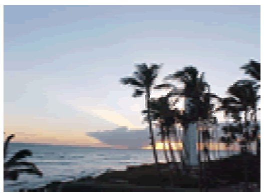
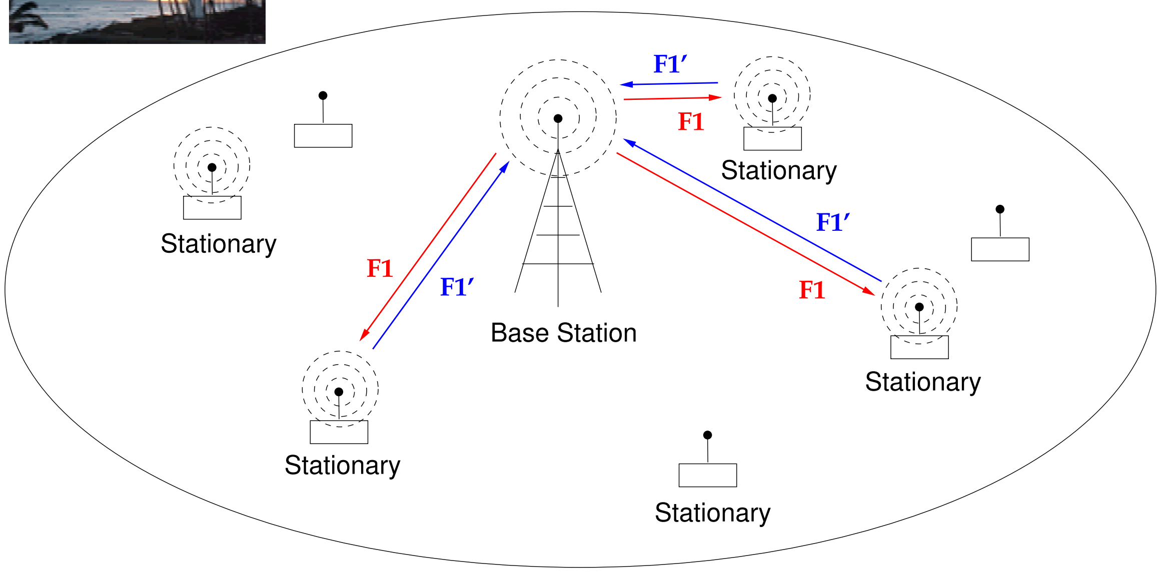
ALOHA packet radio network





ALOHA

$\longrightarrow$ downlink broadcast channel $F1$

$\longrightarrow$ shared uplink channel $F1'$

Ex.: ALOHANET

- data network over radio frequency
- Univ. of Hawaii, 1971; 4 islands, 7 campuses

- Norm Abramson

  → precursor to Ethernet

  → parallel to wired packet switching technology

- carrier frequency

  → uplink: 407.35 MHz; downlink: 413.475 MHz

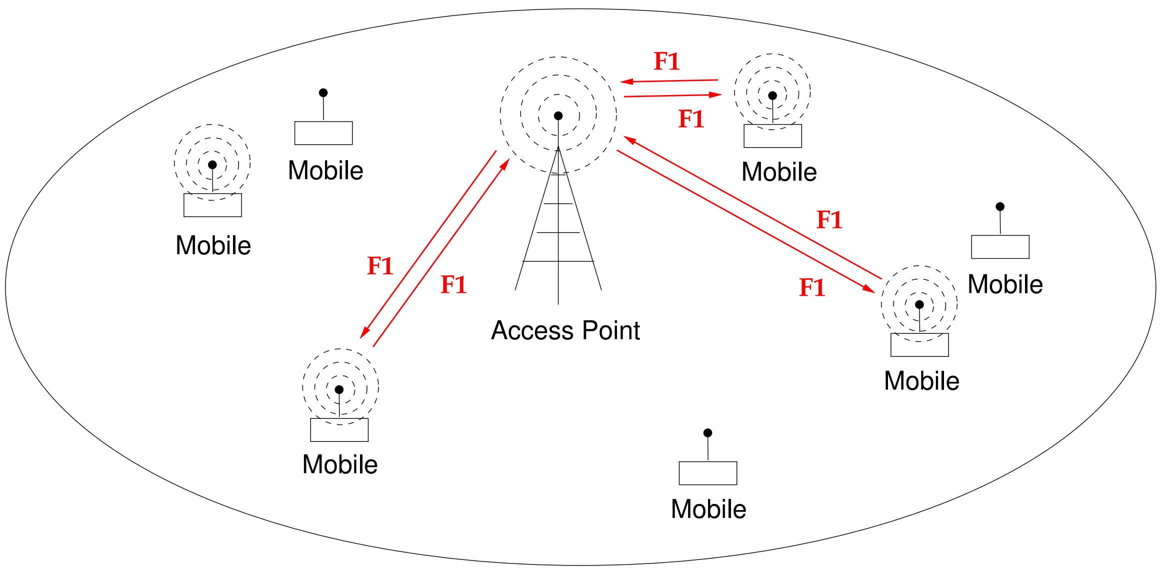
- bit rate: 9.6 kb/s

- contention-based multiple access: MA

  → plain and simple

  → needs explicit ACK frames (stop-and-wait)

Wireless LAN (WLAN): infrastructure mode



WLAN: Infrastructure Network

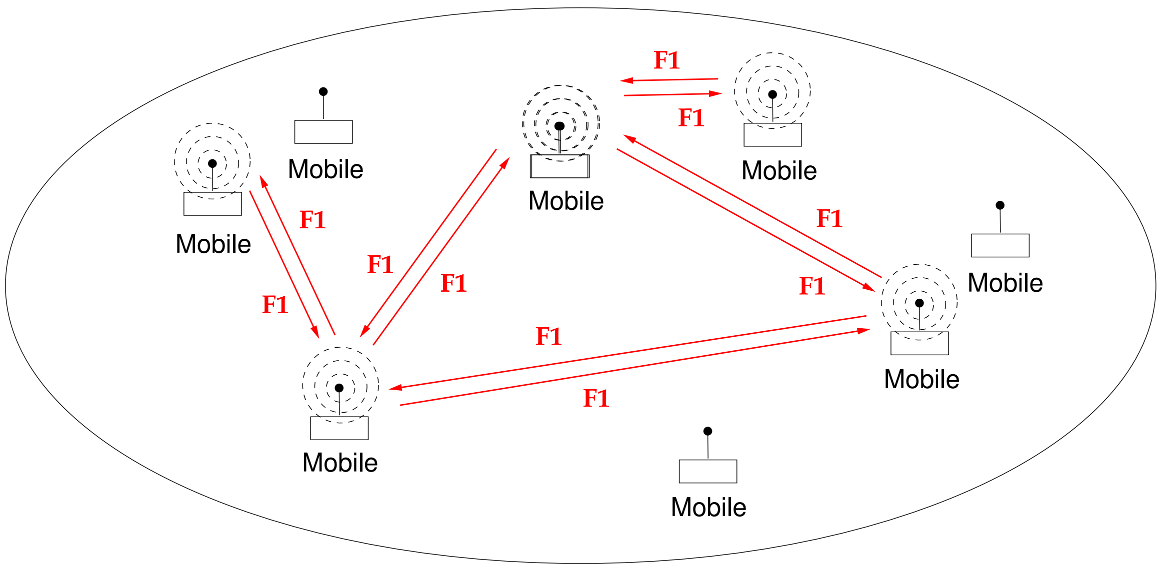
$\longrightarrow$ shared uplink & downlink channel $F1$

- basic service set (BSS)

  $\rightarrow$ "hot spot"

- SSID (service set identifier): name/label of BSS
- base station: access point (AP)
- mobile stations must communicate through AP

WLAN: ad hoc mode



WLAN: Ad Hoc Network

⟶ homogeneous: no base station

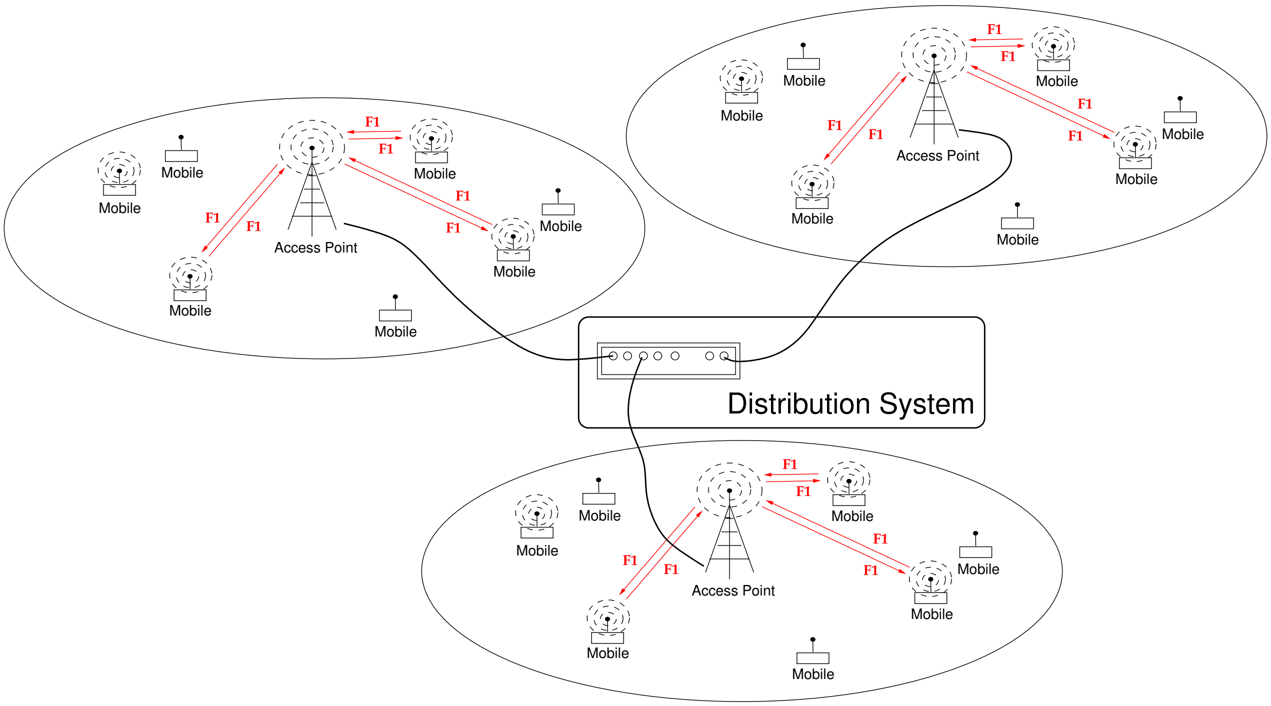
⟶ everyone is the same

⟶ share forwarding responsibility

- independent basic service set (IBSS)
- mobile stations communicate peer-to-peer

→ also called peer-to-peer mode

WLAN: internetworking



WLAN: Extended Service Set

⟶ internetworking between BSS's through APs

⟶ mobility and handoff

- extended service set (ESS): shared SSID
- APs are connected by distribution system (DS)

→ typically: Ethernet switch

How do APs and Ethernet switches know where to forward frames?

→ spanning tree

→ IEEE 802.1 (Perlman's algorithm)

Learning bridge: source address discovery

→ log source MAC address of incoming frames per interface

→ initially (or if unclear): broadcast

→ simple form of routing

→ adequate for small systems

Misconfiguration issues resulting in loops

→ modifications to spanning tree algorithm

Additional headache: mobility

$\longrightarrow$ roaming

$\longrightarrow$ how to perform handoff

$\longrightarrow$ mobility management at link vs. network layer

$\longrightarrow$ link layer handoff dominant (vs. Mobile IP)

Mobility between BSS's in an ESS

- Association

  $\rightarrow$ registration process

  $\rightarrow$ AP sends out periodic beacon frame

  $\rightarrow$ mobile station (MS) associates with one AP

- Disassociation

  $\rightarrow$ upon permanent departure: notification

Handoff from old to new AP:

- Reassociation

  → movement of mobile from one AP to another

  → mobile initiated

  → e.g., AP's signal strength is low

  → passive (beacon) or active (probe) scanning to find alternate AP

  → go through association process

- Handoff

  → inform new AP of old AP

  → forwarding of buffered frames from old to new AP in ESS

IEEE 802.11b/g WLAN spectrum 2.4–2.4835 GHz:

→ 11 channels (U.S.)

→ 2.412 GHz, 2.417 GHz, . . ., 2.462 GHz

→ unlicensed ISM (Industrial, Scientific, Medical) band

→ global: 2.4–2.4835 GHz

→ up to 14 channels (e.g., Japan)

IEEE 802.11a: 5.15–5.35 GHz and 5.725–5.825 GHz

→ UNNI (unlicensed National Information Infrastructure)

→ 23 non-overlapping channels

IEEE 802.11n: both 2.4 and 5 GHz

→ 2.4 GHz: backward compatible

→ 802.11g/n: OFDM

→ uses multiple antennae

→ called MIMO (multiple input multiple output)

→ parallel transmission

IEEE 802.11ac: extension of n/g with more streams, 256-QAM

→ Wi-Fi 5

→ 5 GHz

→ multi user (MU)-MIMO: transmit to multiple users using multiple antennae

→ AP (access point) performs subcarrier allocation

IEEE 802.11ax: Wi-Fi 6 and 6E

→ 1024 QAM

→ Wi-Fi 6E uses 6 GHz band: 5.925-7.125 GHz

→ OFDMA

→ BSS coloring: energy conservation and spatial reuse

IEEE 802.11be: Wi-Fi 7

→ 4096 QAM

→ bandwidth increased to 320 MHz from 160 MHz

→ multi-link: parallel transmission over 2.4, 5, 6 GHz bands

BSS coloring advantage example: WLAN in HAAS

Non-interference specification for 2.4 GHz band (802.11b)

- each channel has 22 MHz bandwidth
- require 25 MHz channel separation

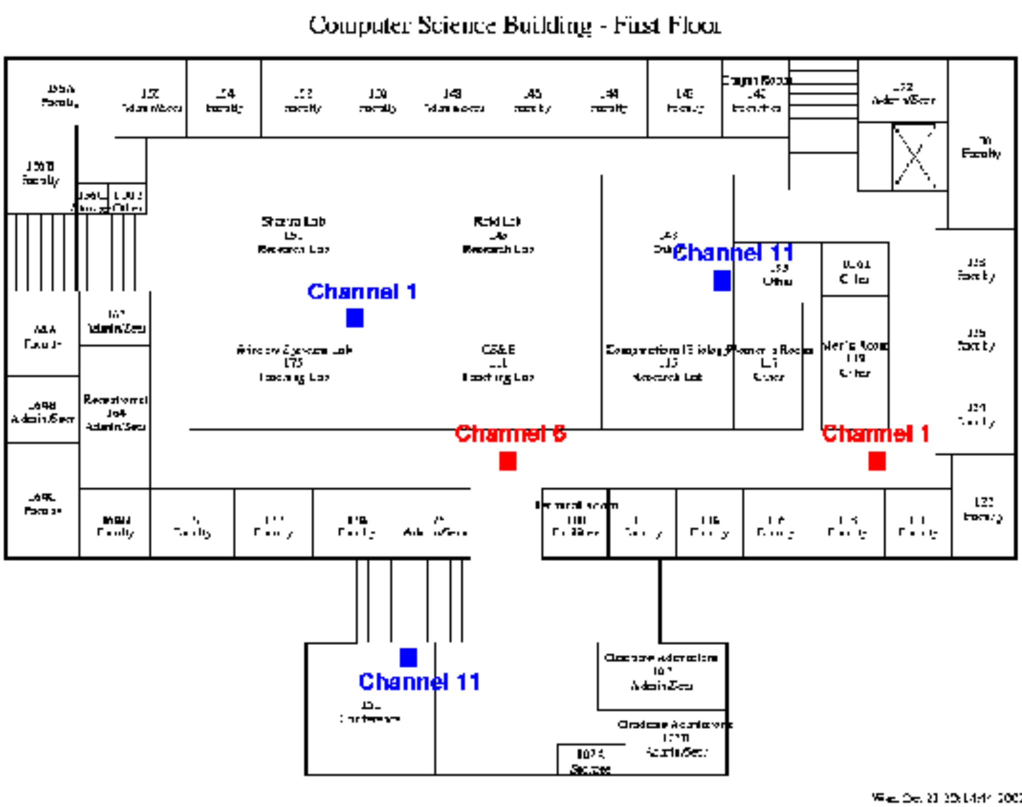
$\longrightarrow$ thus, only 3 concurrent channels possible

$\longrightarrow$ e.g., channels 1, 6 and 11

$\longrightarrow$ 3-coloring. . .

HAAS: BSS's belonging to CS and NSL

First floor frequency reuse:



First floor:

→ APs: color CS BSS frames blue and NSL frames red

→ if blue station on channel 1 senses blue frame transmission then wait

→ if blue station on channel 1 senses red frame transmission then do not wait

Two benefits.

Spatial frequency reuse: if blue channel 1 area is well separated from red channel 1 area, simultaneous frame transmission in the two areas will likely succeed

→ despite collision

→ capture effect

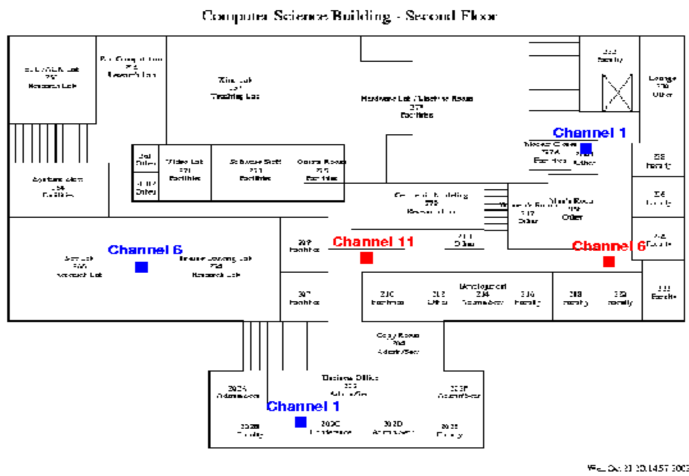
Energy conservation: as soon as different frame coloring detected, stop decoding frame which reduces processing, hence energy consumption

Second floor example:

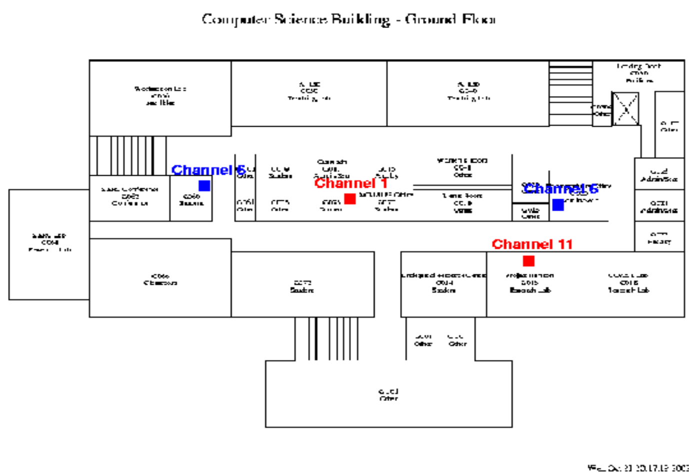
→ channel 6 coloring: same as first floor

→ channel 1 coloring: different coloring for two CS APs

Second floor frequency reuse:



Ground floor frequency reuse:



Basic IEEE 802.11 medium access control (MAC):

$\longrightarrow$ CSMA/CA with exponential backoff

$\longrightarrow$ explicit positive ACK frame

$\longrightarrow$ optional feature: CA (collision avoidance)

Two modes for MAC operation:

- Distributed coordination function (DCF)

  $\rightarrow$ uses CSMA

- Point coordination function (PCF)

  $\rightarrow$ polling-based priority

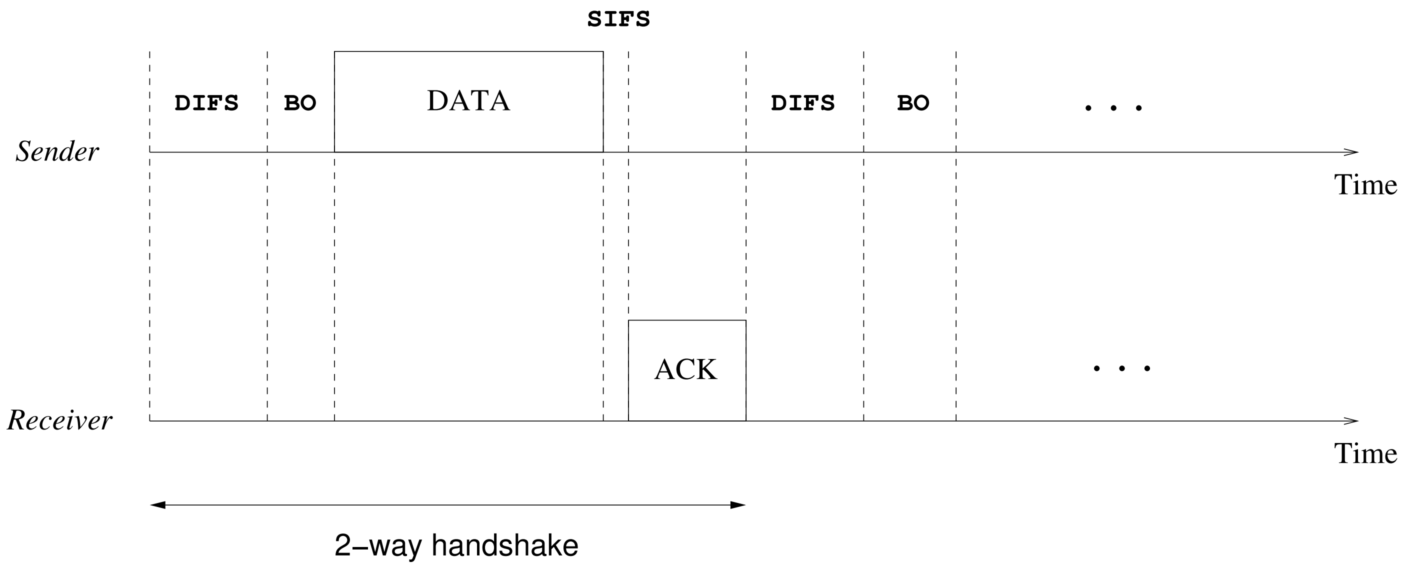
  $\rightarrow$ telephony support

  $\rightarrow$ not used

- Addition of OFDMA resource reservation in Wi-Fi 6

  $\rightarrow$ based on CA

Timeline without collision:



- SIFS (short interframe space): 10 μs
- Slot Time: 20 μs
- DIFS (distributed interframe space): 50 μs

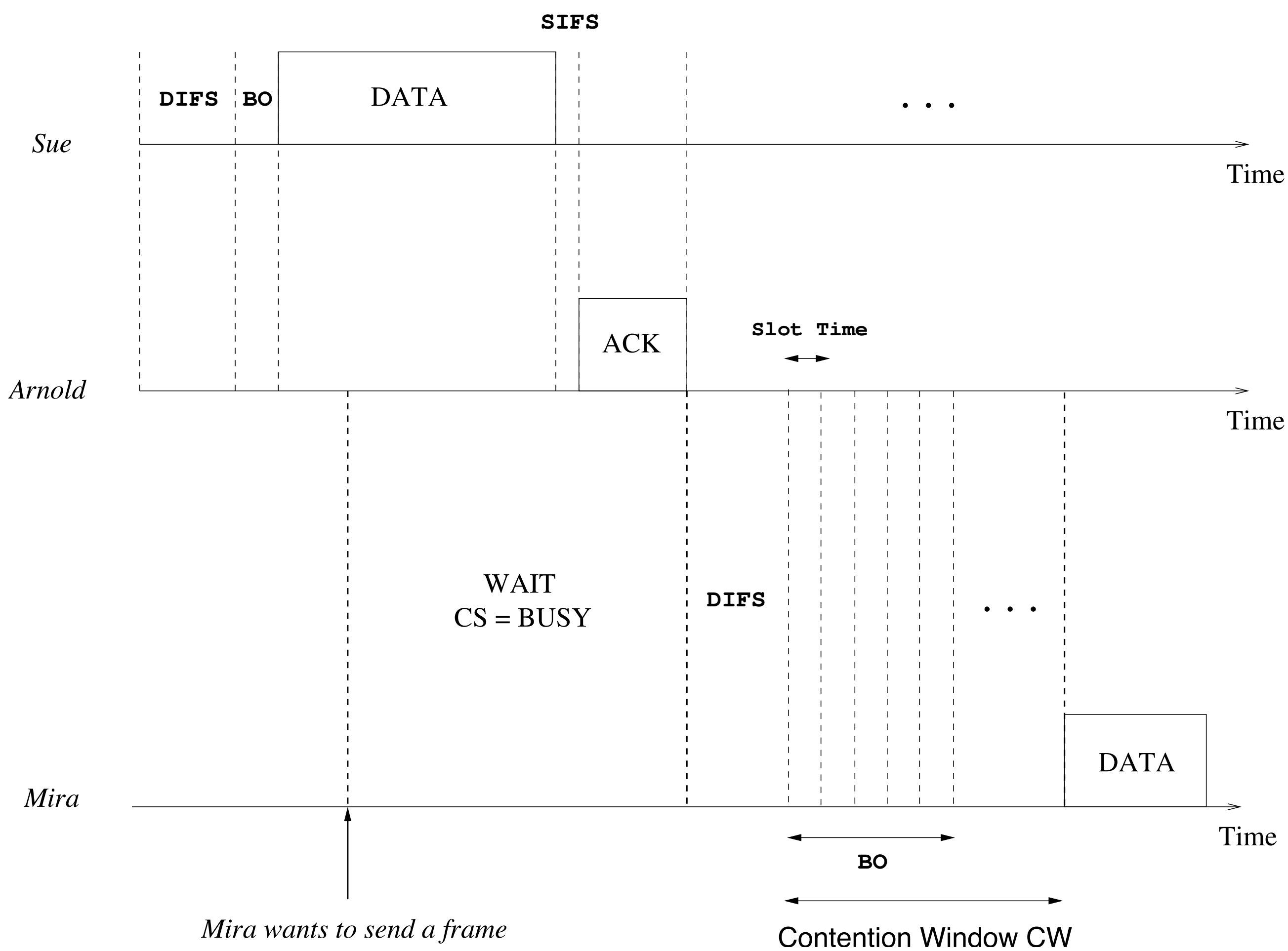
  $\rightarrow$ DIFS = SIFS + 2 $\times$ slot time
- BO: variable back-off (within one `CW`)

  $\rightarrow$ `CWmin`: 31; `CWmax`: 1023

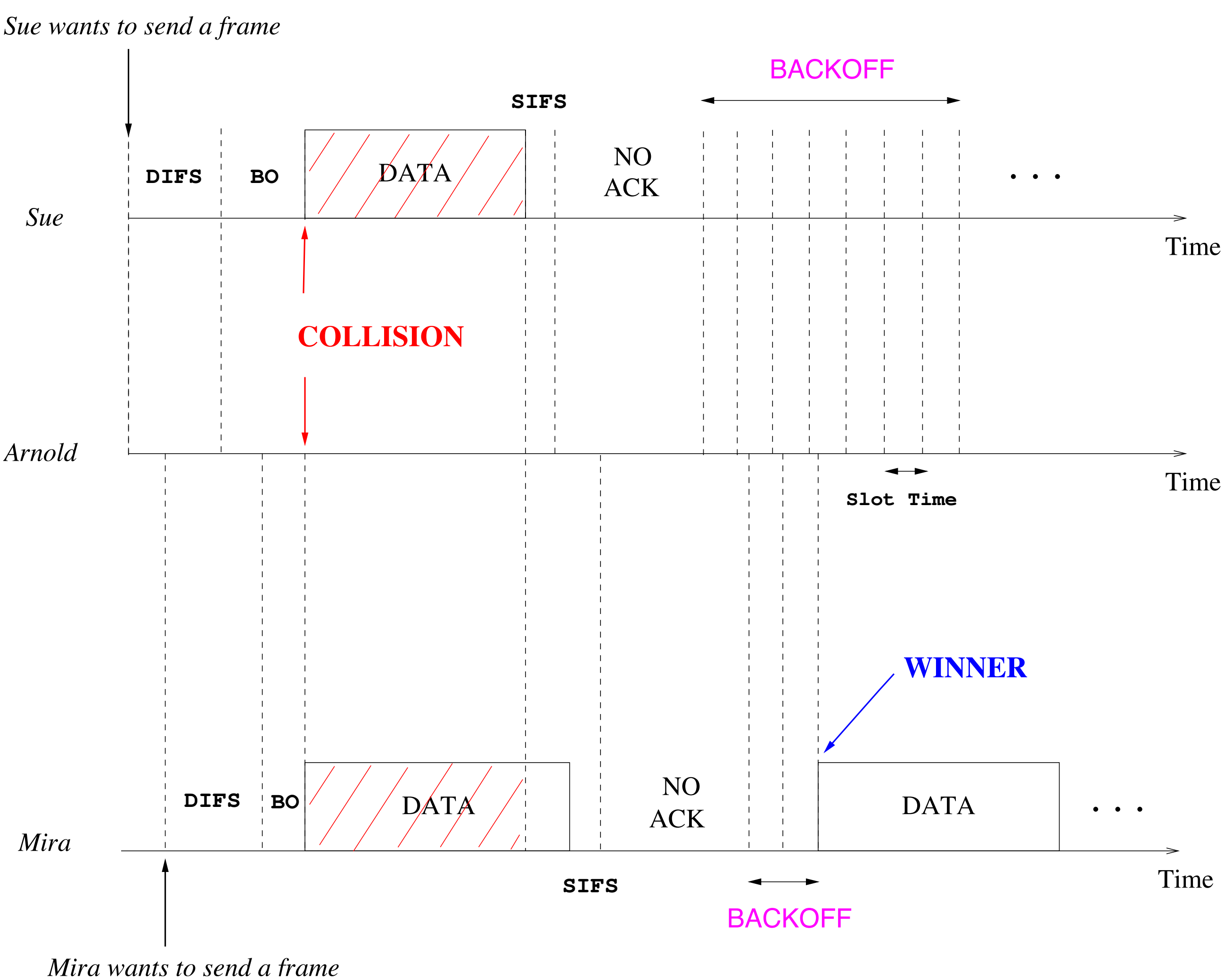
Time snapshot with Mira-come-lately:

→ Sue sends to Arnold

→ Mira joins competition later

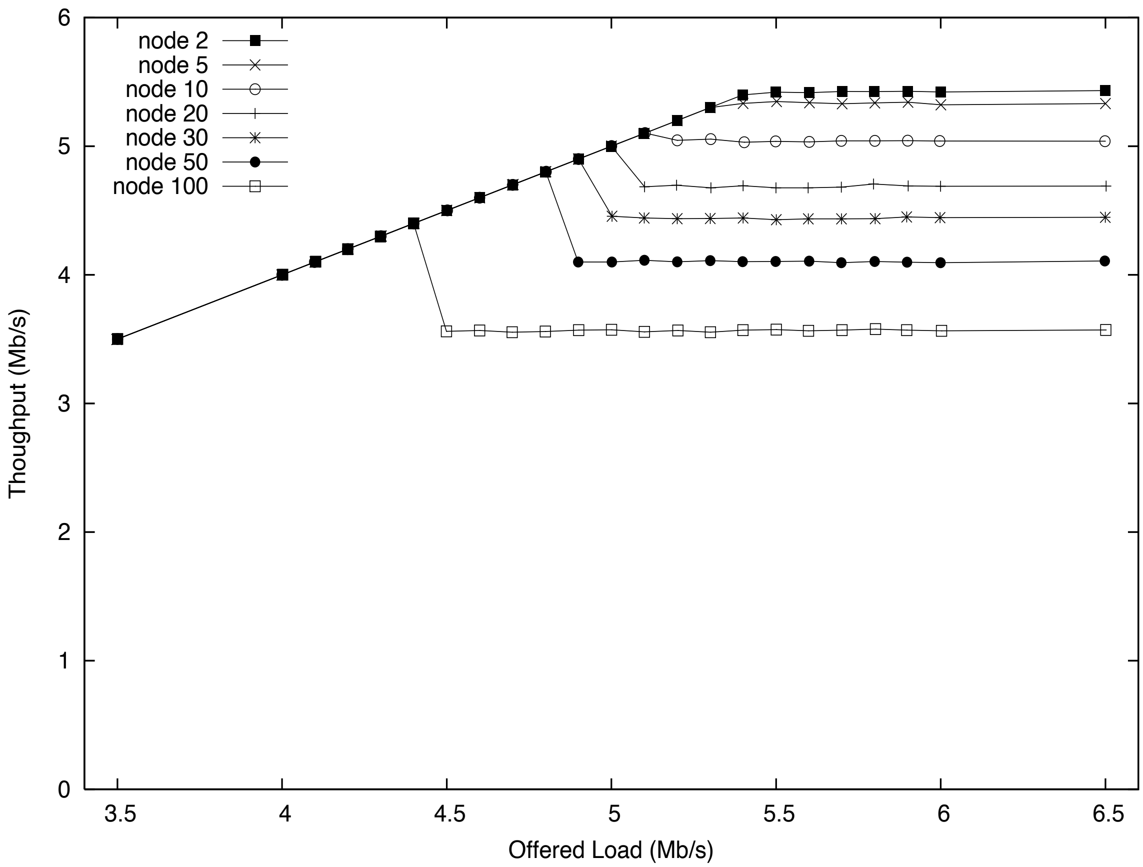


Time snapshot with collision (Sue & Mira):



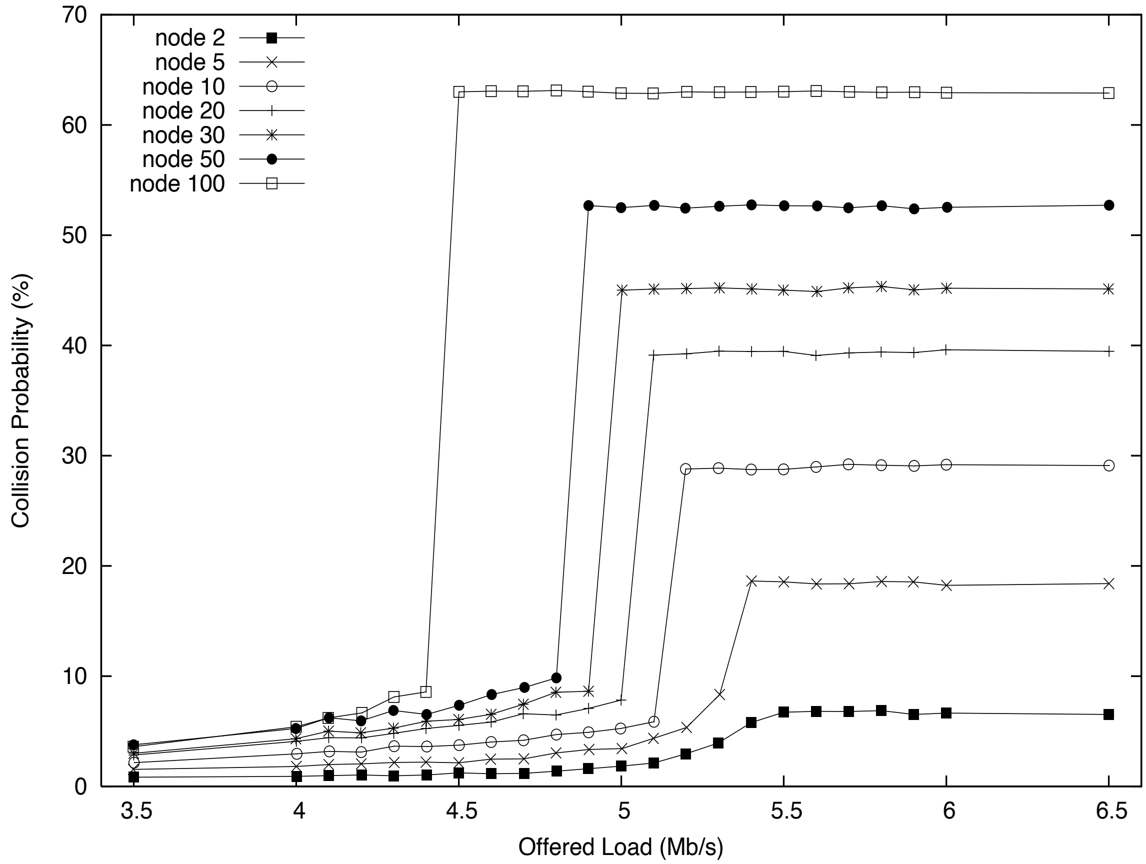
MAC throughput (802.11b):

→ simulation



MAC collision:

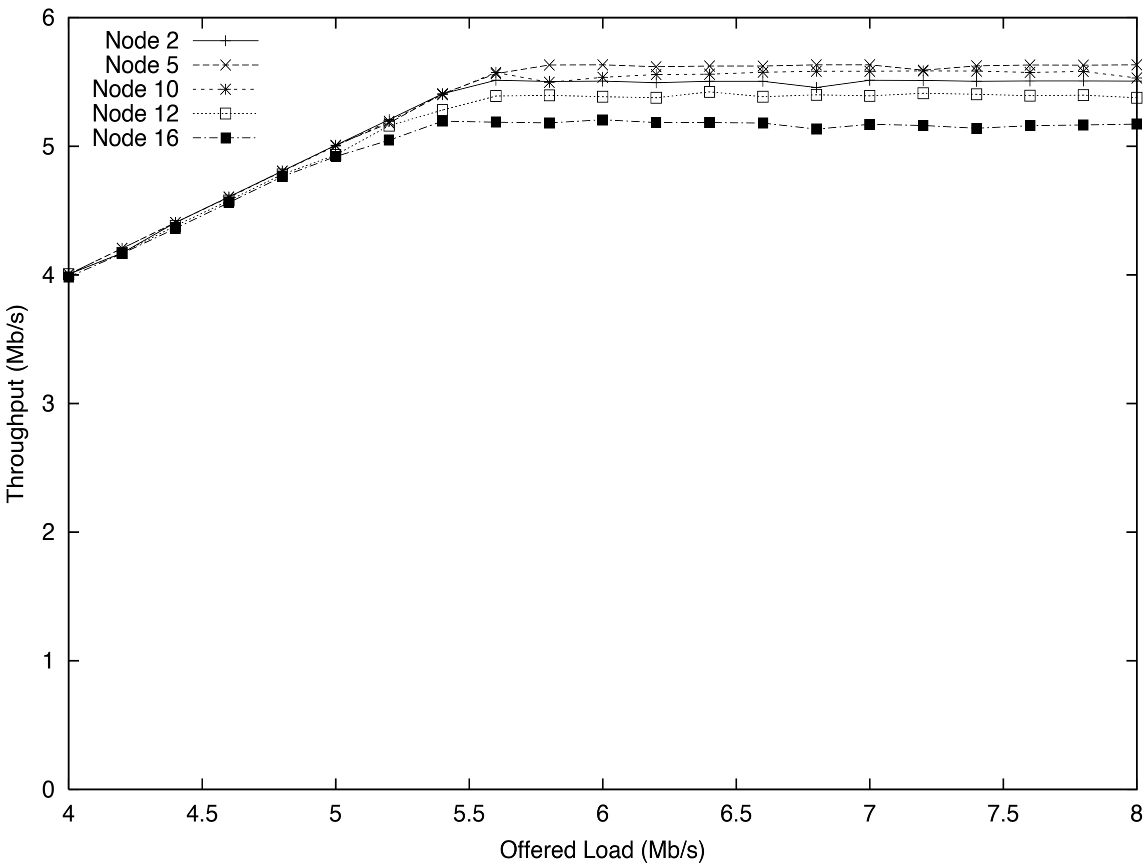
→ simulation



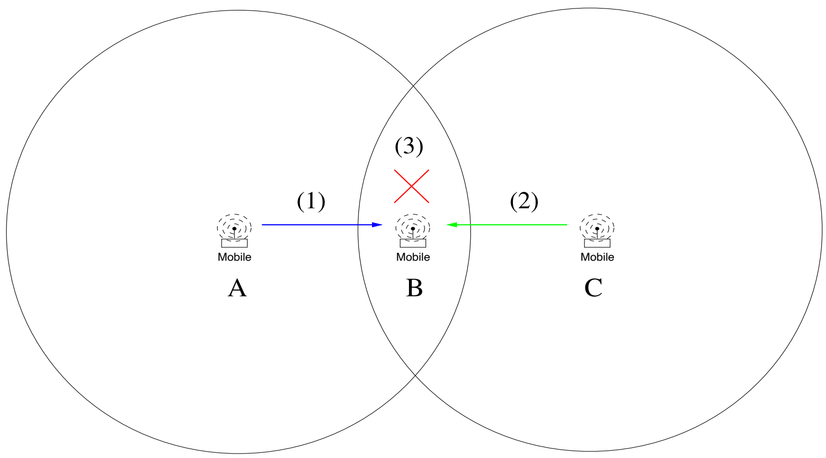
MAC throughput:

→ experiment

→ HP iPAQ pocket PCs running Linux



Hidden station problem:



Hidden Station Problem

(1) A transmits to B

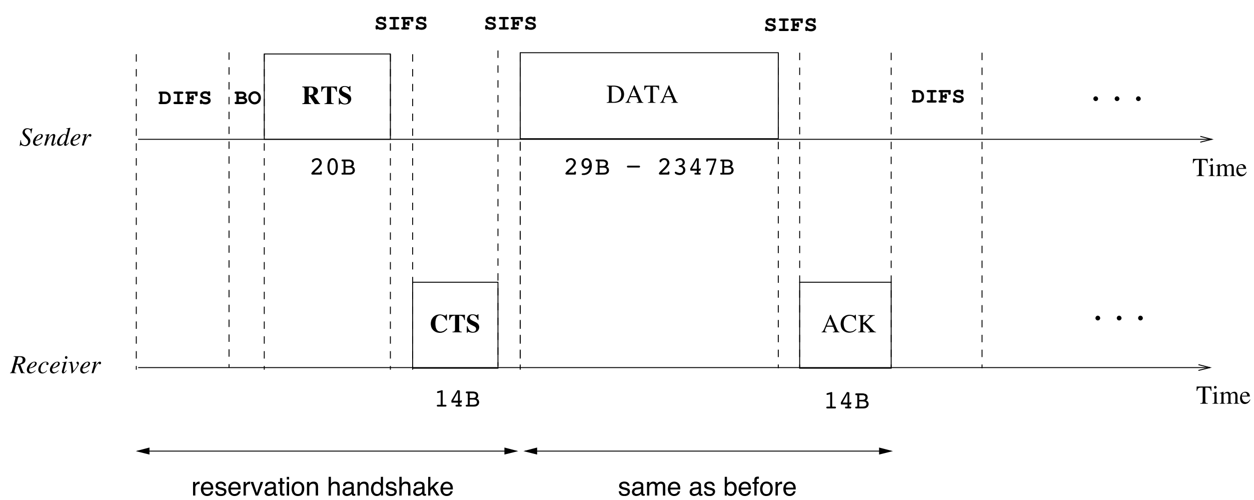
(2) C does not sense A; transmits to B

(3) interference occurs at B: i.e., collision

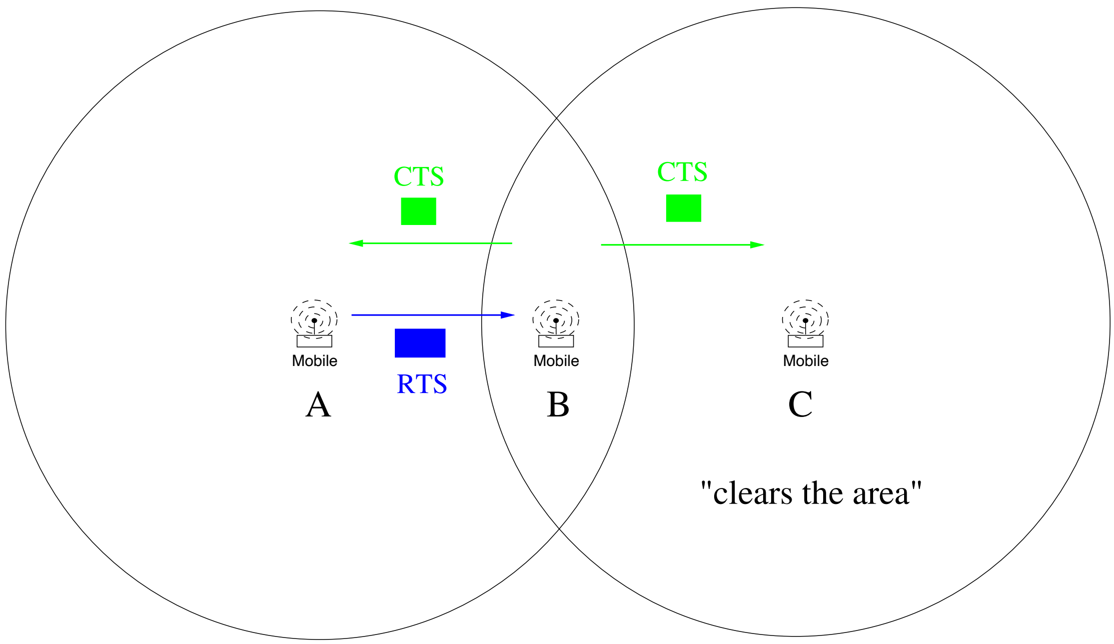
Hidden station problem: introduce CA feature

$\longrightarrow$ RTS/CTS reservation handshake

- Before data transmit, perform RTS/CTS handshake
- RTS: request to send
- CTS: clear to send



Hidden station problem: RTS/CTS handshake "clears" hidden area



RTS/CTS Handshake

RTS/CTS perform only if data > RTS threshold

→ why not for small data?

Was not utilized in real-world deployments

→ repurposed OFDMA resource reservation in Wi-Fi 6

OFDMA resource reservation by AP in IEEE 802.11ax and 802.11be

→ subcarriers bundled into resource units (RUs)

→ TXOP (transmit opportunity) feature of 802.11e

At TXOP, AP acts as coordinator and scheduler: allocate RUs to stations for downlink and uplink communication

Downlink:

→ AP transmits special RTS, MU (multiuser)-RTS

→ MU-RTS contains RU assignment

→ stations not allocated RU remain silent

→ CTS handshake: RU-assigned stations send CTS via OFDMA

→ final ACK handshake to check reliable transmission

Unfairness problem of WLAN:

- spatial diversity

  → multi-path propagation

- CSMA

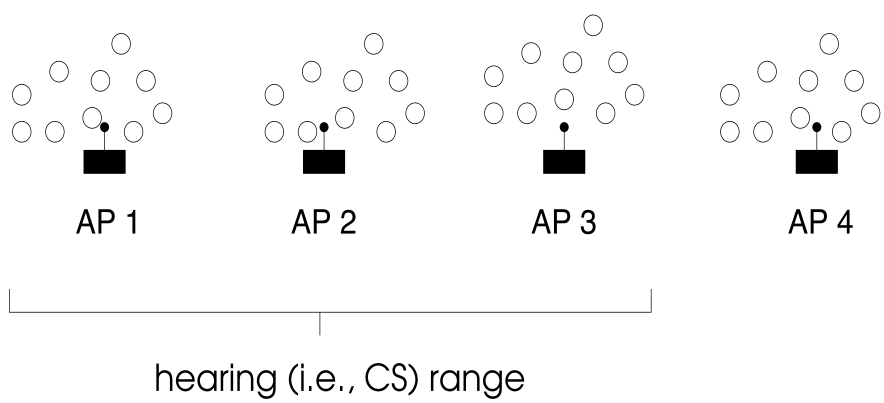
  → different user density

  → CS disadvantages those who can hear more

Example: four 802.11 hot spots, each with 10 clients

→ e.g., 4 neighboring coffee shops on a street

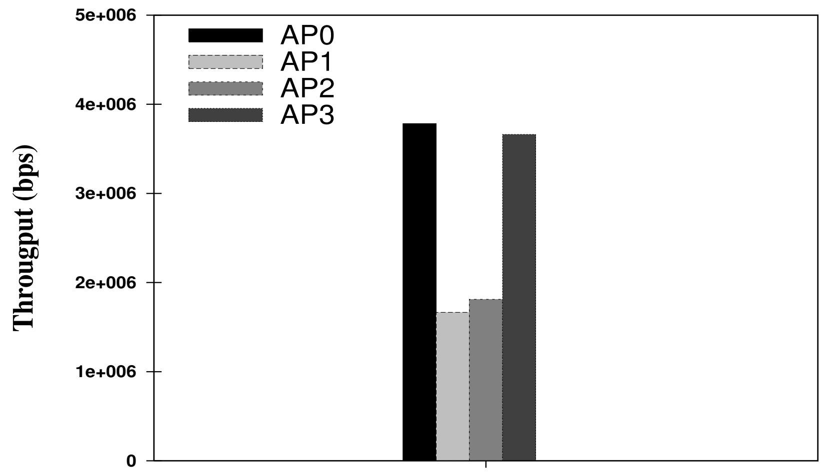
→ approximate range limitation of WLAN: ∼100 m



→ 3 neighboring hot spots (BSS's) are within hearing range of each other

→ AP1 and AP4 are outside CS range

Throughput at four hot spots:



→ middle two get half the throughput

→ depending on configuration, can be even less