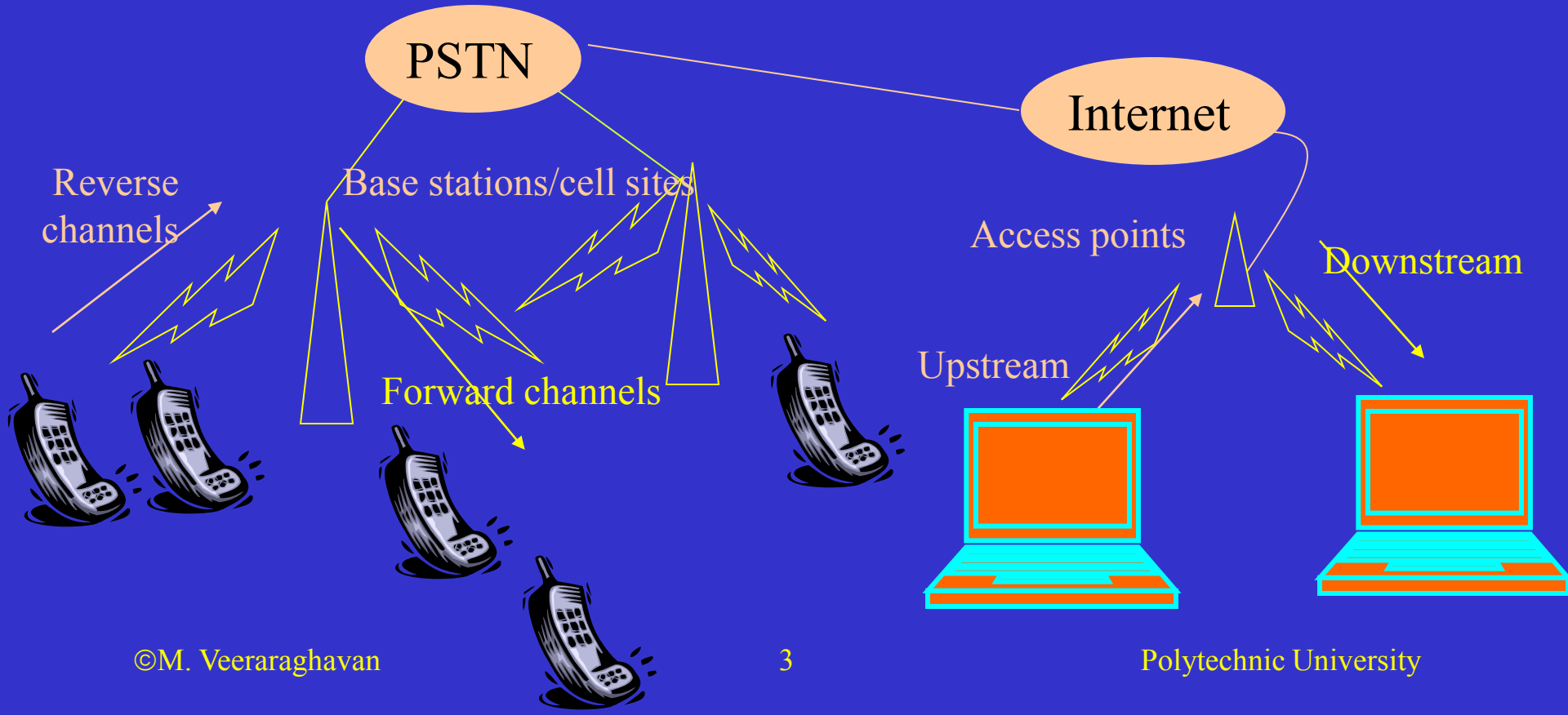
Wireless MAC protocols

Outline

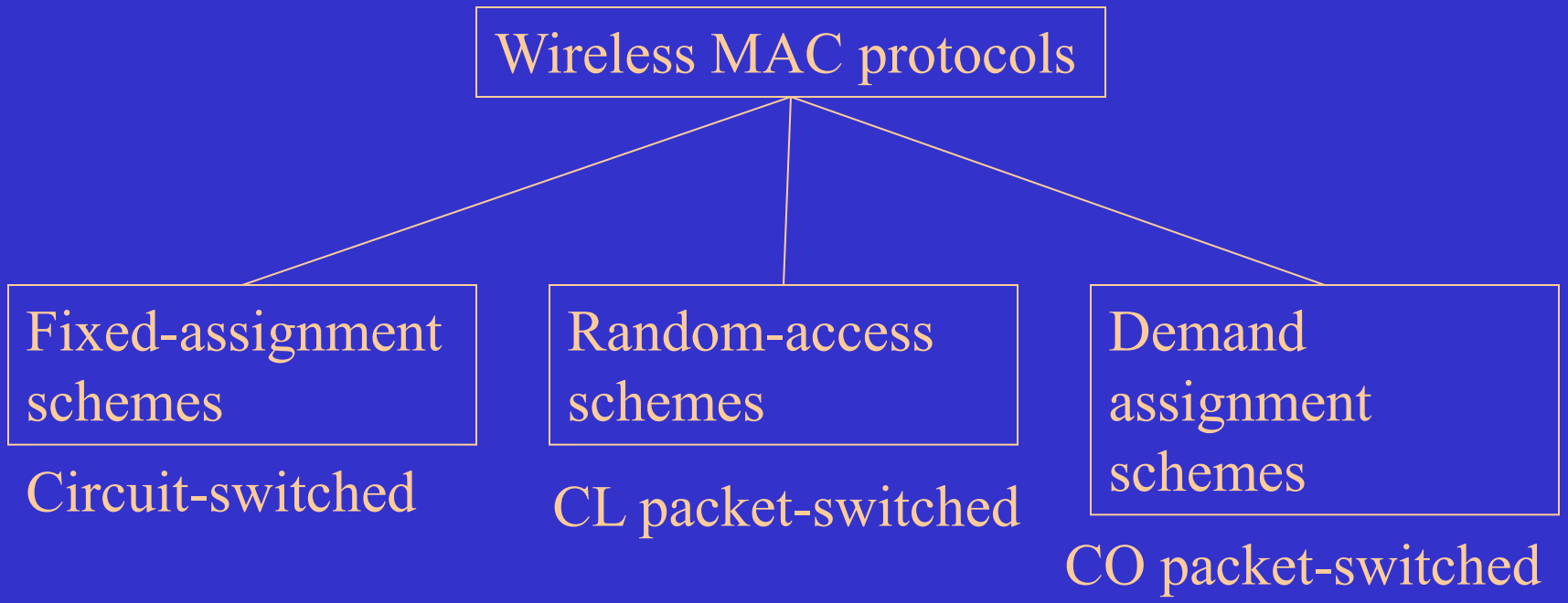
- Need for wireless MAC protocols
- Obtain assignment of resources per call
  - ala circuit switching
  - fixed assignment
- Obtain assignment of resources per packet
  - ala packet switching
    - CL flavor: random-access
    - CO flavor: demand-assignment

Need for wireless MAC protocols

- Wireless is naturally a shared medium



Classification of wireless MAC protocols



Outline

- Need for wireless MAC protocols
- ➢ Obtain assignment of resources per call
  - — ala circuit switching - fixed assignment
  - —FDMA and TDMA
- Obtain assignment of resources per packet
  - — ala packet switching
    - — CL flavor: random-access
    - — CO flavor: demand-assignment

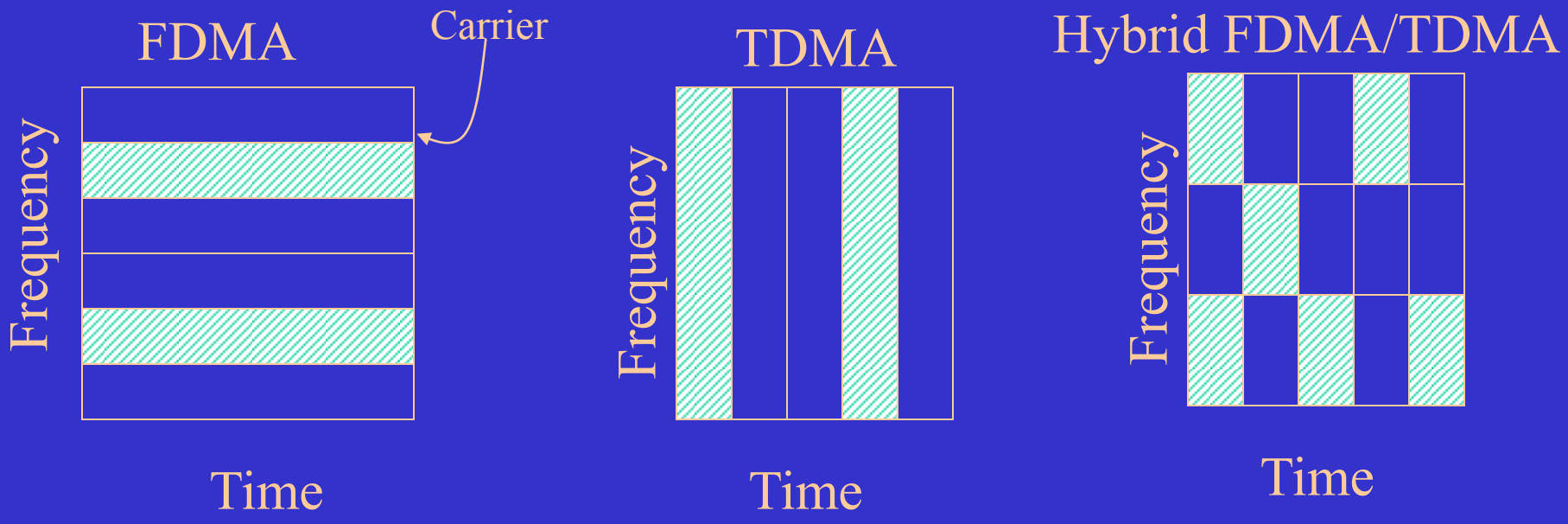
FDMA (Frequency Division Multiple Access)

- Similar to broadcast radio and TV, assign a different carrier frequency per call
- Modulation technique determines the required carrier spacing
- Each communicating wireless user gets his/her own carrier frequency on which to send data
- Need to set aside some frequencies that are operated in random-access mode to enable a wireless user to request and receive a carrier for data transmission

TDMA (Time Division Multiple Access)

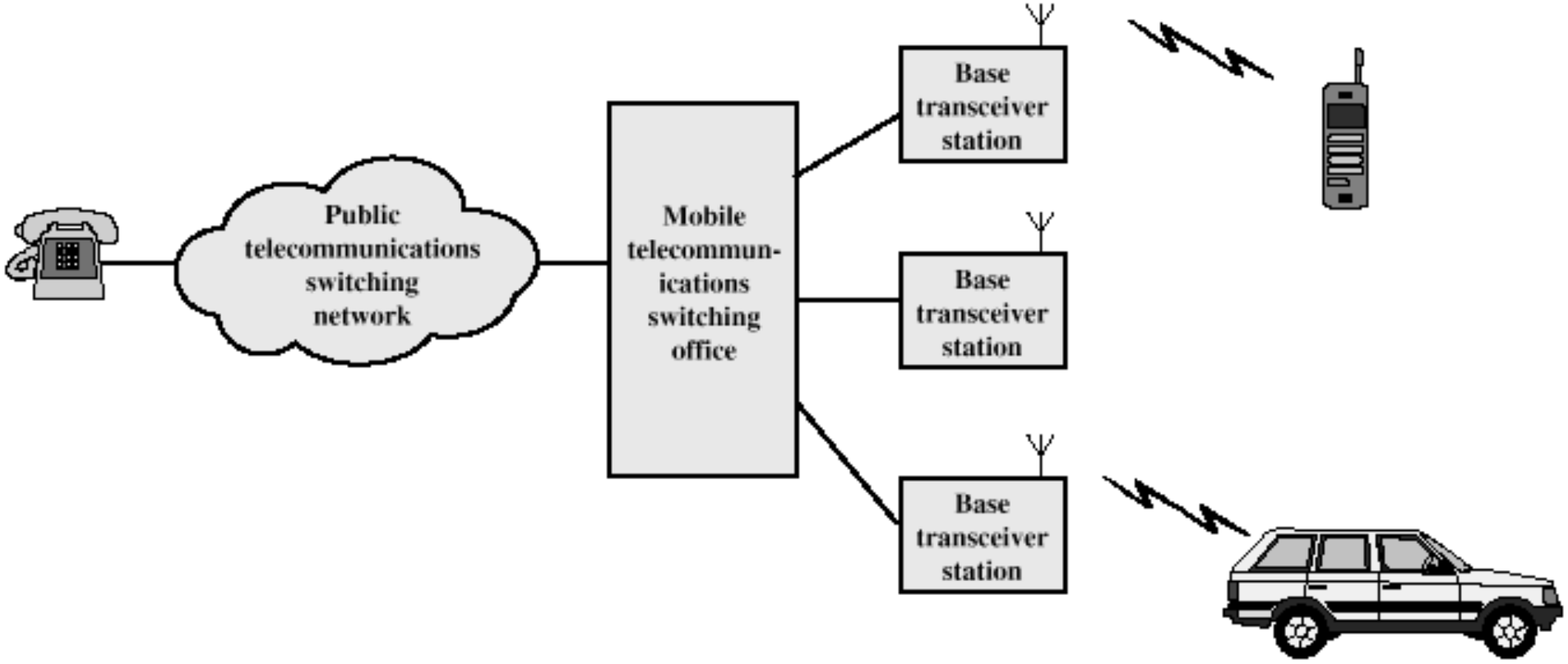
- Each user transmits data on a time slot on multiple frequencies
- A time slot is a channel
- A user sends data at an accelerated rate (by using many frequencies) when its time slot begins
- Data is stored at receiver and played back at original slow rate

Frequency vs. time



Basic principle of communication: Two regions in the time-frequency plane with equal areas can carry the same amount of information

Cellular System Overview

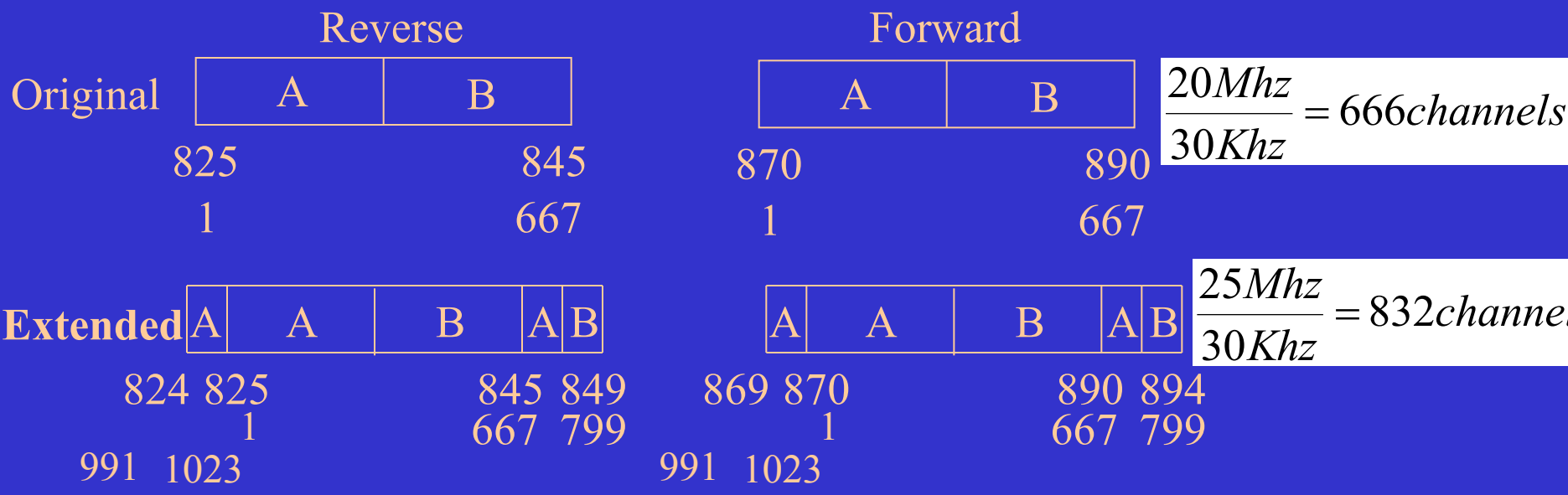


Cellular Systems Terms

- Base Station (BS) – includes an antenna, a controller, and a number of receivers
- Mobile telecommunications switching office (MTSO) – connects calls between mobile units
- Two types of channels available between mobile unit and BS
  - Control channels – used to exchange information having to do with setting up and maintaining calls
  - Traffic channels – carry voice or data connection between users

AMPS cellular system

- FDMA
  - Analog cellular network: Advanced Mobile Phone System (AMPS)
  - Spectrum allocation by FCC: A and B allocations to different providers



Duplex techniques

- Separates signals transmitted by base stations from signals transmitted by terminals
  - Frequency Division Duplex (FDD): use separate sets of frequencies for forward and reverse channels (upstream and downstream)
  - Time Division Duplex (TDD): same frequencies used in the two directions, but different time slots

Question

- Is AMPS an FDD or TDD scheme?

Examples

- FDD:
  - Cellular systems: AMPS, NA-TDMA, CDMA, GSM
- TDD
  - Cordless telephone systems: CT2, DECT, PHS

Carrier frequencies corresponding to channel numbers in AMPS

Reverse direction $f_r(C) = 825{,}000 + 30C$ kHz $\quad 1 \le C \le 799$

$f_r(C) = 825{,}000 + 30(C - 1023)$ kHz $\quad 991 \le C \le 1023$

Forward direction $f_f(C) = f_r(C) + 45{,}000$ kHz

- Every mobile phone can be programmed to use channels of corresponding subscriber (A or B)
- For every phone call, a mobile user uses two channels; one in the forward direction and the second one in the reverse direction
- How is a mobile user assigned these channels for the call?

Control channels

- A set of channels are set aside as "control channels"
  - channels 313-354 (21 channels in each band)
  - forward control channels (FOCC)
    - broadcast channels (one-to-many)
  - reverse control channels (RECC)
    - random access (many-to-one)

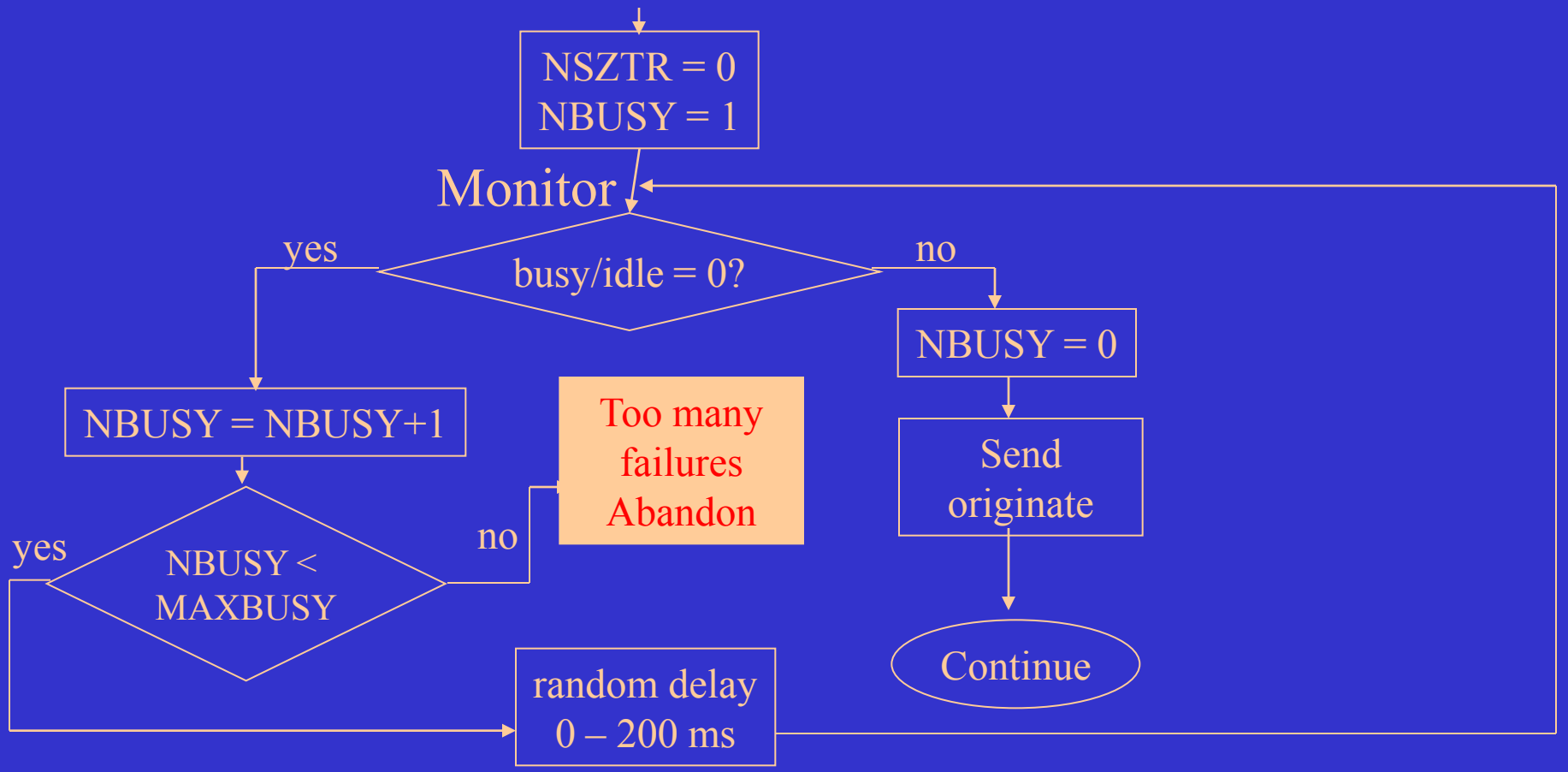
RECC Access Protocol

- A RECC is used by multiple endpoints to request a traffic channel
- But before a mobile issues call origination request on an RECC, it needs to make sure that the RECC is idle
- First, endpoints tune into FOCC; find the strongest one and then determine
  - whether corresponding RECC is busy or idle

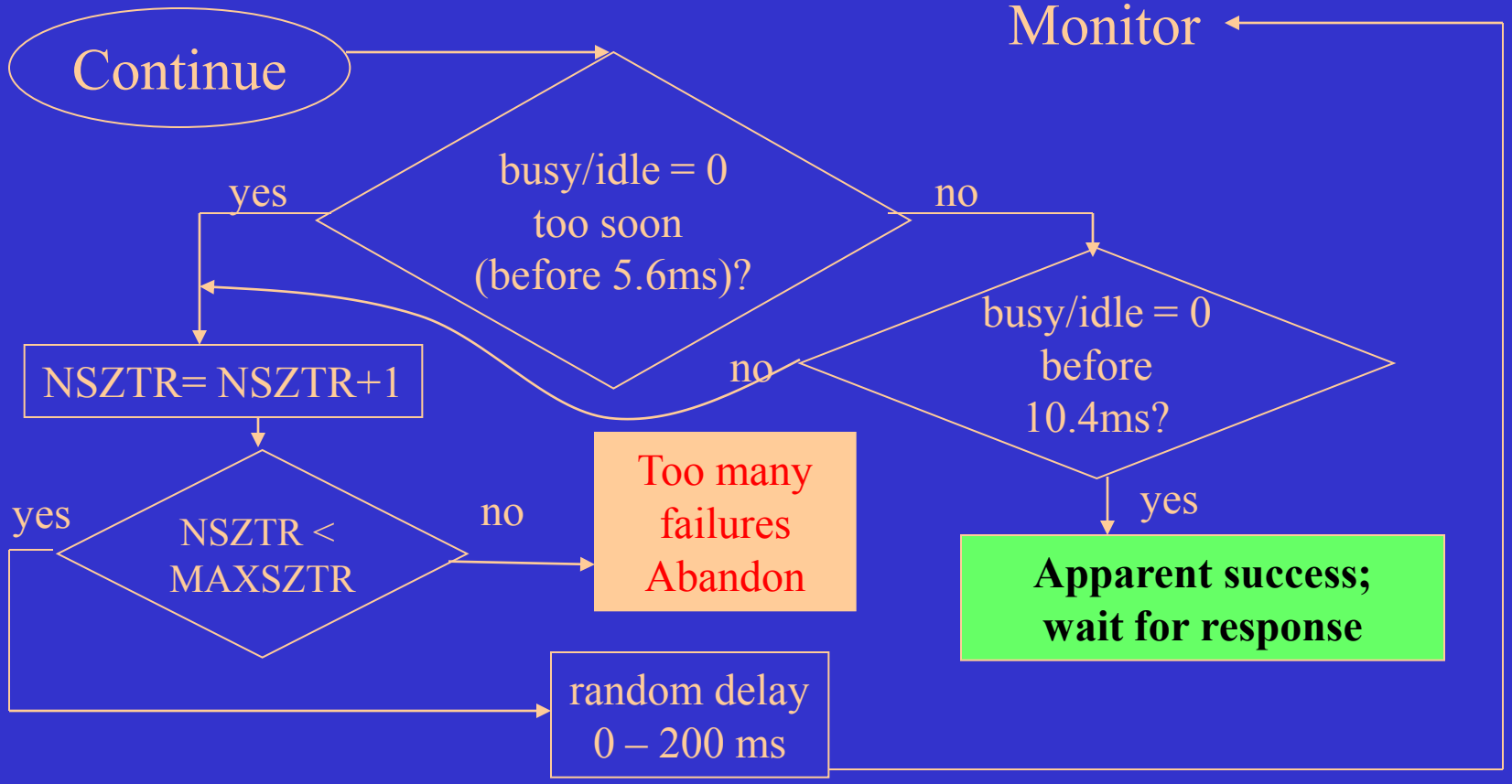
Broadcasts on FOCC

- When a mobile handset is switched on, it locks into the strongest FOCC
  - If in the band of the "other" service provider, then "roaming" signal is displayed
  - If there are no strong signals, display "no service"
  - Basestation broadcasts busy/idle status of each RECC on its corresponding FOCC
  - Basestation sends global action message specifiying
    - maximum number of tries if busy (MAXBUSY)
    - maximum number of attempts to seize the RECC (MAXSZTR)

Random access protocol on a RECC



RECC Random access protocol contd.



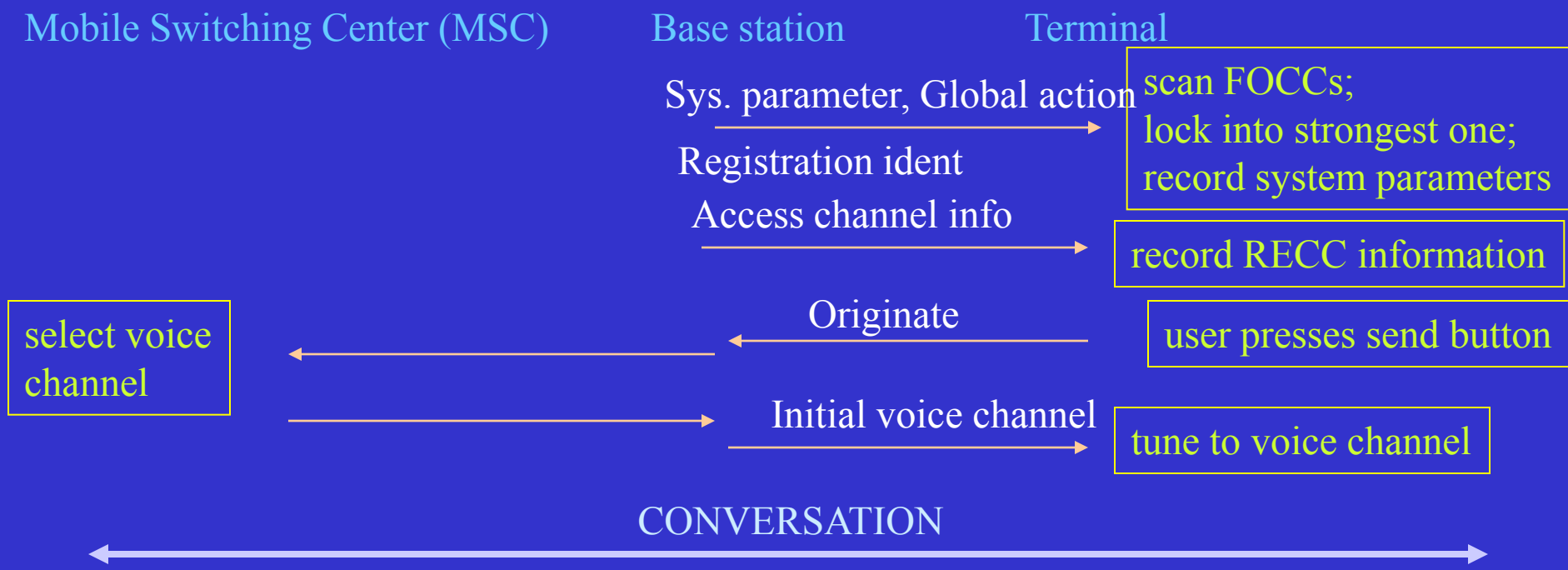
Messages on control channels

- Sent on FOCC
  - System parameter
    - identifies provider, indicates number of forward and reverse control channels
  - Global action
    - indicates MAXBUSY and MAXSZTR
  - Registration ident
    - specifies frequency to be used by terminal for sending registration messages
  - Other messages: Page, Initial voice channel, Release, Confirm registration, etc.

Messages on control channels

- Sent on RECC
  - Originate (call origination)
  - Page response
  - Registration
- Sent on forward voice channel
  - Handoff, Change power level, etc.
- Sent on reverse voice channel
  - Order confirmation, etc.

Messages exchanged: call originating from mobile



Messages exchanged: call terminating at a mobile

- Tradeoff between Page and Registration
- If terminals register, then a Page does not need to be sent to many cells
  - For systems with a large number of base stations, volume of page messages can overwhelm the system
- Page sent with identification of called mobile on broadcast FOCC
- Latter responds with a Page response on RECC

Dimension of space

- Question: Transmission on a wireless link can be heard by all terminals within range of base station
  - What is that range?
  - What controls that range?
  - What parameters determine the number of simultaneous calls within this range?

Power

- Radiated power at a base station is 25W per channel for wide area coverage
- Radiated power from a terminal is the range of 8dBm (6mW) to 36 dBm (4W) in steps of 4dB (each power level is 2.5 times higher)

$$S(dBm) = 10\log_{10}\frac{P(mW)}{1mW}$$

Spectrum efficiency

- C: Number of conversations per Mhz that would be possible in a single cell with no interference from neighboring cells
- N: Channel reuse factor – indicates the capacity reduction due to interference from signals transmitted in other cells
- Spectrum efficiency E

$$E = C / N$$ conversations/cell/Mhz

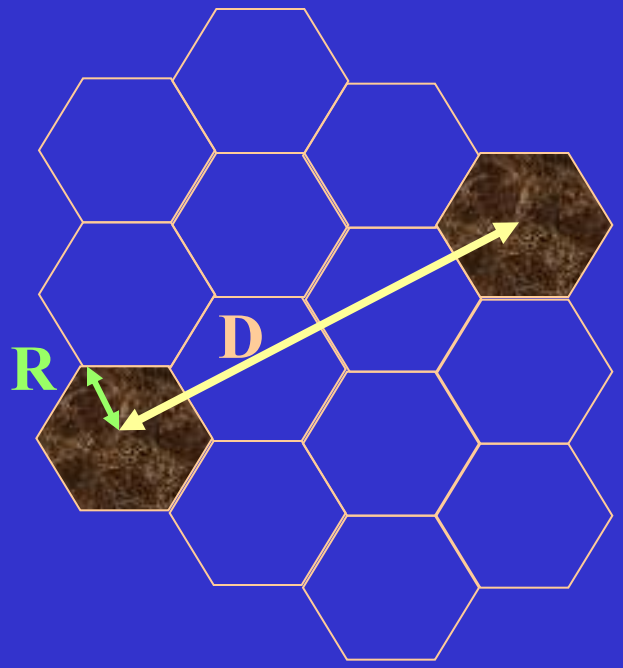
- Required received signal-to-interference ratio is 18dB for high-quality sound reproduction at the receiver

$$\frac{S}{I} \geq \left(\frac{S}{I}\right)_{req}$$

Received signal strength

- Received signal strength depends upon
  - attenuation that increases with distance
  - random variations due to environmental fluctuations (shadow or slow fading: obstacles)
  - signal fluctuations due to the motion of a terminal (Rayleigh fading or fast fading)
  - distortions because components of the signal travel along different paths to the receiver

Hexagonal cell frequency plan



- D: Distance between a base station and the nearest base station that uses the same channels
- R: Radius of a cell
- Reuse distance = D/R
- Channel plan: method of assigning channels to cells to guarantee a minimum reuse distance between cells that use the same channel

$\frac{D}{R} \succ \left(\frac{D}{R}\right)_{req}$ which is the minimum reuse distance for which $\frac{S}{I} \succ \left(\frac{S}{I}\right)_{req}$

Hexagon properties

- Radius of a hexagon, R: radius of the circle that circumscribes it (which is equal to the distance from the center to any vertex; also equal to the length of a side)
- Distance between adjacent cells is d

$$d = \sqrt{3}R$$

- Area of a hexagon is

$$A = 1.5\sqrt{3}R^2$$

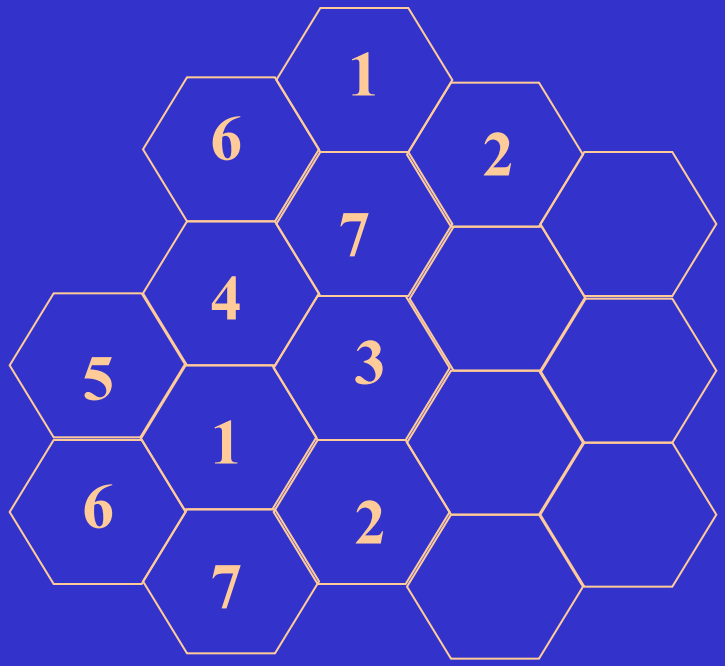
Reuse factor

- Divide available channels into N groups
- N: reuse factor; select N such that cells assigned the same frequencies will have a D:R ratio greater than $(D:R)_{req}$
- For hexagons, reuse factor N is given by

$$N \geq \frac{1}{3}\left(\frac{D}{R}\right)^2_{req}$$

- Practical values of N
  - range from 3 to 21
  - most commonly used: 7 (D/R = 4.6)

Channel plan with a reuse factor N=7



Service provider A

- Has a total of 832/2 = 416 channels
- Set aside 21 for control
- Therefore 395 traffic channels
- Per cell, we can have 56 and 3/7 channels (N=7)
- Four cells are given 56 channels and three cells are given 57 channels
- The 395 channels fit over 25Mhz
- Therefore, the spectrum efficiency of an AMPS system is

$$E = \frac{C}{N} = \frac{395}{7 \times 25} = 2.26$$ conversations/cell/Mhz

Question

- So how many control channels are present in each cell?
- What is the implication of this question?

Typical parameters

	Macrocell	Microcell
Cell radius	1 to 20km	0.1 to 1km
Transmission power	1 to 10W	0.1 to 1W
Average delay spread	0.1 to 10ms	10 to 100ns
Maximum bit rate	0.3Mbps	1Mbps

- Average delay spread refers to the multipath delay spread (the same signal takes different paths, and there is a difference in delay incurred by the different paths)

Increasing Capacity

- Add new channels
- Dynamic channel allocation – frequencies can be taken from adjacent cells by congested cells
- Cell splitting – cells in areas of high usage can be split into smaller cells
- Cell sectoring – cells are divided into a number of wedge-shaped sectors, each with their own set of channels (typical: 3)
- Microcells – antennas move to buildings, hills, and lamp posts

Radio channel handoff

- Intra-cell handoff is when the channel needs to be changed when the user is still within a cell
  - Reason: user moves into a sector served by a different directional antenna
- More commonly understood meaning for handoff: base-station to base-station (cell site)
  - Neighboring cells use different channels (for interference reasons)
  - As a user moves from cell to cell, channels are changed

When to handoff?

- Relative signal strength
  - handoff from basestation A to basestation B if signal strength at B exceeds that at A
- Relative signal strength with threshold
  - signal at A is lower than the threshold
  - the signal at B is stronger
- Relative signal strength with hysteresis
  - if signal at B is stronger by a hystersis amount H
  - hand back to A only if signal at A is higher by H

When to handoff?

- Relative signal strength with hysteresis and threshold
  - current signal drops below a threshold
  - target base station is stronger by a hystersis margin H
- Prediction techniques
  - handoff based on the expected future value of the received signal strength