aloha network protocol** that **uses *slotted* transmissions**

•

•**Unslotted Aloha** = the **Aloha network protocol** that **uses *unslotted* transmissions**

Slotted Aloha

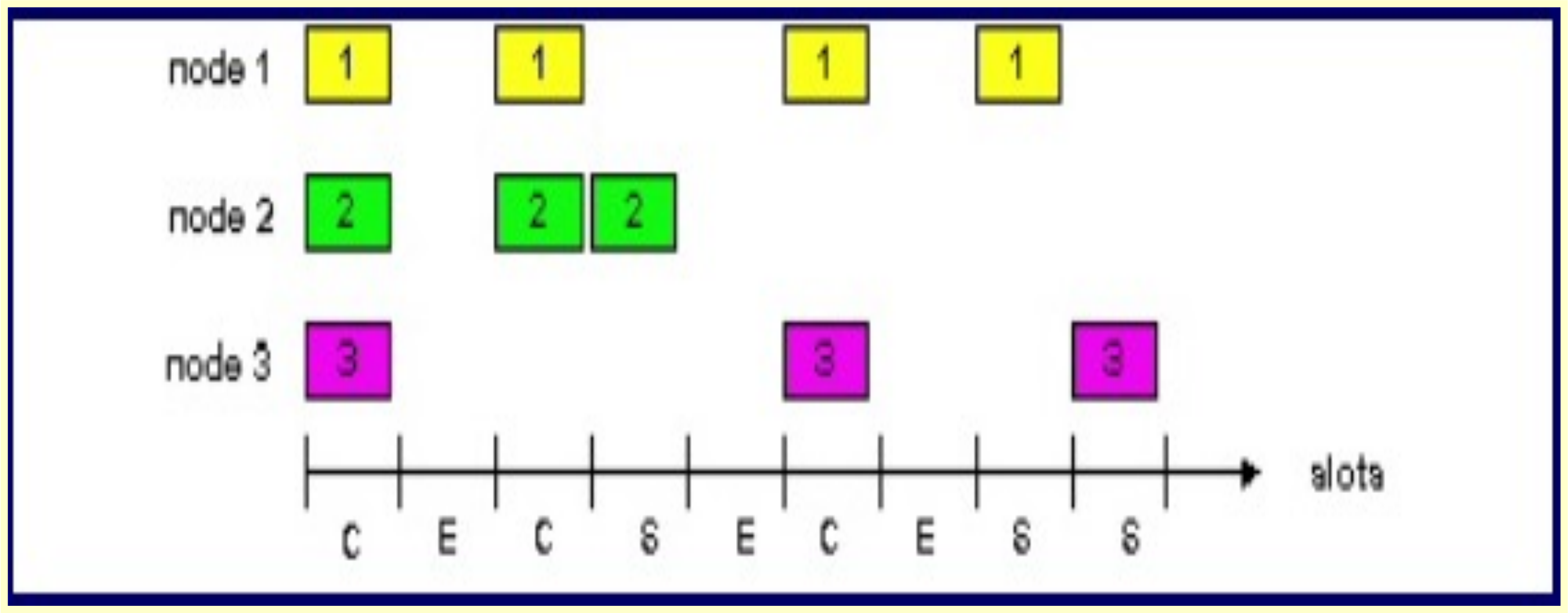
- Time is divided into equal size slots
- (Size of each slot is same as pkt trans. time)

- Node with new Packet: Transmit at beginning of next slot

- If Collision: Retransmit pkt in future slots with probability **p**, until successful.

Slotted Aloha

C = Collision, E = Empty, S = Success



Requirement for slotted Aloha

- The nodes need to remain **Time-Synchronized with each other**

- Difficult but not impossible

- Shall we gain more than Unslotted Aloha ?

Can we use our older analysis framework too ?

The probability that there is no packet transmission starting in interval **t** is EXP(-tR) –

We can use this quantity directly for our study -

<u>Under slotted ALOHA :</u>

The chance that the transmission is going to get repeated = The chance that at least two or more nodes will transmit together in the interval t

= 1 - EXP(-tR)

Can we use our analysis framework?

- $R = r + R[1 – \exp(-R.t)]$

- Can be simplified to –

$$r = R.Exp(-Rt)$$

$$\text{OR, } r.t = R.t \;.\; EXP(-R.t)$$

Channel Utilization =
Channel Traffic X EXP (-Rt)

Utilization

Take derivative with respect to R and get the maxima -

Channel Utilization reaches a maximum

value of 1/e =0.37

For this value of r.t the channel traffic is equal to 0.5

The traffic on the channel becomes unstable at r.t = 1/e and the average number of retransmissions becomes unbounded.

Analysis of Slotted Aloha

A simpler approach -

P{Any node has a packet to transmit in a slot} = p

What is the probability that the packet will go correctly ?

If no other node transmits at that slot …. (1-p)

The same for N-1 nodes = P{no packet to transmit}
i.e., Chance that none of the N – 1 nodes transmit

Analysis of Slotted Aloha

P{none of the other guys should transmit} =

$= p \times (1 - p) \times (1 - p) \ldots. = p\,(1 - p)^{N-1}$

= Probability for no collision

So, Success Probability = S = $p(1-p)^{N-1}$

For N users total success = N.S = Throughput

Analysis of Slotted Aloha

What will maximize the throughput ?

What is the max value of p ?

S’ = 0 {i.e., set the derivative w.r.t. p to zero }

$\frac{d}{dp}$ [$Np(1-p)^{N-1}$] = 0, [p = 1/N]

Derivation details -

$d/dp \ [Np\,(1-p)^{N-1}] = 0$

OR, $N\,(1.(1-p)^{N-1} + p(N-1)(1-p)^{N-2}(-1)) = 0$

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

OR, $(1-p) = p(N-1)$

OR, $N-1 = (1 - p) / p$

OR, $N = (1-p)/p + 1$, $N = 1 / p$; **$p = 1/N$**

Analysis of Slotted Aloha

Put the value of p back to [Np (1-p) $^{N-1}$]

Max throughput = $Np(1-p)^{N-1}$

$= N \,.\, 1/N \,.\, (1-1/N)^{N-1}$

$= (1 - 1/N)^{N-1}$

When N is infinity …. ?

Analysis of Slotted Aloha

When N is infinity …. ?

Max throughput =

$= (1 – 1/N)^{N-1} = 1/e =$ **37% = .37**

Some central server is necessary for

Time-Synchronization -- **Overhead**

Analyze unslotted Aloha …

A different way of analyzing the unslotted Aloha

P(success by given node) = P(node transmits) $\cdot$

P(no other node transmits in $[t_0\text{-}1,t_0]$ $\cdot$

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

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

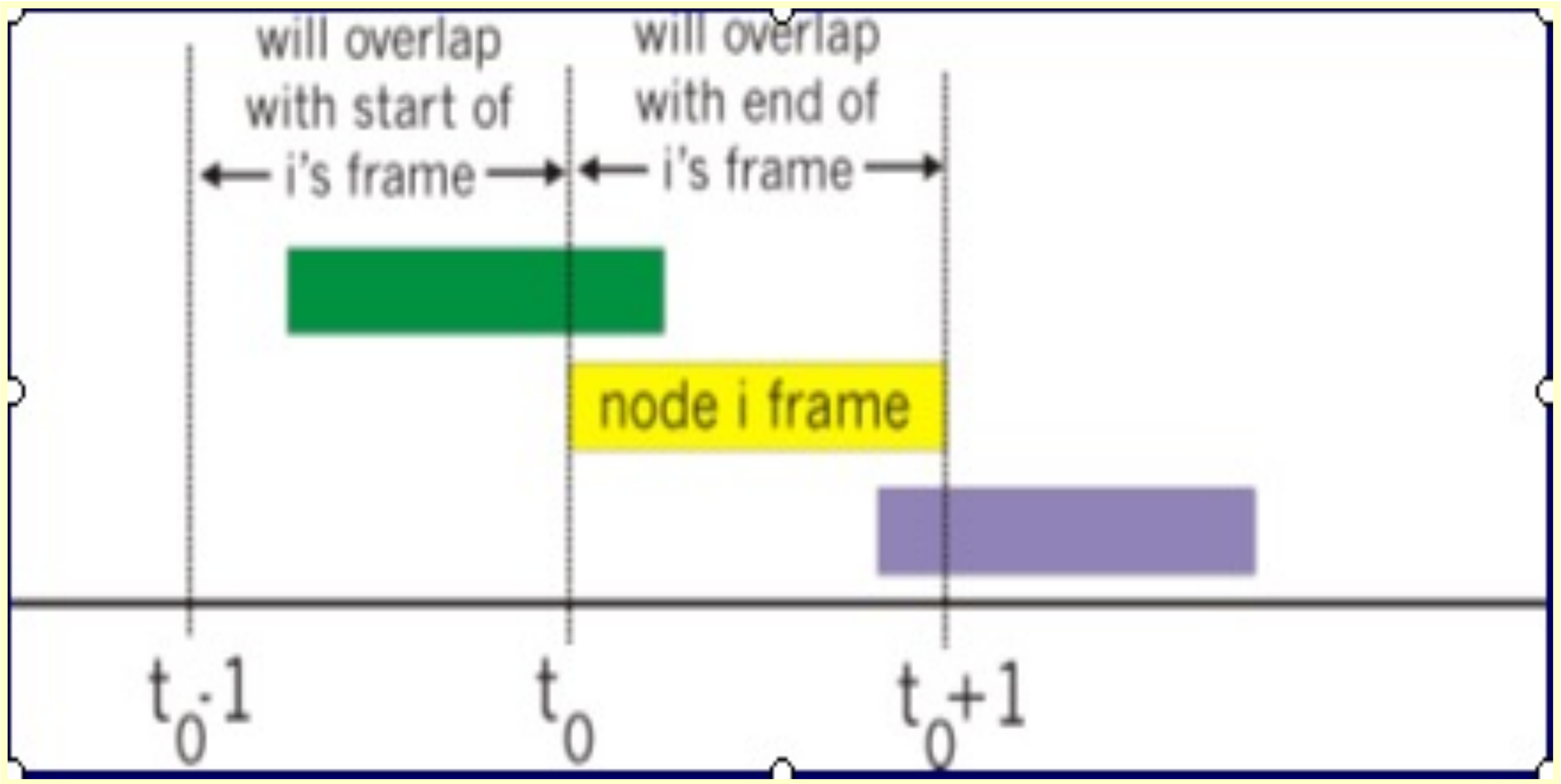
P(success by any of N nodes) = $N\, p \cdot (1\text{-}p)^{(N\text{-}1)} \cdot$

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

… choosing optimum p as n -> infinity ...

$= 1/(2e) = .18$

Analyze unslotted Aloha …

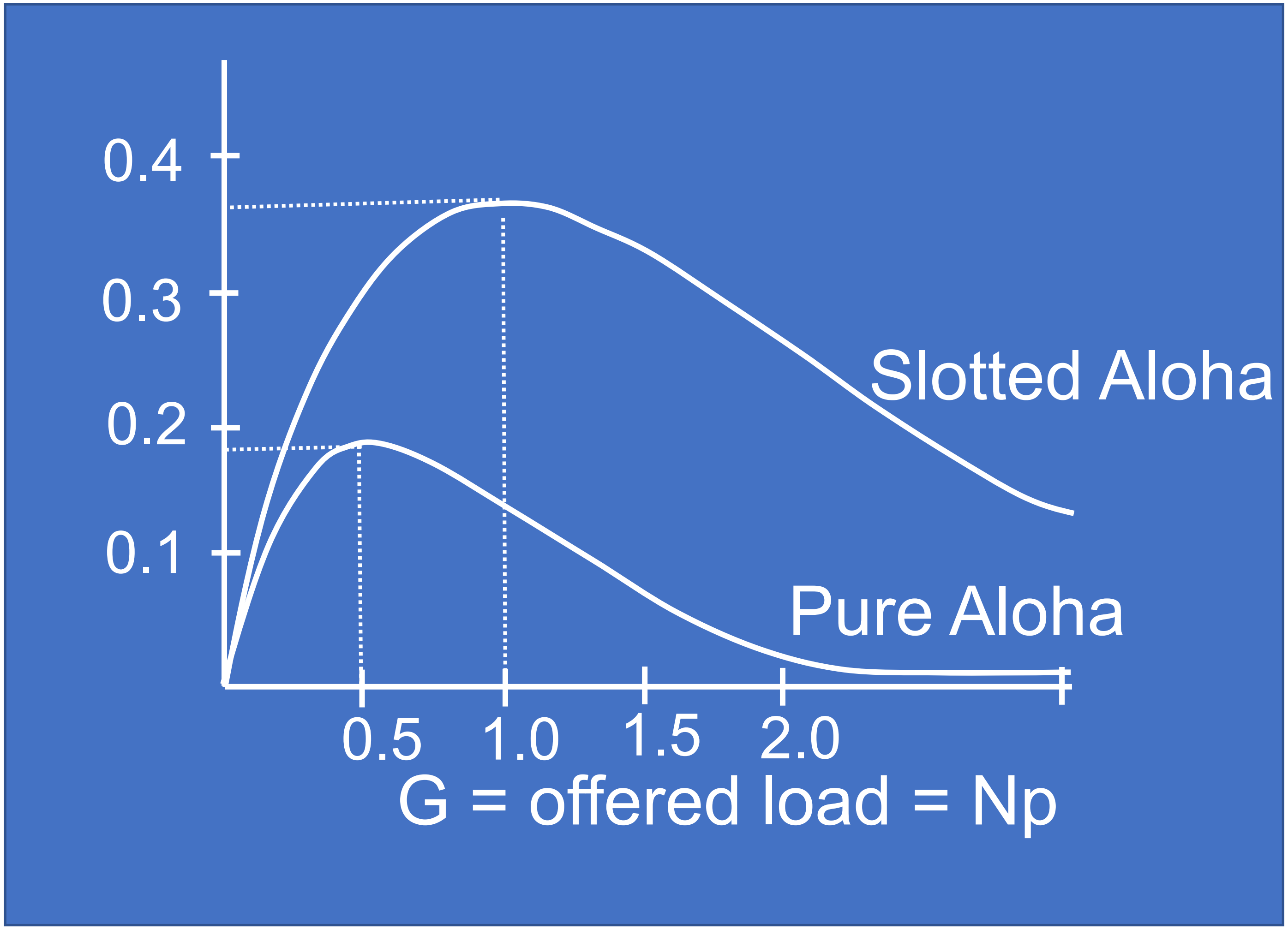


Comparing Slotted and Unslotted

- Slotted -
  - useful transmissions 37% of time!

- Unslotted –
  - useful transmissions 18% of time!

Performance Comparison



Slotted Aloha

<u>Q:</u> What is max fraction slots successful?

<u>A:</u> Suppose N stations have packets to send

- each transmits in slot with probability *p*
- prob. successful transmission *S* is:

by single node: $S = p\,(1-p)^{(N-1)}$

by any of N nodes

S = Prob (only one transmits)

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

… choosing optimum p as n -> infty ...

= 1/e = .37 as N -> infty

Sample Problems

Consider two devices, A and B, that use the slotted ALOHA protocol to contend for a channel. Suppose device A has more data to transmit than device B, and device A's transmission probability *pA* is greater than device B's transmission probability, *pB*.

1. Provide a formula for device A's average throughput. What is the total efficiency of the protocol with these two devices?
2. If pA=2pB, is device A's average throughput twice as large as that of device B?

   Why or why not?

   If not, how can you choose *pA* and *pB* to make that happen?

3. In general, suppose there are *N* devices, among which device A has transmission probability *2p* and all other devices have transmission probability *p*. Provide expressions to compute the average throughputs of device A and of any other device.

Solution

A's average throughput is

Transmission Probability of A

X (1- Transmission Probability of B) = $pA (1 – pB)$

Total Efficiency = A gets success or B gets success

$= pA(1-pB) + pB(1-pA)$

Solution

A's throughput = $pA(1-pB) = 2pB - 2pBpB$

B's throughput = $pB(1-pA) = pB - 2pBpB$

A's throughput is 2 times as large as B's throughput

Solution

To make the desired effect

$pA.(1-pB) = 2pB (1 – pA)$

We need $pA = 2 – pA/pB$

Solution

Provided all devices have transmission probability as p and A has 2p . There are total N devices

A's throughput = $2p(1-p)^{N-1}$

Any other node has throughput =

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

Sample Questions

Suppose four active devices A, B, C and D—are competing for access to a channel using slotted ALOHA.

Assume each device has an infinite number of packets to send. Each device attempts to transmit in each slot with probability *p*.

The first slot is numbered slot 1, the second slot is numbered slot 2, and so on.

A) What is the probability that device A succeeds for the first time in slot 5?

B) What is the probability that some device (either A, B, C or D) succeeds in slot 4?

C) What is the probability that the first success occurs in slot 3?
D) What is the efficiency of this four-node system?

Solution

Try yourself …