Multiple Access (3)

Required reading:
Forouzan 12.2, 12.3
Garcia 6.3, 6.4.1, 6.4.2

CSE 3213, Fall 2015
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Medium Sharing Techniques

Static Channelization

- FDMA
- TDMA

Dynamic Medium Access Control

Scheduling

Attempt to produce an orderly access to transmission medium.

- **Reservation**
- Polling
- Token Passing

Random Access

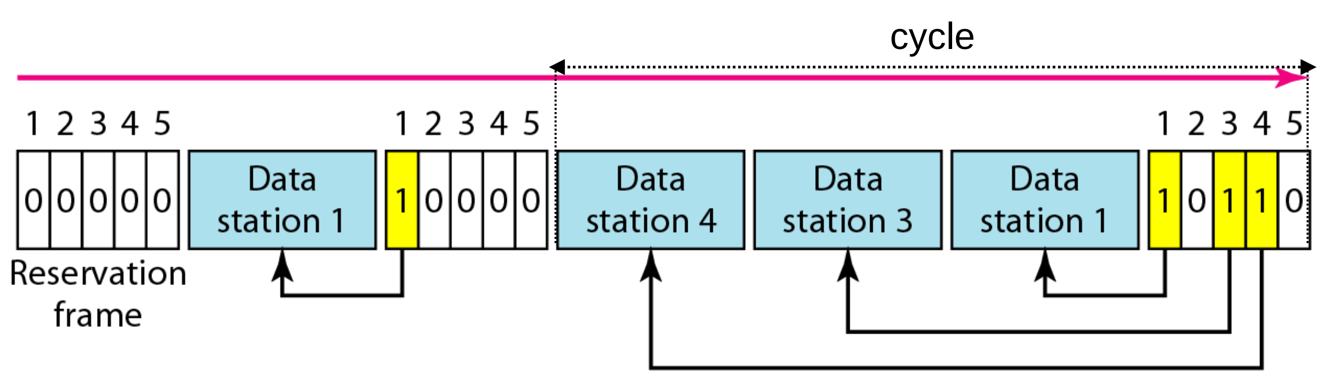
- ALOHA
- CSMA

- relatively simple to implement and under light load provide low-delay transfer ☺
- randomness in access can limit the max achievable throughput and can result in large variability in frame delays ☹

Reservation Systems

Reservation Systems – stations take turns transmitting a single frame at the full rate R [bps]

- transmission is organized into cycles
- cycle = reservation interval + frame transmissions
- reservation interval has a minislot for each station
  - stations announce their intention to transmit a frame by broadcasting ‘reservation bit’ during appropriate minislot
- length of cycle corresponds to number of stations that have a frame to transmit!



The reservation scheme generalizes and improves on the TDMA scheme, by taking slots that would have gone idle and making them available to other stations.

Reservation Systems (cont.)

Efficiency of Reservation Systems

– assume frame transmission times = X [sec], and minislot transmission times = v*X [sec], where 0<v<1

- effective frame transmission time:

$$\text{effective } t_{frame} = X + v \cdot X = (1+v) \cdot X$$

- efficiency under full load, i.e. all stations are transmitting:

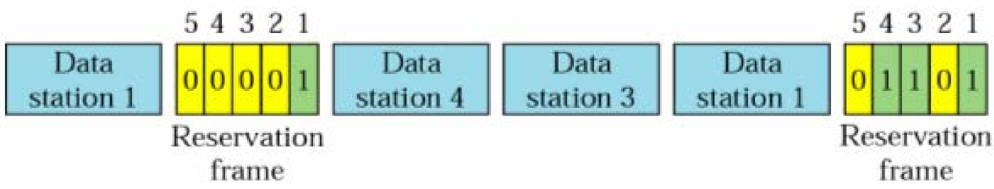
$$\text{efficiency} = \frac{\text{time to send useful bits}}{\text{overall time to send bits}} = \frac{MX}{MX + MvX} = \frac{1}{1+v}$$

If $v \to 0$ then $R \to 1$

- throughput in case of k-frame reservation – one minislot can reserve up to k frames

$$\text{efficiency} = \frac{kMX}{kMX + MvX} = \frac{1}{1 + v/k}$$

If k>> then $R \to 1$



Reservation Systems (cont.)

When to Use Reservation Scheme

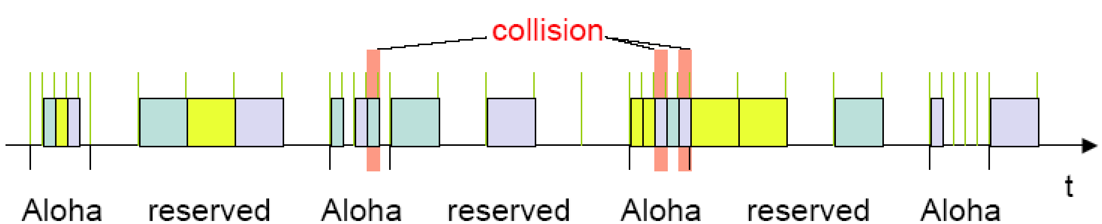
– if most stations, most of the time, have large volumes of data to send

- as k >>, overhead becomes insignificant

When NOT to Use Reservation Scheme

1) if large number of stations transmit data infrequently
   - dedicating a minislot for each station is inefficient
   - solution: use fewer minislots to reduce overhead, make stations content for minislots using slotted ALOHA
     - drawback: low efficiency under heavy traffic load

2) if propagation delay is not negligible
   - slots go unused, or collisions occur, because reservations cannot take effect quickly enough



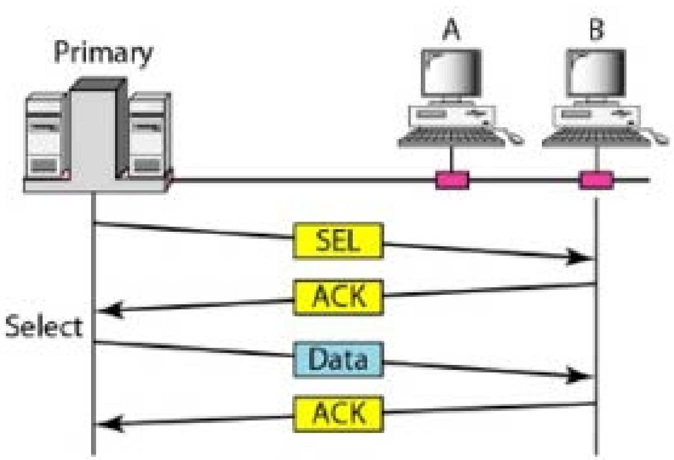
Medium Sharing Techniques

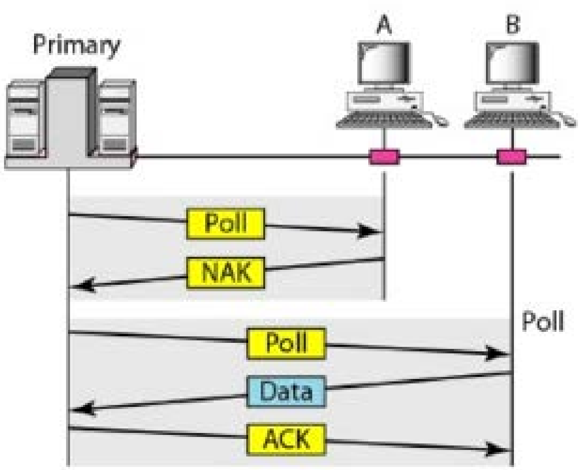
- **Static Channelization**
  - FDMA
  - TDMA
- **Dynamic Medium Access Control**
  - **Scheduling**
    - Reservation
    - **Polling**
    - Token Passing
  - **Random Access**
    - ALOHA
    - CSMA

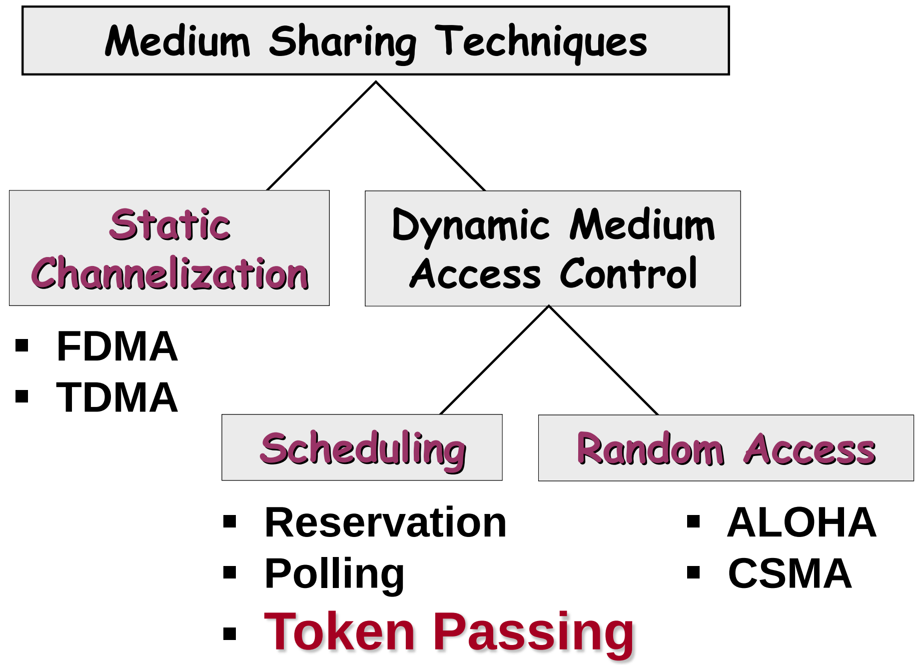
Polling Systems

Polling Systems – one device is designated as a **primary station** (master) and other devices are **secondary stations** (slaves)

- primary device controls the link and coordinates slaves' transmissions to avoid collision
- secondary devices follow master's instructions
- all data exchanges must be made through the primary device even when the ultimate destination is the secondary device
- if master has something to send to a slave **SEL (select) function** is used, which insures that the right slave is 'up' and listening
- **POLL function** is used by the master to solicit transmissions from slave devices







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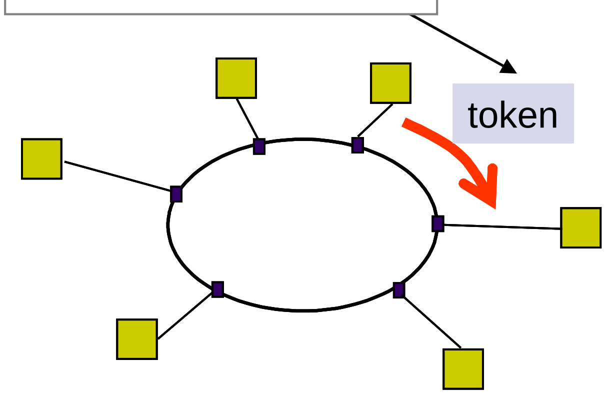
Token-Passing Systems

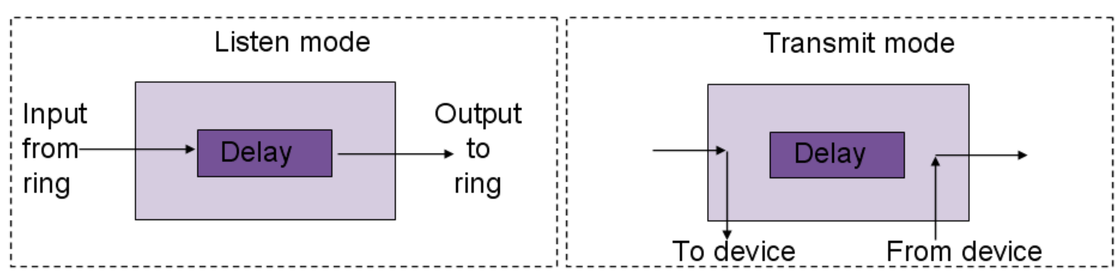
Token-Passing Systems – '**decentralized / distributed polling**' **system – stations are arranged in a ring-shaped network**

- **a permit for frame transmission (token) is passed from station to station**
- **when not transmitting, each station's interface acts like a repeater – it reproduces each bit from its input to its output**
- **when free token is received and station has data to send, the interface changes token to 'busy' and enters transmit mode**
- **once transmission is over, token is changed back to 'free'**
- **Token Holding Time – upper limit on how long a station can hold token** **(i.e. determines how much data the station can send at once)**

token = frame delimiter – can appear at the beginning/end of regular data frame

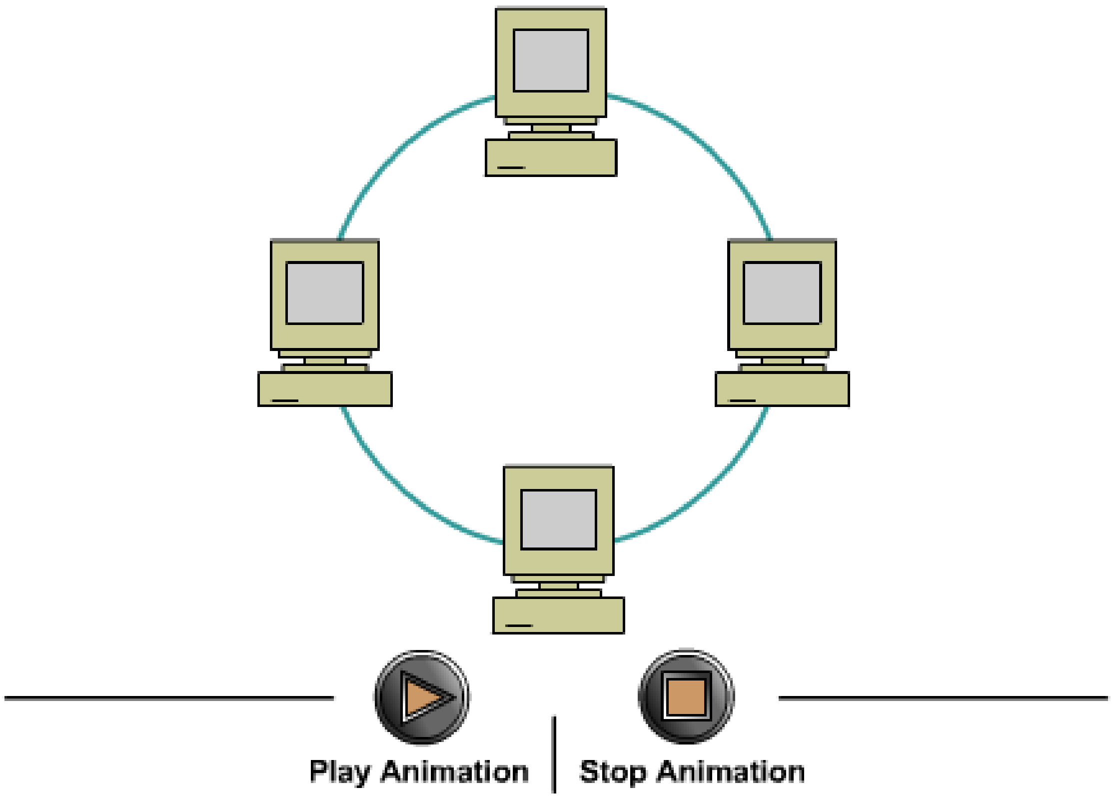
Free = 01111110
Busy = 01111111





Token-Passing Systems (cont.)

Example **[Token Ring Applet]**



http://www.webclasses.net/demo/intro/5.2/sp/units/unit4_sec6.html

Token-Passing Systems (cont.)

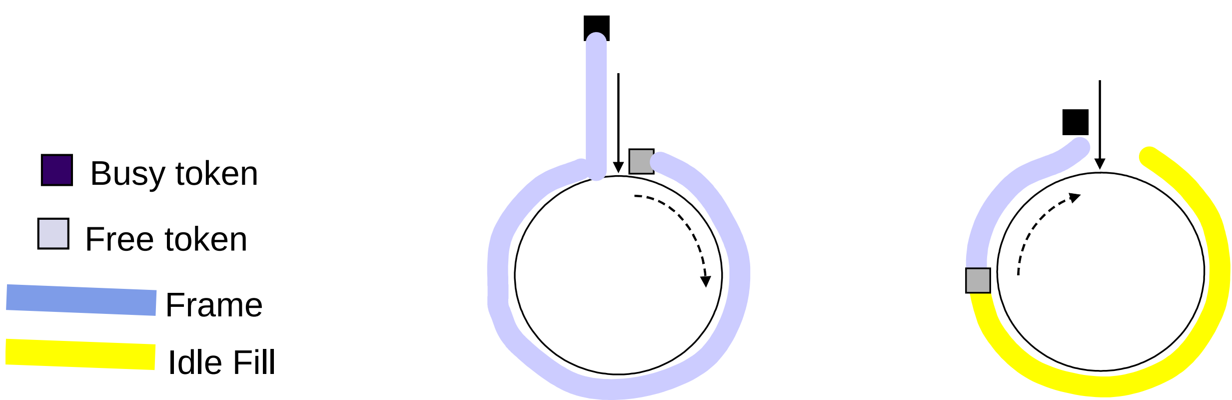
Frame Removal – **each frame placed on the ring eventually must be removed; approaches to frame removal:**

(a) destination station removes the frame

(b) frame travels back to transmit. station which, then, removes the frame (preferred – indirect form of acknowledgment)

Ring Latency – **# of bits that can be simultaneously in transit around the ring**

- **frame size > ring latency ⇒ bits arriving back to the station correspond to the same frame that the station is transmitting**
- **frame size < ring latency ⇒ more than one frame may be present in the ring at any given time**



Token-Passing Systems (cont.)

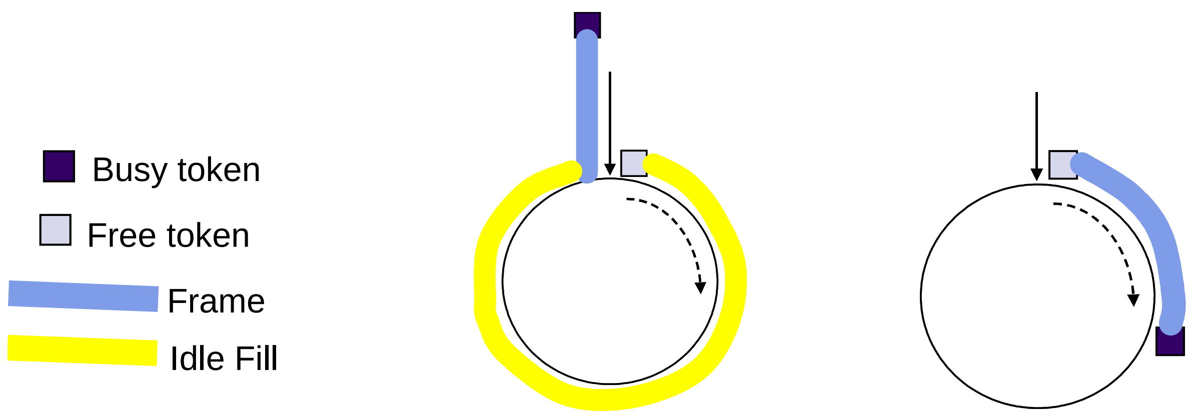
Approaches to Token Release

(1) Delayed Token Release – aka Single-Frame Operation – insert 'free' token after return of entire frame

- **simplified ACK process – destination node signals correct reception by appending an ACK to the end of frame**
- **used in slower networks!** **(frame size ≈ ring latency)**

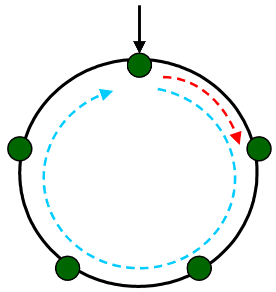
(2) Early Token Release – aka Multitoken Operation – insert 'free' token right after completion of frame transmission

- **time required to pass a free token minimized**
- **if frame size << ring latency ⇒ several frames can be in transit at the same time, in different parts of the network ⇒ considerably higher throughput**
- **used in faster networks!** **(frame size << ring latency)**



Token-Passing Systems (cont.)

Throughput in Delayed Token Release



- **assume:**
  - **ring latency (prop. time) in sec – τ'**
  - **M stations in the ring**

  average distance between neighboring stations = τ'/M

- **effective frame transmission time = X + prop. delay + time to pass token to next neighbour**

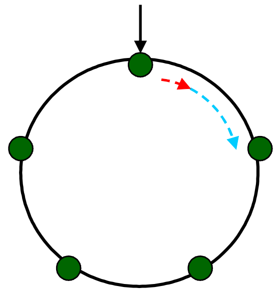
$$\text{effective frame trans. time} = \tau' + X + \frac{\tau'}{M}$$

time to pass token to the neighbor

$$\text{efficiency} = \frac{X}{X + \tau' + \frac{\tau'}{M}} = \frac{1}{1 + \frac{\tau'}{X}\cdot\left(1 + \frac{1}{M}\right)} = \frac{1}{1 + a'\cdot\left(1 + \frac{1}{M}\right)}$$

$a' = \frac{\tau'}{X}$

Throughput in Early Token Release

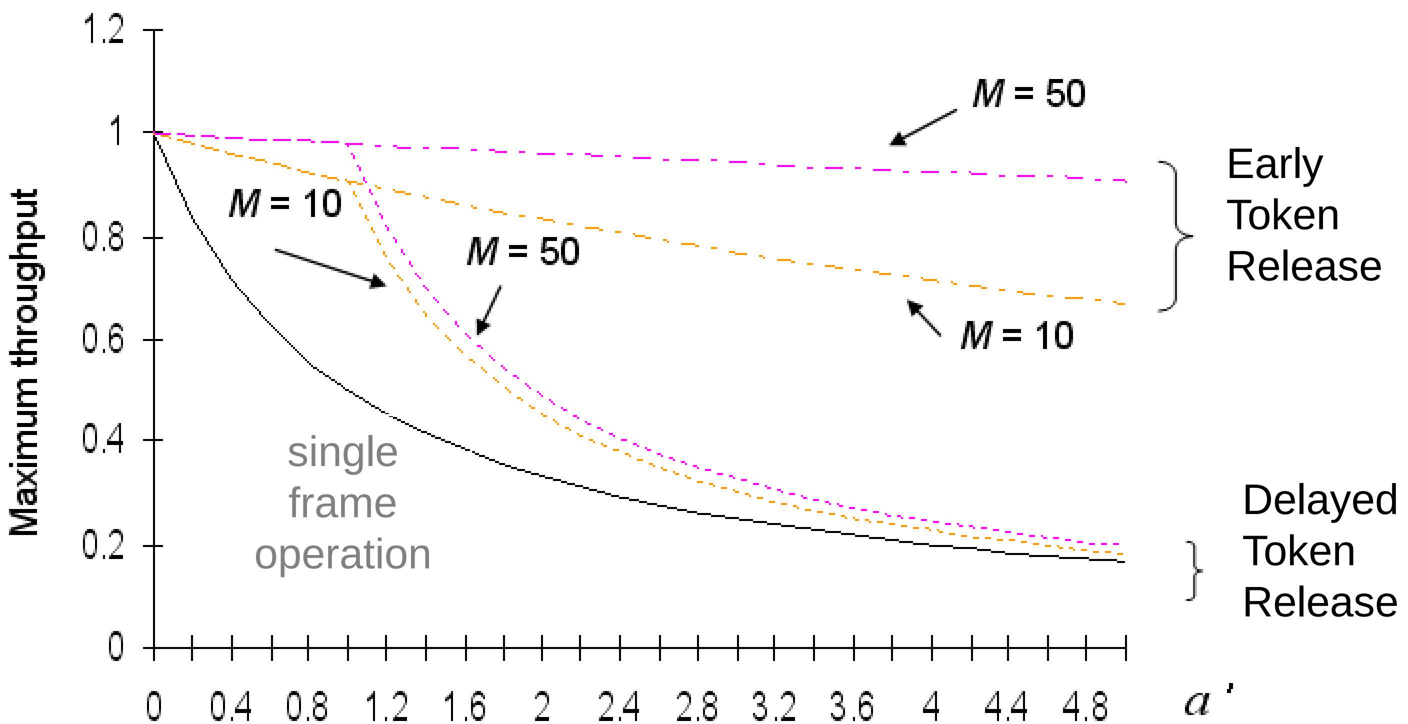


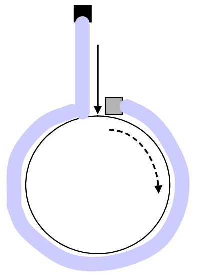
- **effective frame transmission time = X + prop time to neighbour**

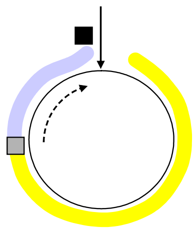
$$\text{effective frame trans. time} = X + \frac{\tau'}{M}$$

$$\text{efficiency} = \frac{X}{X + \frac{\tau'}{M}} = \frac{1}{1 + \frac{\tau'}{X}\frac{1}{M}} = \frac{1}{1 + \frac{a'}{M}}$$

Token-Passing Systems (cont.)





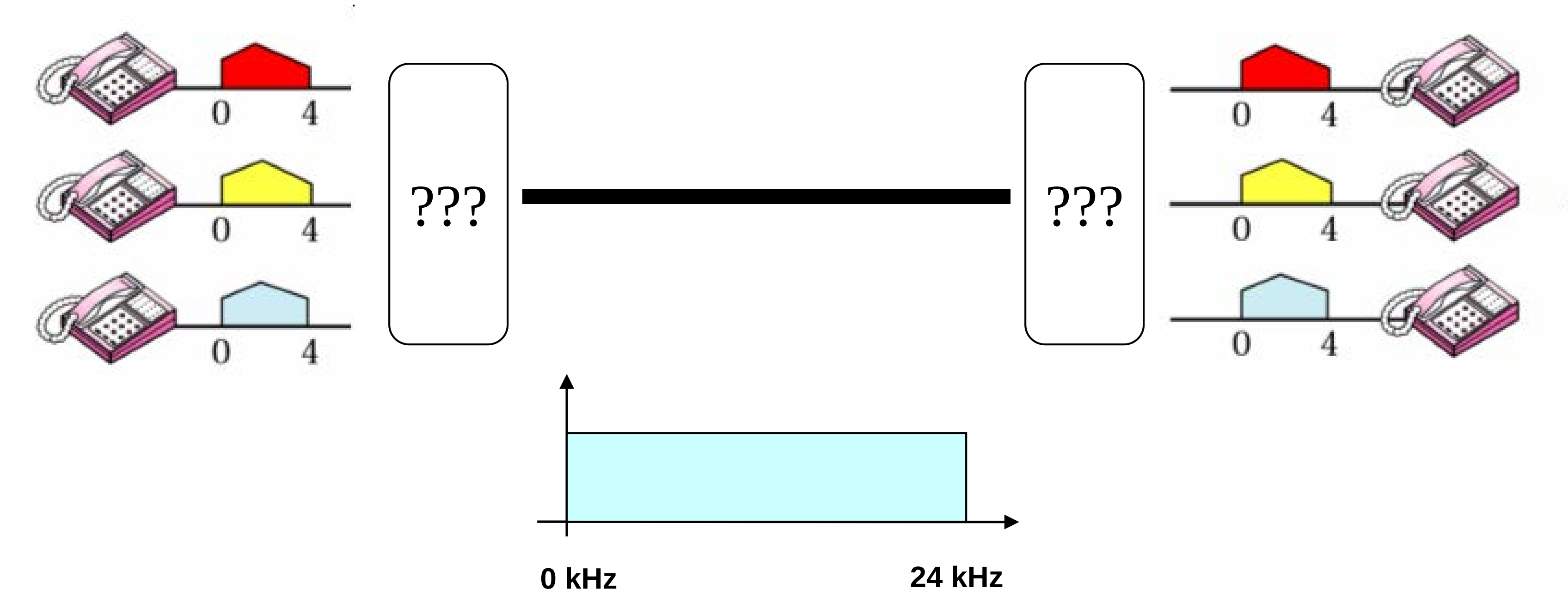


- **a' << 1** (τ'<<X) **, any token reinsertion strategy acceptable**
- **a' ≈1** (τ'=X) **, delayed token release acceptable**
- **a' >1** (τ'>X)**, early token release strategy necessary**

Random Access vs. Scheduling Access Control

	Random Access (ALOHA, CSMA)	Scheduling Access
delay	small under light loads ☺	longer but generally less variable between stations
throughput	sufficient under light load, drops significantly under heavy loads	increases under heavy load ☺
fairness	not guaranteed ☹	guaranteed ☺
sensitivity to node failure	small ☺	high, particularly in polling and token ring systems ☹

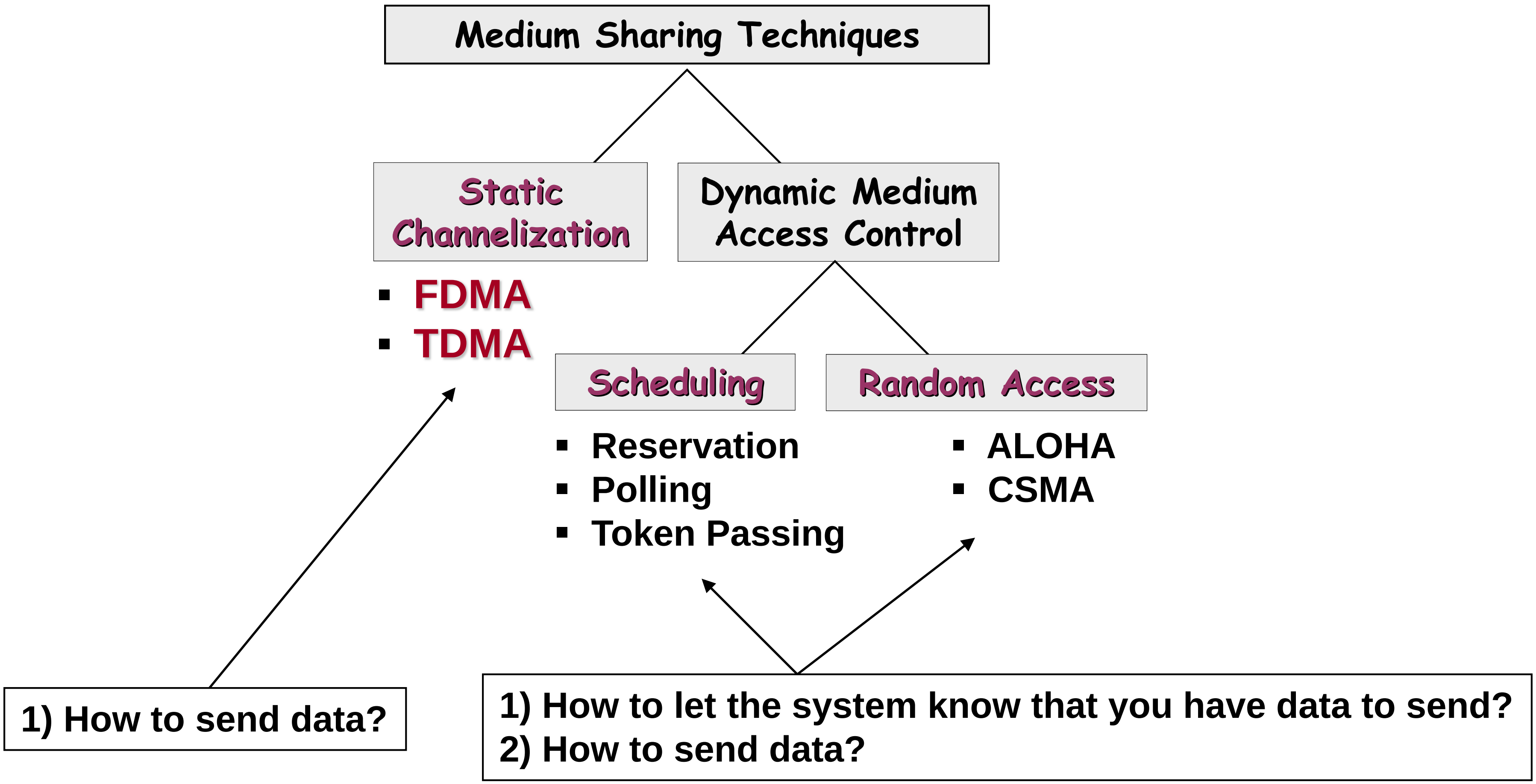
Channel Sharing in Telephone Systems



Telephone systems:

1) Large number of users present in the system; although only a fraction is active at any point in time.

2) Traffic (voice) should be transmitted with minimum delay and jitter.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1) How to send data?
1) How to let the system know that you have data to send?
2) How to send data?

Channelization

Channelization – **semi-static bandwidth allocation of portion of shared medium to a given user**

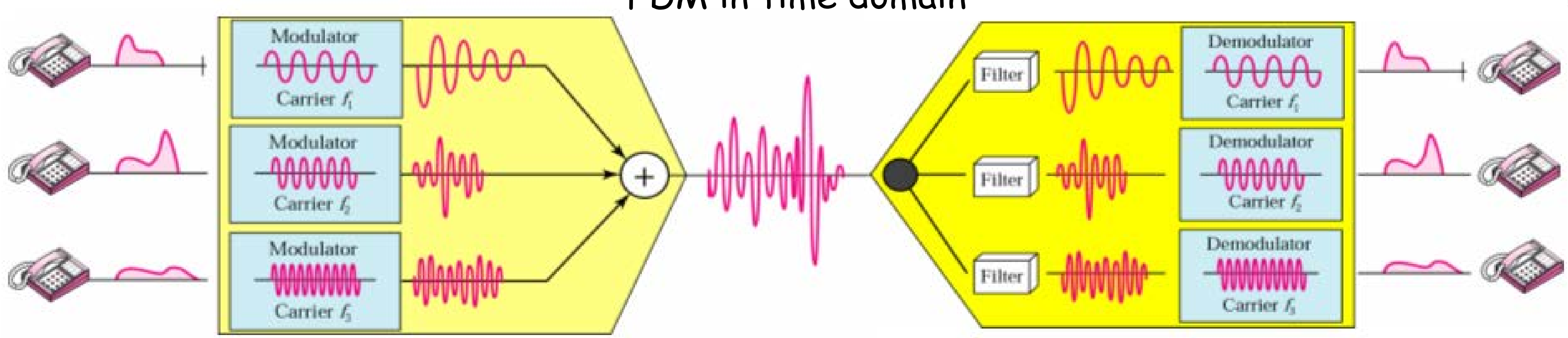
- **highly efficient in case of constant bit-rate (streaming) traffic**
- **inefficient in case of**
  - **(a) bursty traffic**
  - **(b) when different users have different traffic requirements**
  - **(c) large number of users – poor scaling**
- **bandwidth can be shared in**
  - **frequency (FDMA) – broadcast radio/TV, analog cellular phone**
  - **time (TDMA) – telephone backbone, GSM digital cellular phone**
  - **through code (CDMA) – 3G cellular**

FDMA

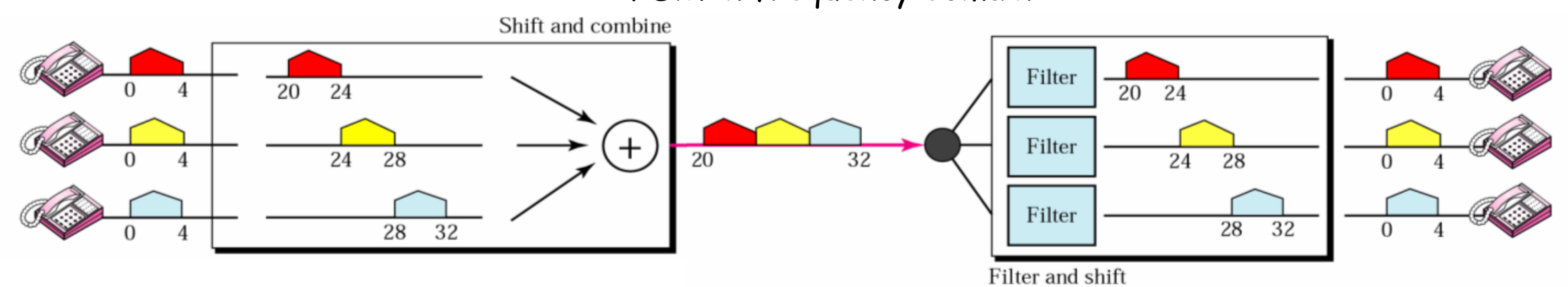
FDM – **Frequency Division Multiplex** – **analogue technique for transmitting multiple <u>information signals</u> on a single communication channel**

- **each signal is modulated with different carrier frequency – the signals are then combined into a <u>single composite signal</u>**
- **<u>carrier frequencies are separated by sufficient bandwidth to prevent overlapping of modulated signals in frequency domain</u>**

FDM in time domain



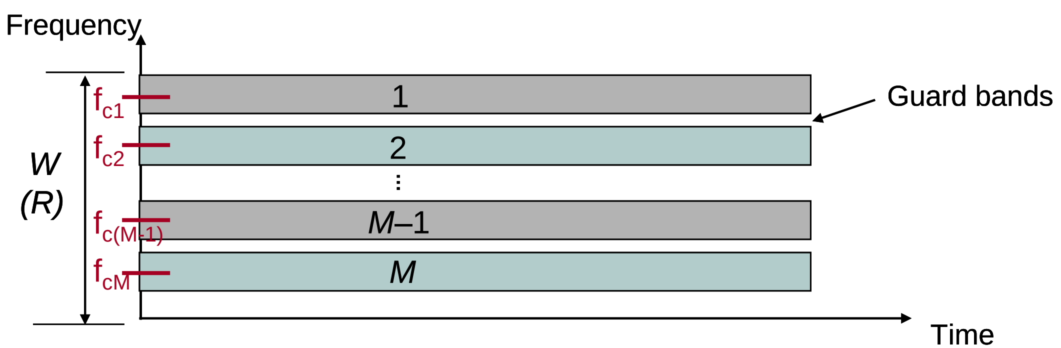
FDM in frequency domain



FDMA (cont.)

FDMA – **Frequency Division Multiplex Access – FDM-based technique that enables multiple users to share the same medium**

- **channel is divided into M separate frequency bands (so-called channels) centered around M different carrier frequencies**
- **to prevent interference, the channels are separated by guard bands**
- **each band is reserved for a specific user – the user transmits its modulated signal on the given band, without interruption**
- **each user transmits at most R/M [bps]**



FDMA Advantage – **easy to implement – no need for node synchronization**

FDMA Disadvantage **(1) guard bands ensure separation, but waste bandwidth**
(2) # of simultaneously served users ≤ # of channels

FDMA (cont.)

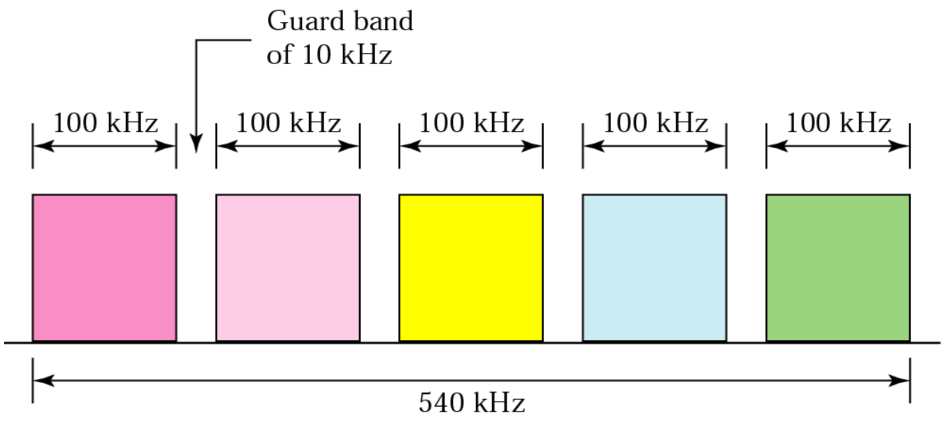
Example [FDMA]

Five channels, each with a 100-KHz bandwidth, are to be multiplexed together. What is the minimum bandwidth of the link if there is a need for a guard band of 10 KHz between the channels to prevent interference?

For five channels, we need at least four guard bands. This means that the required bandwidth is at least

$$5 \times 100 + 4 \times 10 = 540 \text{ KHz},$$

as shown below.



FDMA (cont.)

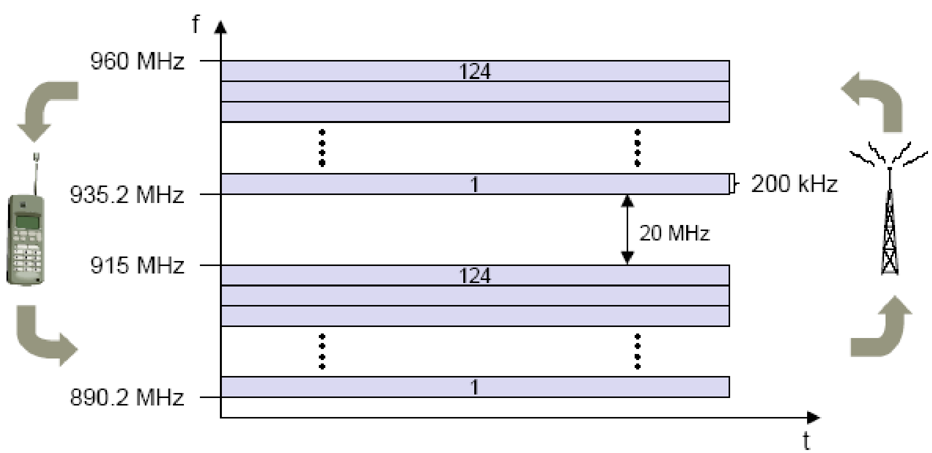
Example [AMPS]

The Advanced Mobile Phone System (AMPS) uses two bands. The first band, 824 to 849 MHz, is used for sending; and 869 to 894 MHz is used for receiving.

Each user has a bandwidth of 30 KHz in each direction. (The 3-KHz voice is modulated using FM, creating 30 KHz of modulated signal.)

How many people can use their cellular phones simultaneously?

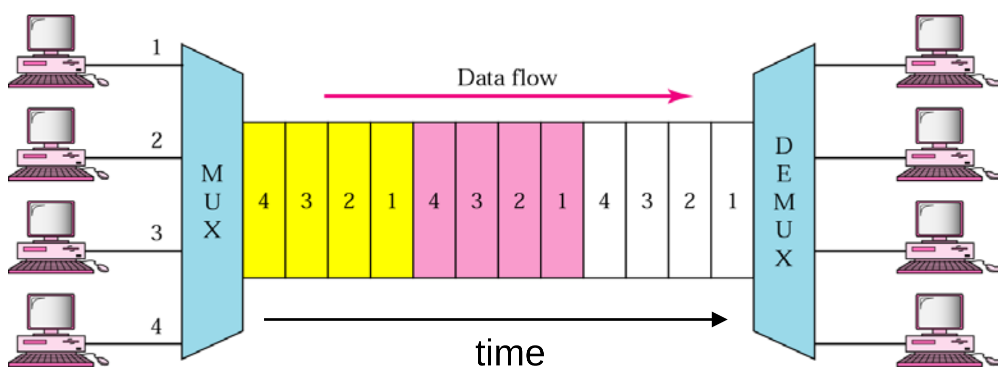
Each band is 25 MHz. If we divide 25 MHz into 30 KHz, we get 833.33.
In reality, the band is divided into 832 channels.

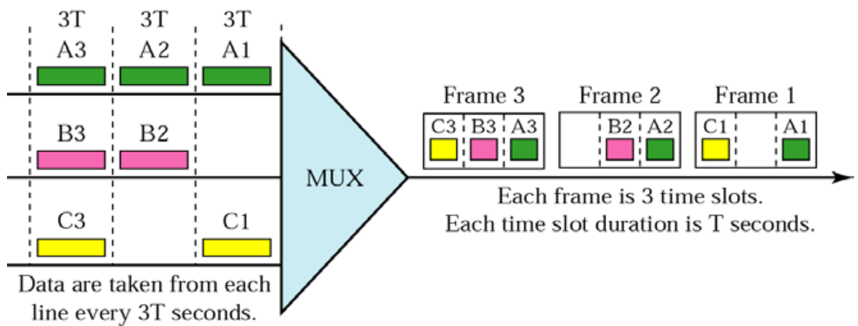


TDMA

TDM – **Time Division Multiplex – digital technique for transmitting multiple signals on a single communication channel**

- **channel transmission time is divided into time slots of duration T**
- **data flow of each signal/station is divided into units!!! (frames)**
  - **frame transmission time = T**
- **channel slot are assigned to one of M signals/stations in turn**



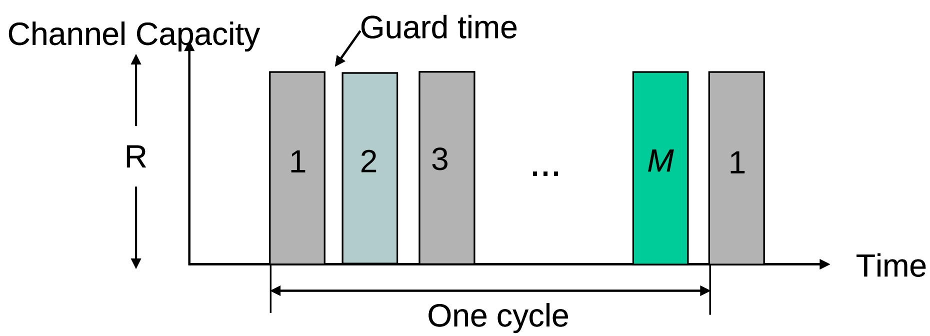


The data rate of the shared link is n times faster …

TDMA (cont.)

TDMA – Time Division Multiplex Access – TDM-based technique for sharing of medium among multiple users

- **each station transmit during its assigned time slot and uses entire frequency band (channel capacity) during its transmission**
- **different stations in different locations may experience different propagation delays ⇒ guard times are required to ensure that the transmission from different stations do not overlap**



TDMA Advantage – TDMA can accommodate a wider range of bit rates by allowing a station to be allocated several slots or by allowing slots to be variable in duration

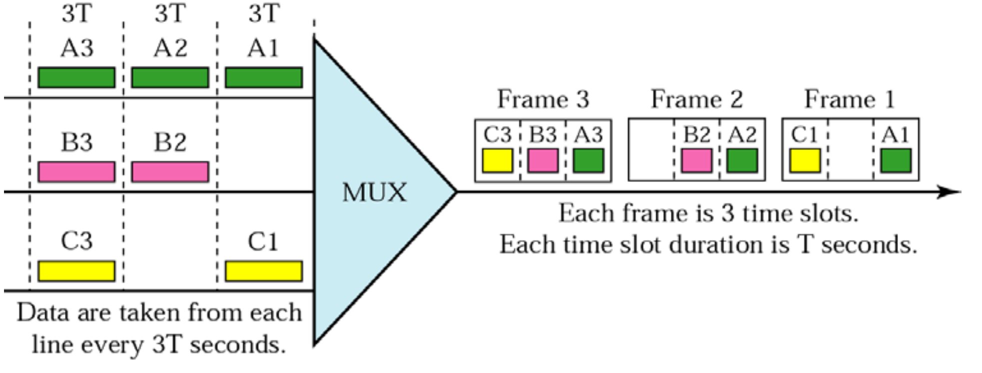
TDMA Disadvantage

(1) stations must be synchronized to a common clock
(2) propagation delays must be taken into account

TDMA (cont.)

Example [TDMA]

Four 1-Kbps connections are multiplexed together. Find
(1) the duration of 1 bit before multiplexing,
(2) the transmission rate of the shared link,
(3) the duration of 1 bit after multiplexing.



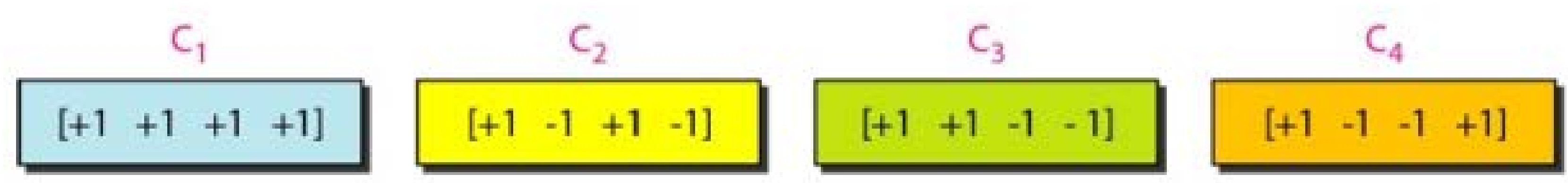
(1) The duration of 1 bit before multiplexing is 1/1 Kbps, or 0.001 s (i.e. 1 ms).
(2) The rate of the link is 4*1 Kbps = 4 Kbps.
(3) The duration of one bit after multiplexing is 1/4 Kbps or 0.00025 s (i.e. 0.25 ms).

CDMA

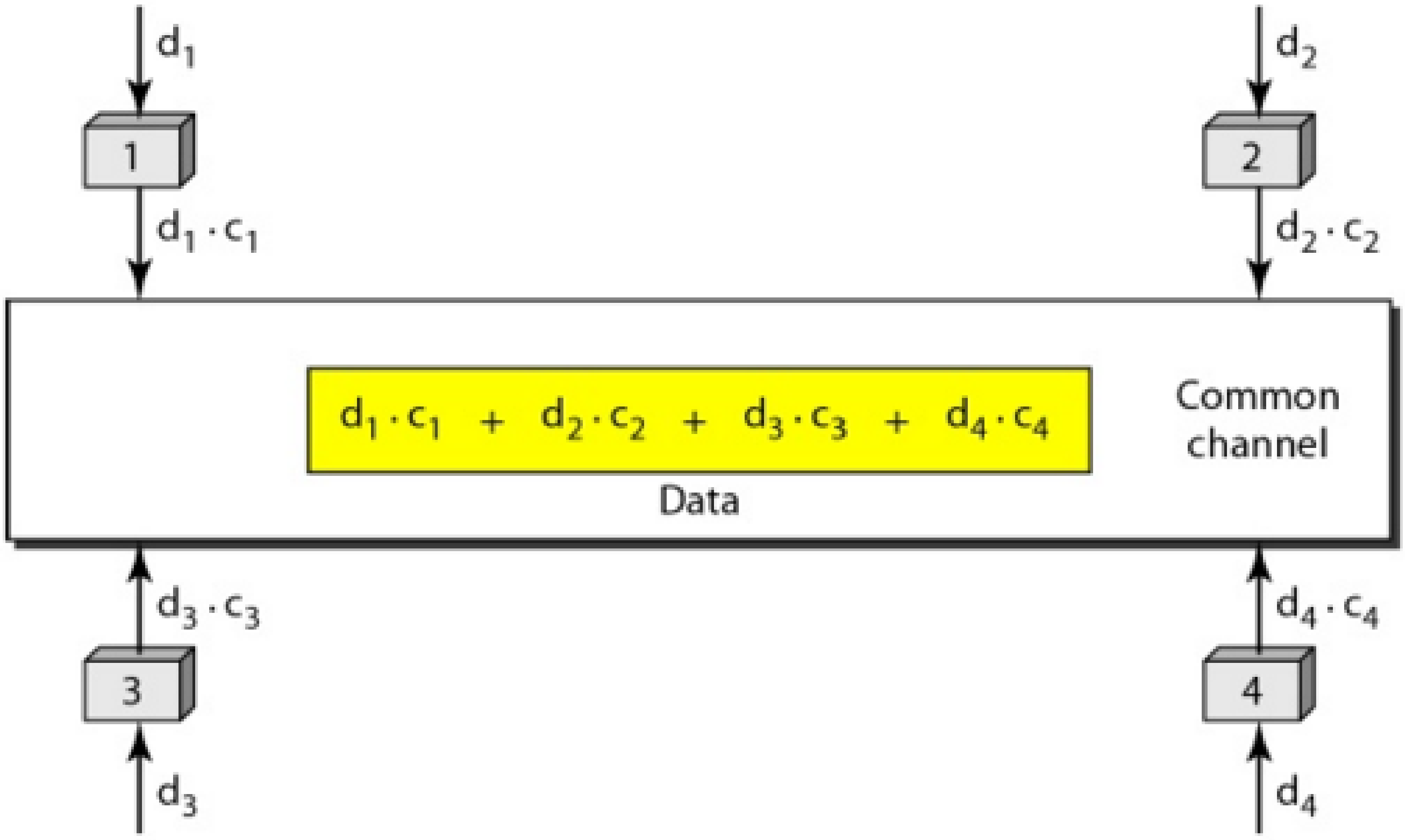
CDMA – Code Division Multiplex Access – scheme in which there is only one channel that occupies the entire bandwidth

- **each station is assigned a unique code / sequence, so-called chip**
- **in a system of N stations, chips satisfy the following properties:**

1) ***each chip is made of N elements***
2) ***multiplication of two chips => every element of one chip is multiplied by respective element of the other chip and the the results are added (inner product)***
3) ***inner product of each chip with itself equals N***
4) ***inner product of any chip with any other chip equals 0***



Example **[CDMA with N=4]**



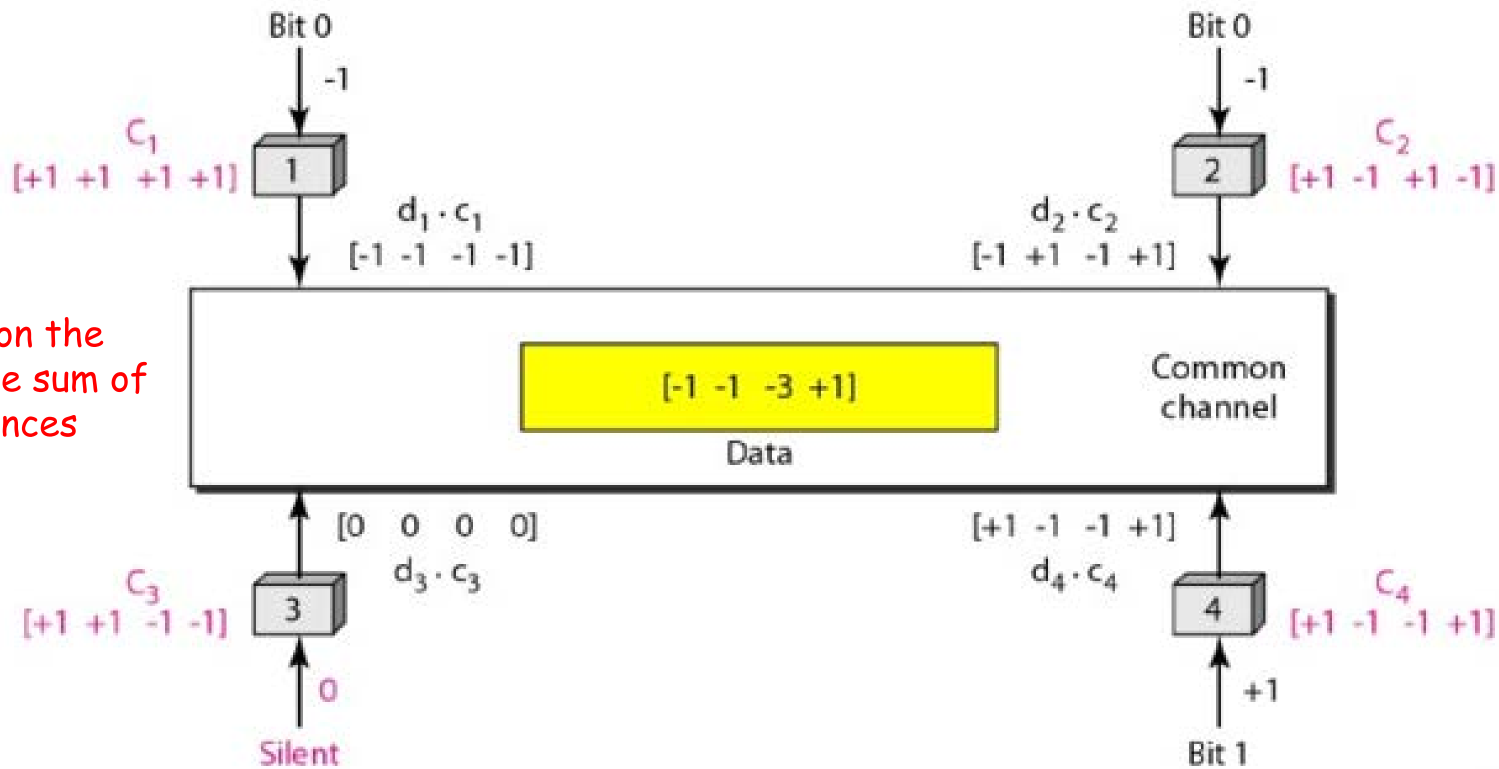
CDMA (cont.)

CDMA Data Representation

CDMA Coding

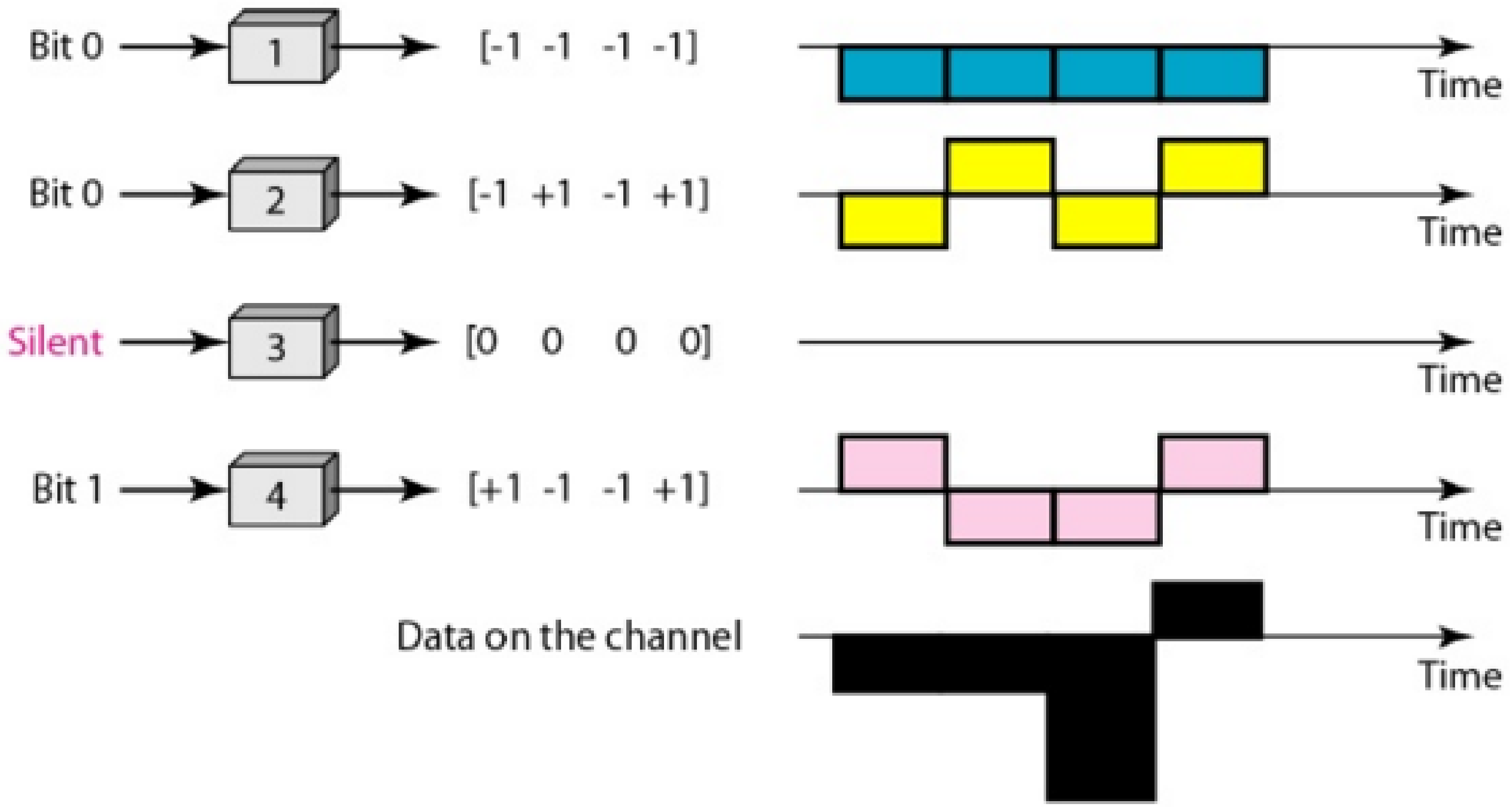
– **each station multiplies its data (bit) value with its chip, and resultant sequence is sent to the channel**

sequence on the channel is the sum of all sequences



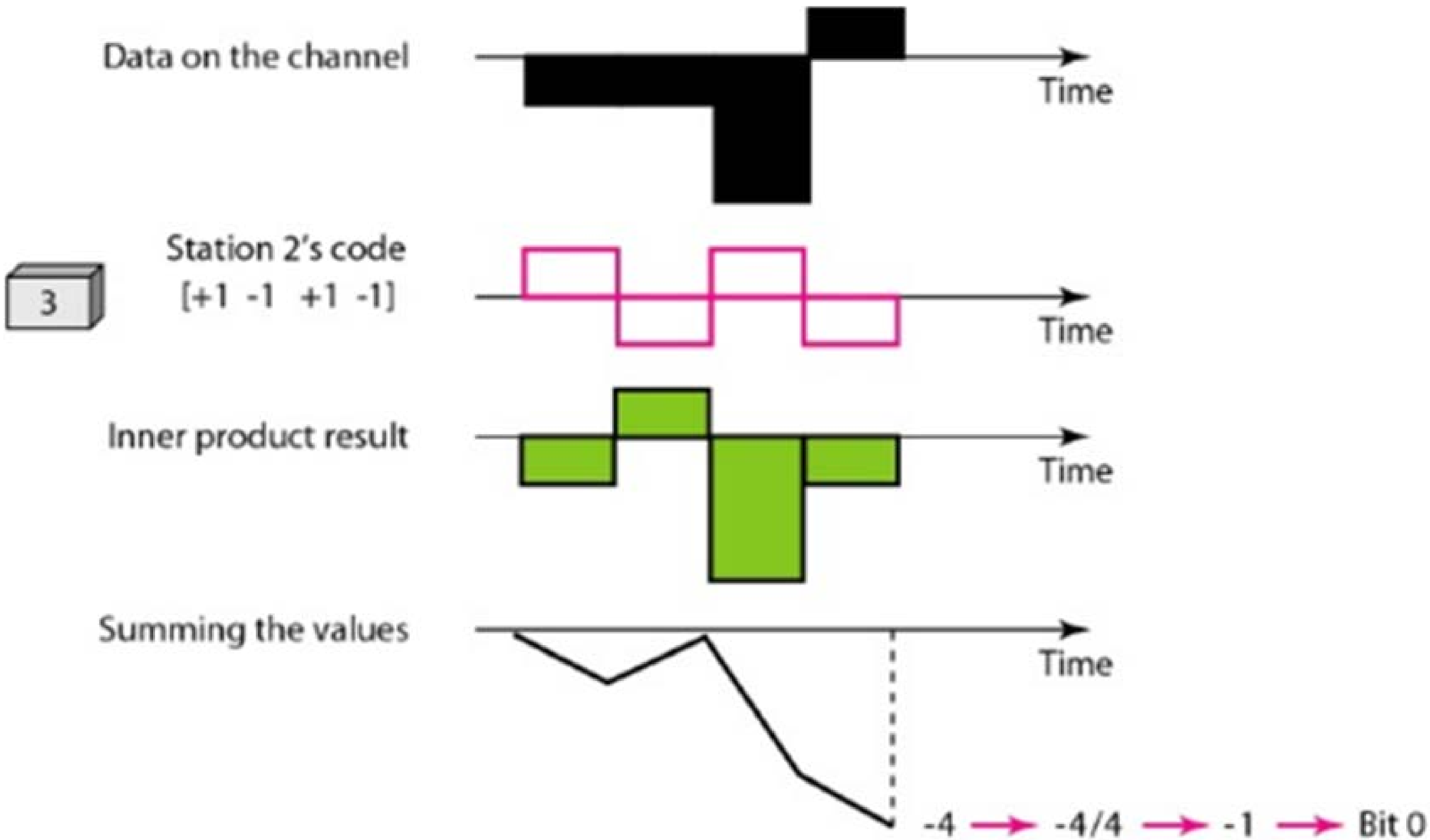
CDMA (cont.)

CDMA Decoding – **data sent by station X is recovered by multiplying the cumulative received signal by X's chip**



CDMA (cont.)

Example **[station-3 receiving station-2's data]**



CDMA (cont.)

- **Advantages of CDMA** over TDMA and FDMA
  - higher (soft) system capacity
  - soft handoff
  - simple frequency planning
  - inherent frequency diversity against multipath fading
  - Voice activity factor and antenna sectorization are readily exploited using CDMA.

- Advantages
  – No timing coordination unlike TDMA
  – CDMA uses spread spectrum, resistant to interference (multipath fading)
  – No hard limit on number of users