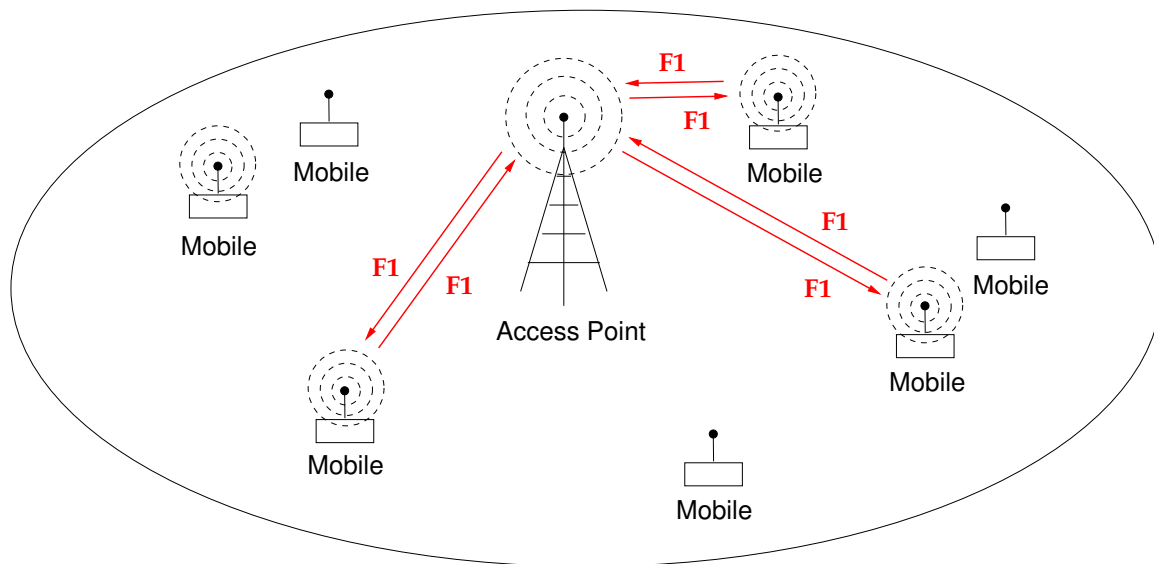


Wireless LAN (WLAN): infrastructure mode

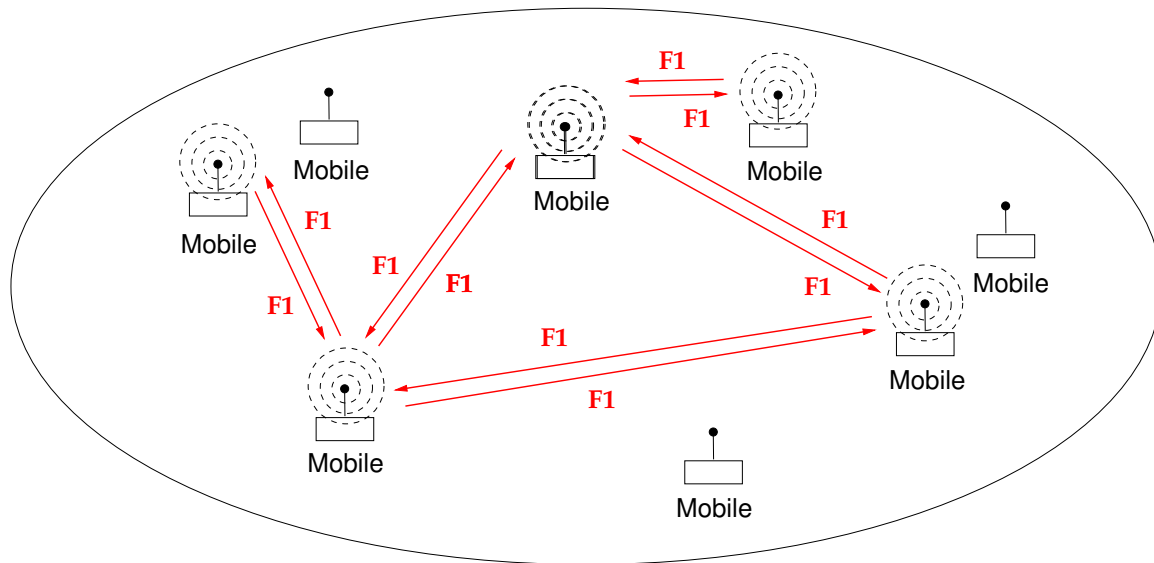


WLAN: Infrastructure Network

→ shared uplink & downlink channel $F1$

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

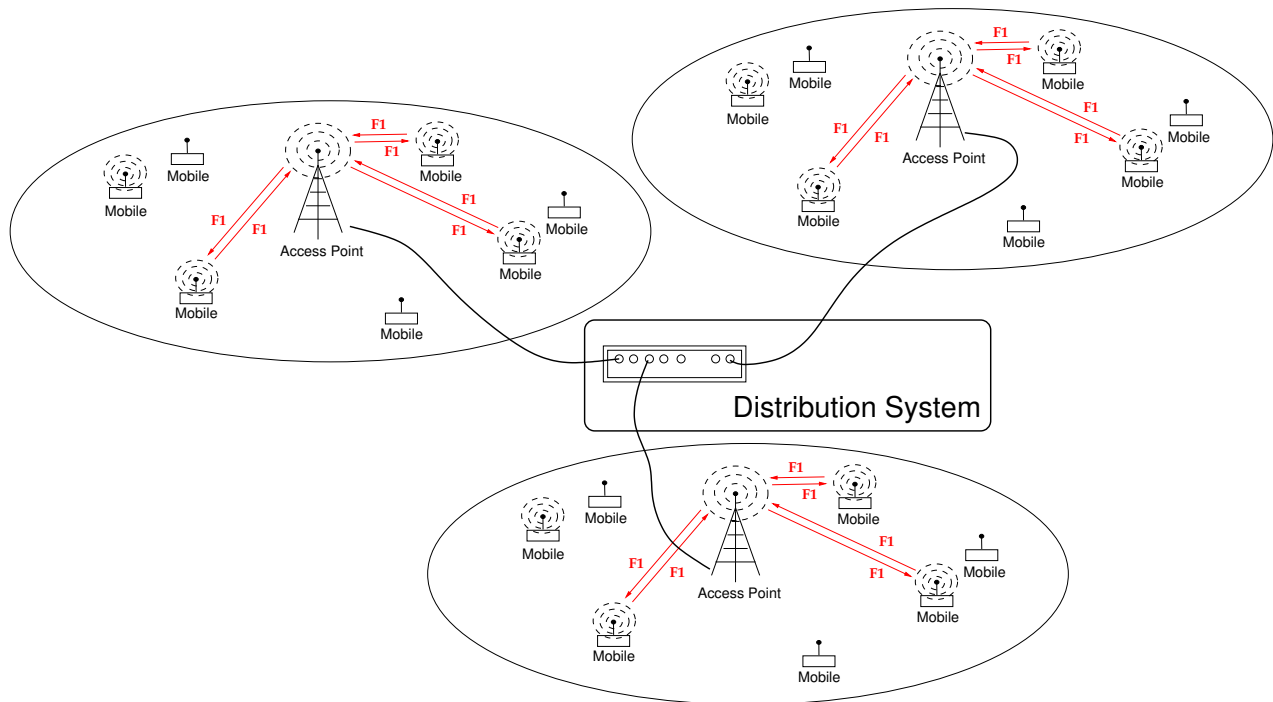
WLAN: ad hoc mode



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

- roaming
- how to perform handoff
- mobility management at link vs. network layer
- link layer handoff dominant (vs. Mobile IP)

Mobility between BSS's in an ESS

- Association
 - registration process
 - AP sends out periodic beacon frame
 - mobile station (MS) associates with one AP
- Disassociation
 - 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

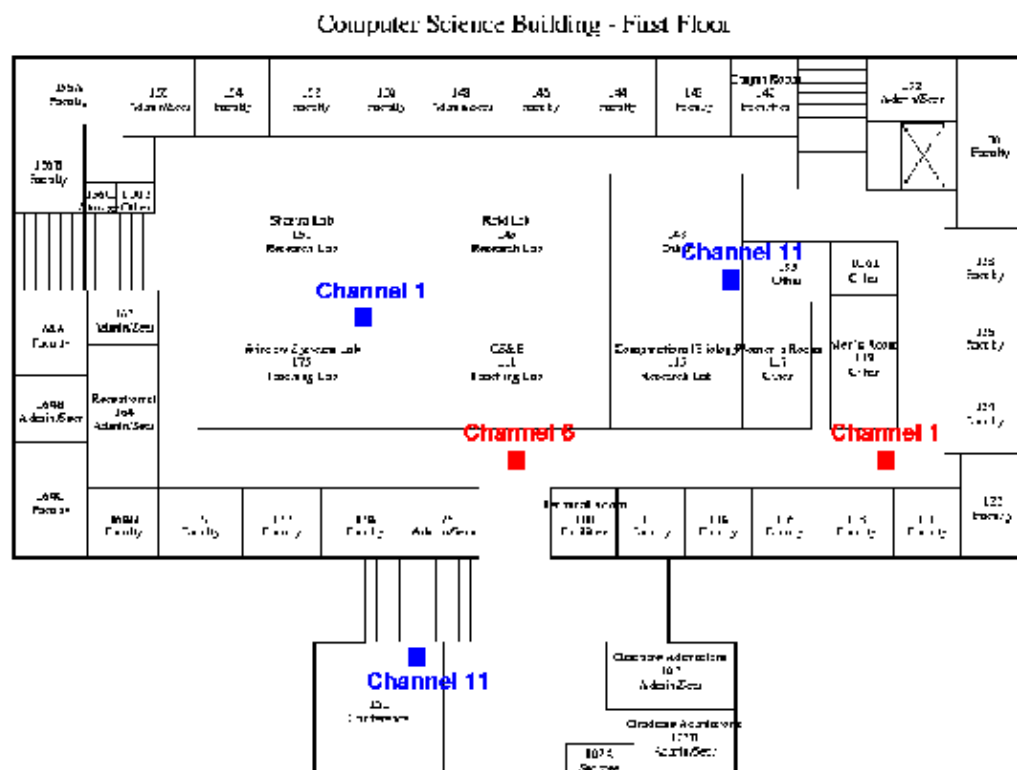
Non-interference specification for 2.4 GHz band (802.11b)

- each channel has 22 MHz bandwidth
- require 25 MHz channel separation
 - thus, only 3 concurrent channels possible
 - e.g., channels 1, 6 and 11
 - 3-coloring...

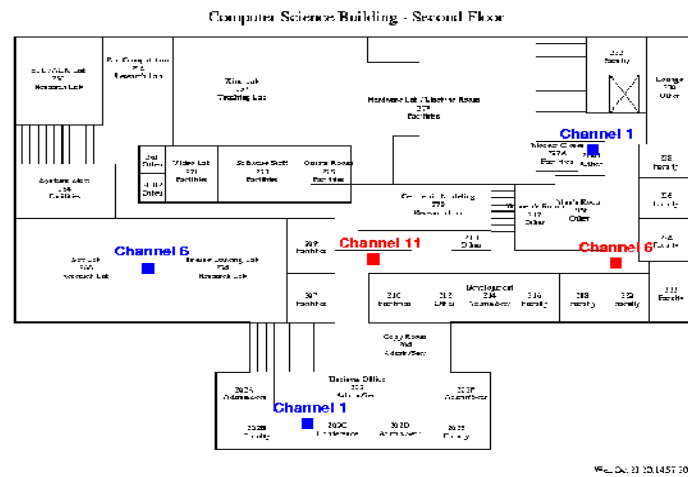
HAAS: BSS's belonging to CS and NSL



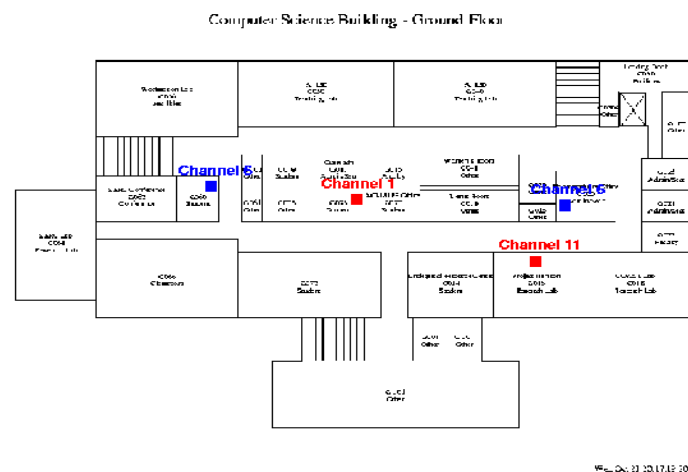
First floor frequency reuse:



Second floor frequency reuse:



Ground floor frequency reuse:



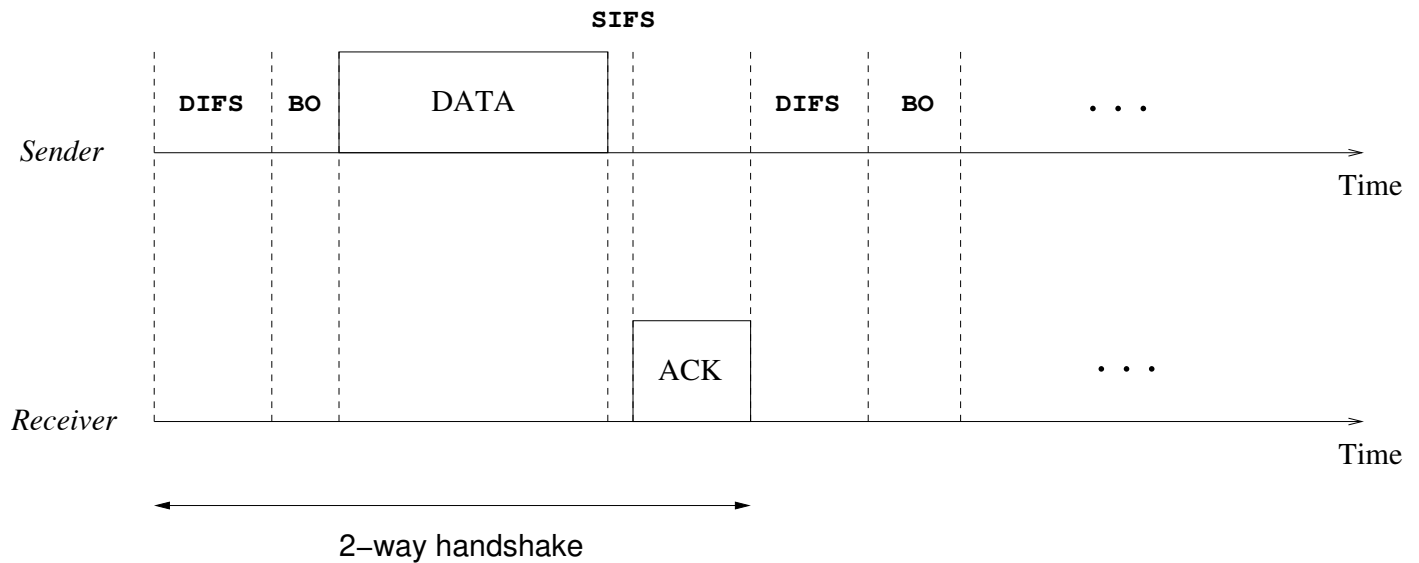
Basic IEEE 802.11 medium access control (MAC):

- CSMA/CA with exponential backoff
- explicit positive ACK frame
- optional feature: CA (collision avoidance)

Two modes for MAC operation:

- Distributed coordination function (DCF)
 - uses CSMA
- Point coordination function (PCF)
 - polling-based priority
 - telephony support
 - not used
- Addition of OFDMA resource reservation in Wi-Fi 6
 - based on CA

Timeline without collision:

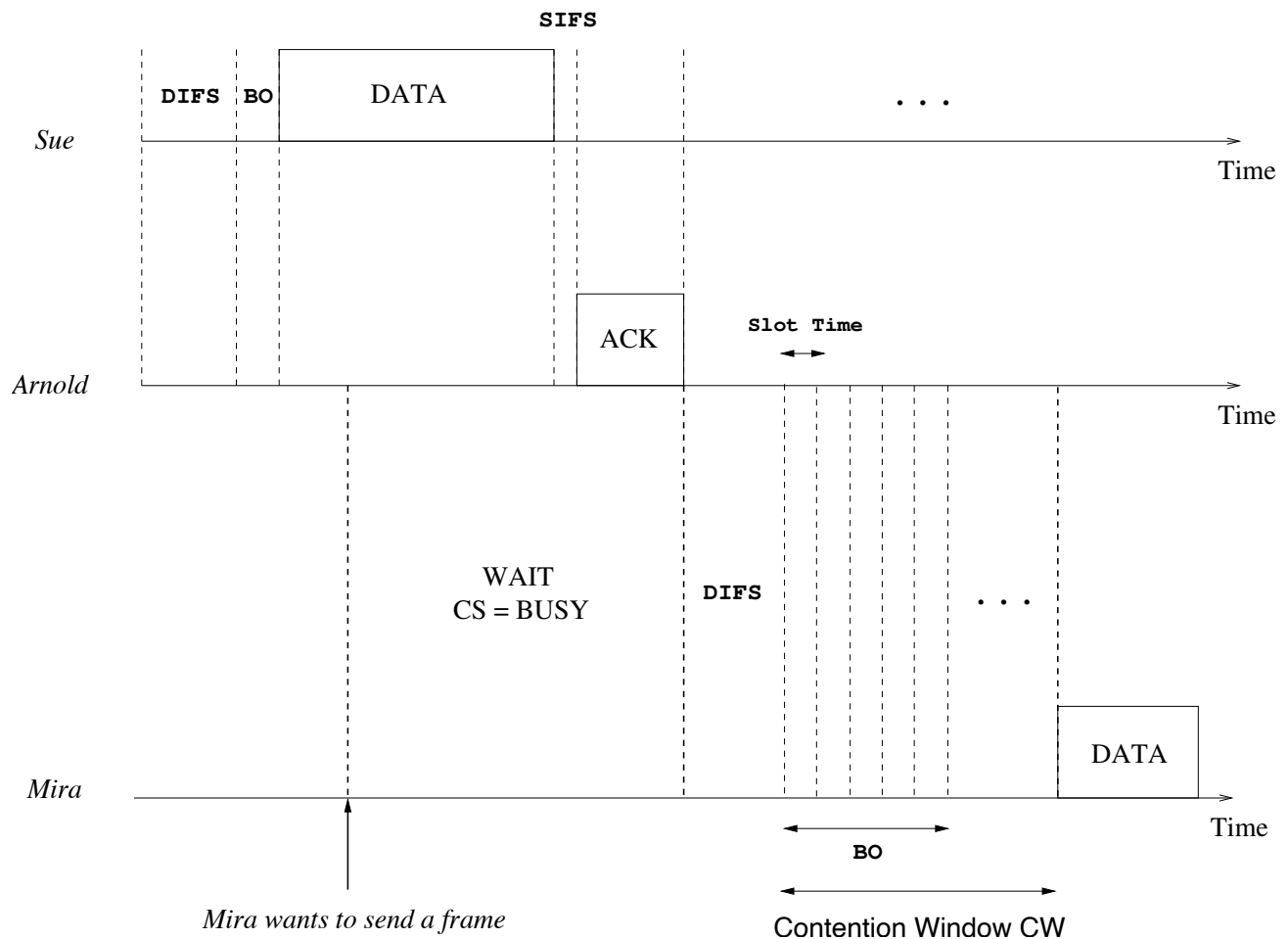


- SIFS (short interframe space): $10 \mu s$
- Slot Time: $20 \mu s$
- DIFS (distributed interframe space): $50 \mu s$
 $\rightarrow \text{DIFS} = \text{SIFS} + 2 \times \text{slot time}$
- BO: variable back-off (within one CW)
 $\rightarrow \text{CW}_{\min}: 31; \text{CW}_{\max}: 1023$

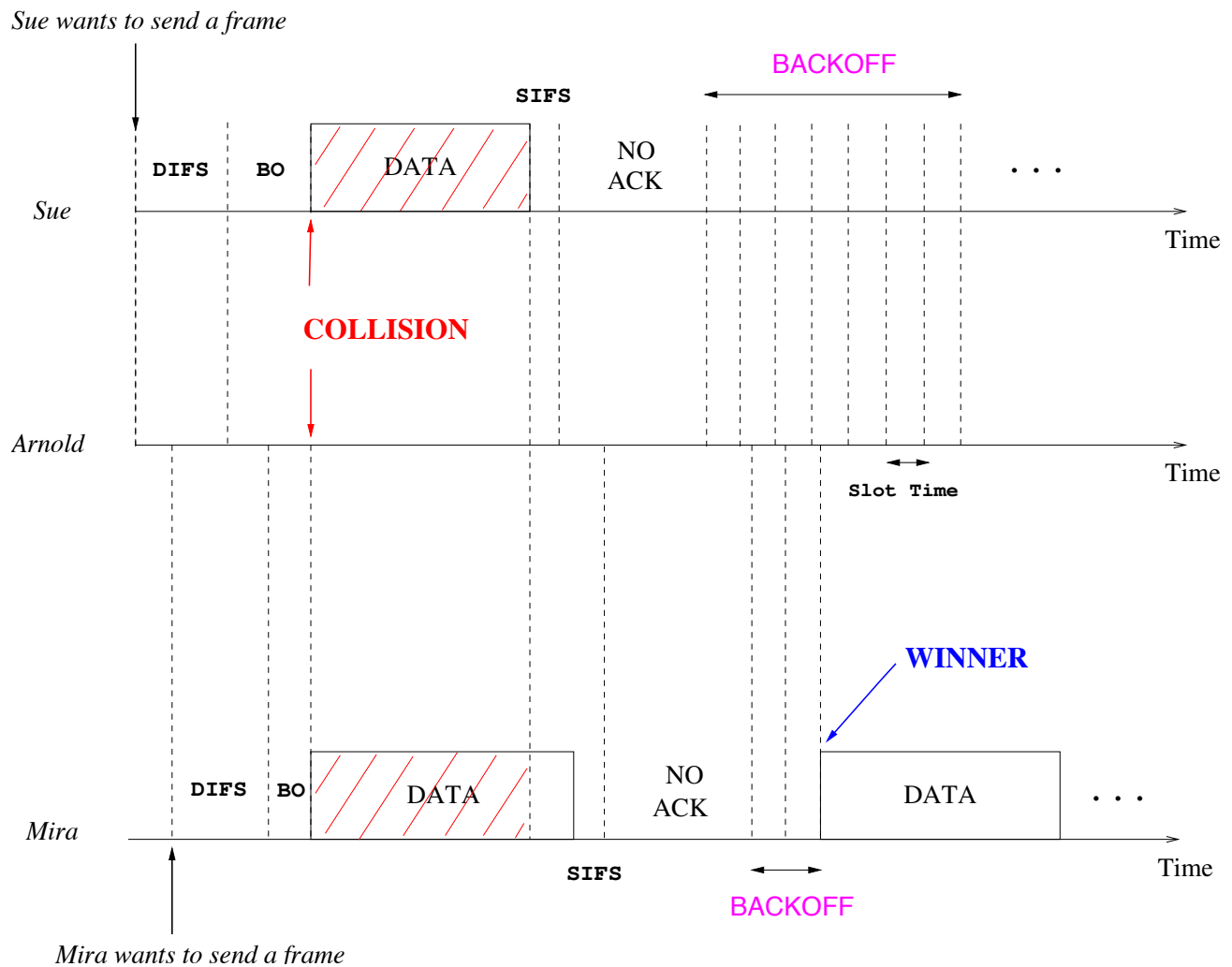
Time snapshot with Mira-come-lately:

→ Sue sends to Arnold

→ Mira joins competition later

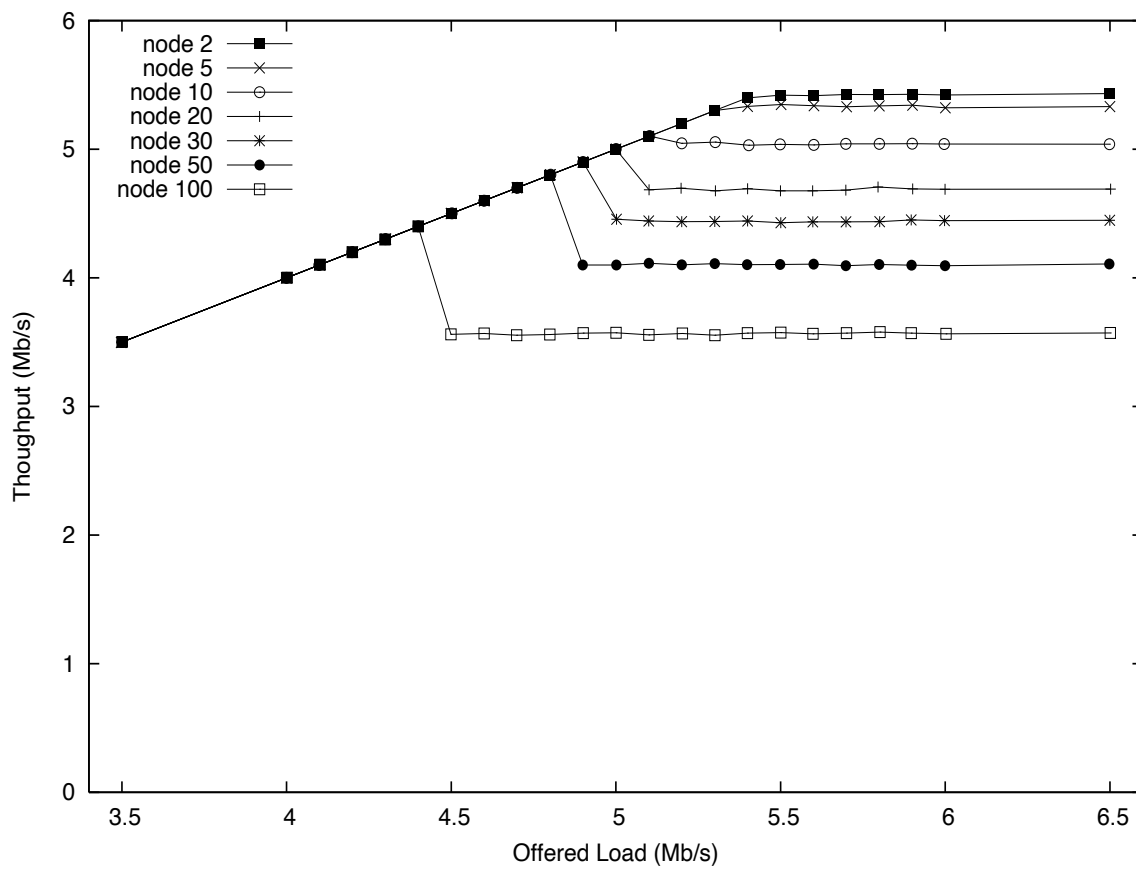


Time snapshot with collision (Sue & Mira):



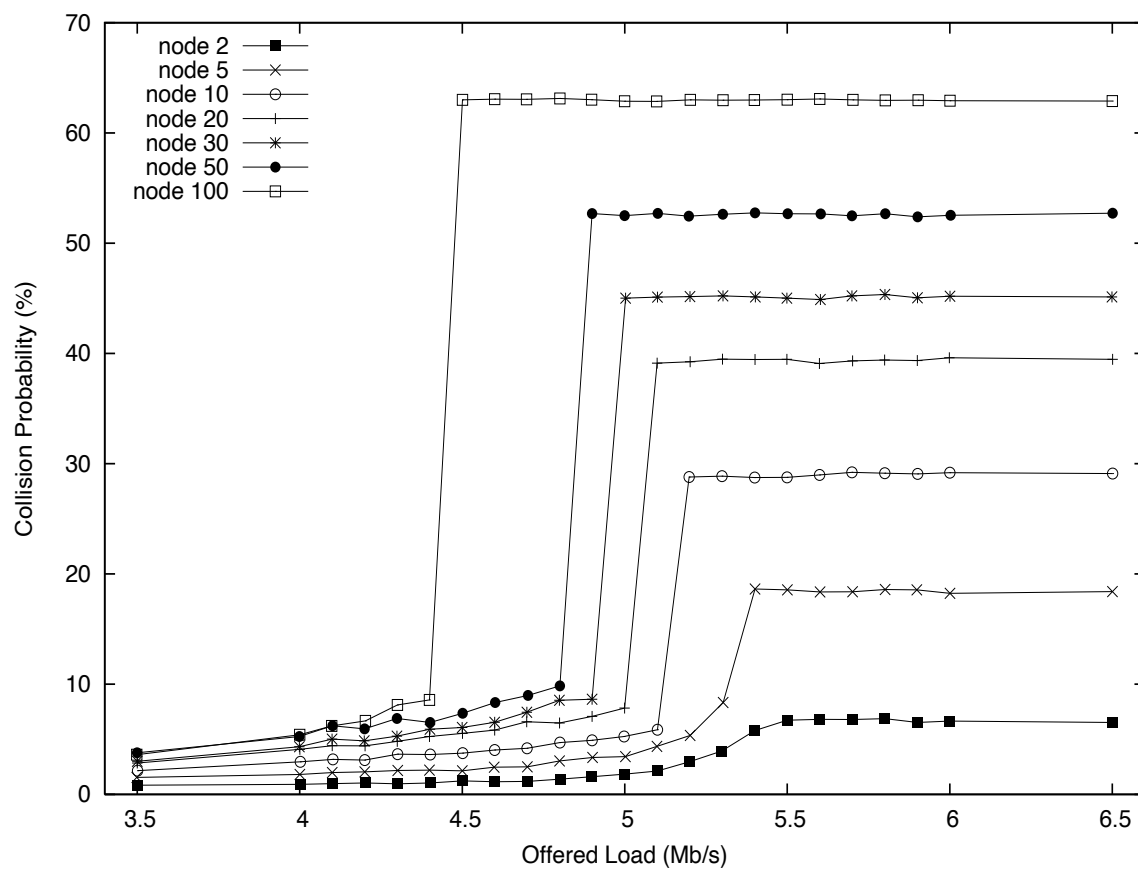
MAC throughput (802.11b):

→ simulation



MAC collision:

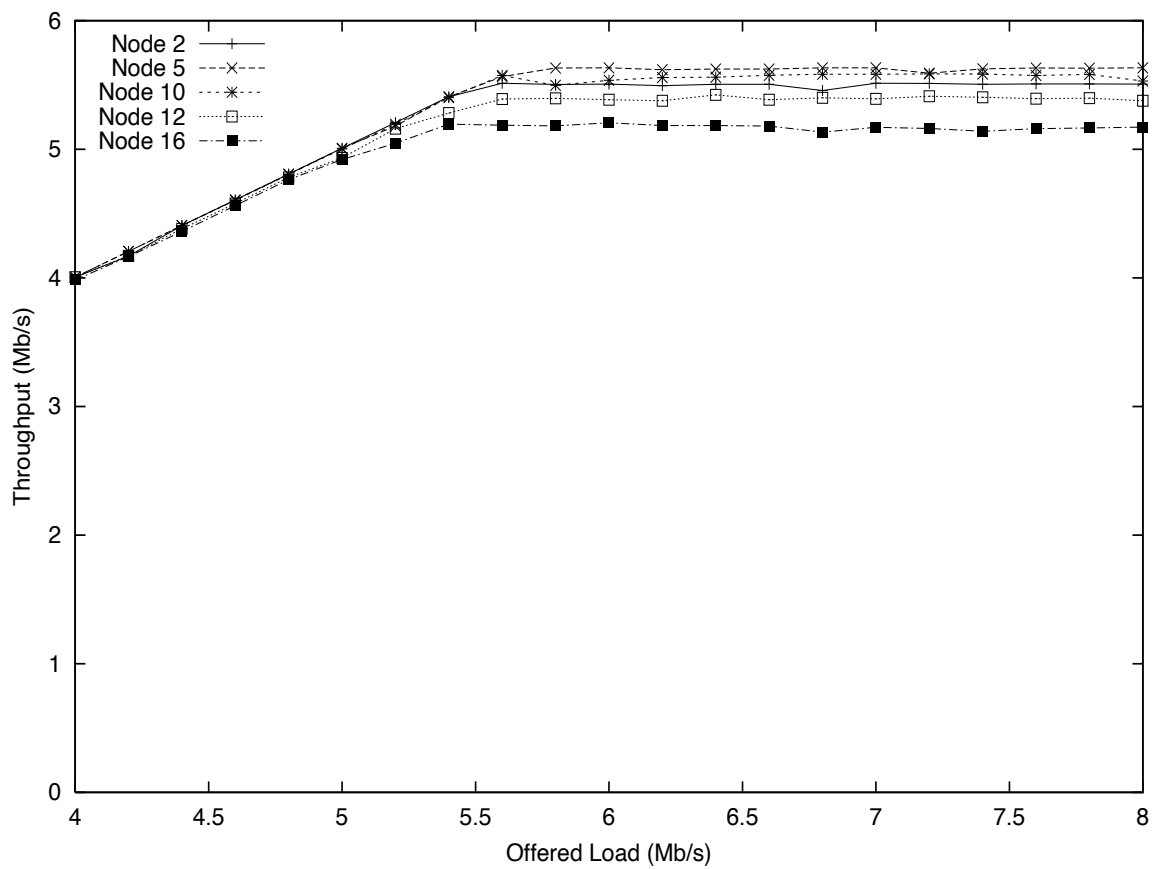
→ simulation



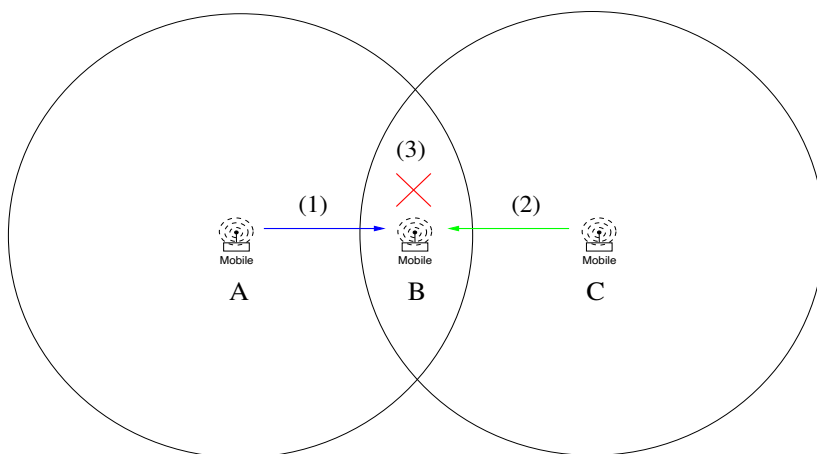
MAC throughput:

→ experiment

→ HP iPAQ pocket PCs running Linux



Hidden station problem:



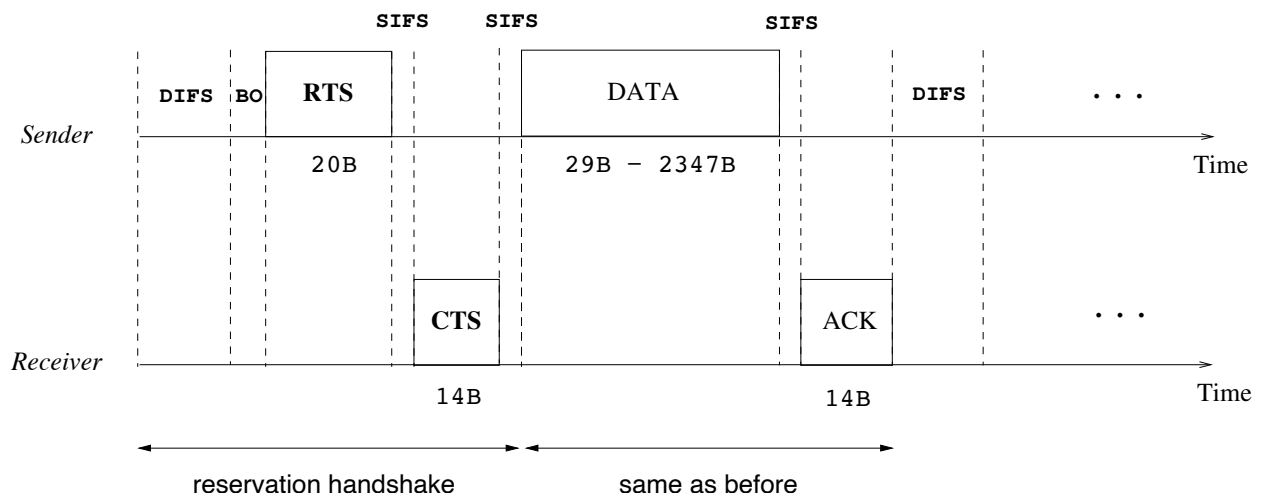
Hidden Station Problem

- (1) A transmits to B
- (2) C does not sense A ; transmits to B
- (3) interference occurs at B : i.e., collision

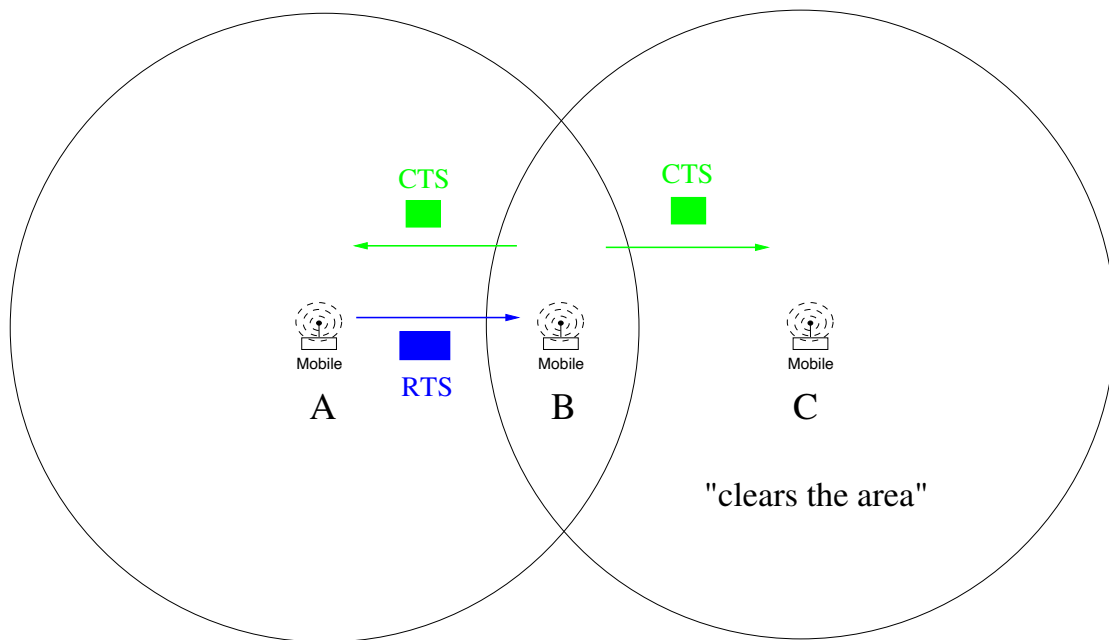
Hidden station problem: introduce CA feature

→ 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

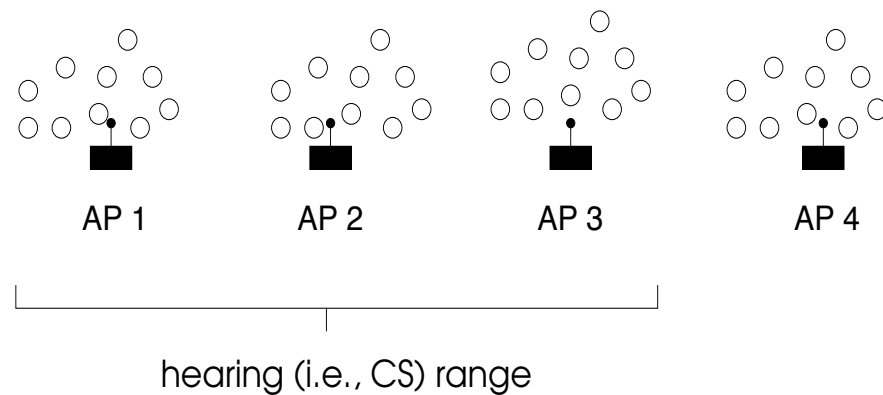
Unfairness problem of WLAN:

- 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

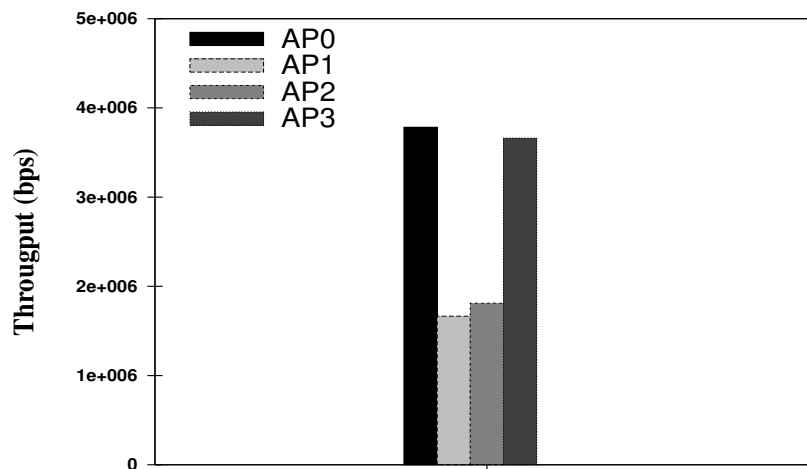
→ approximate range limitation of WLAN: ~ 100 m



→ 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