EC744 Wireless Communications Spring 2007

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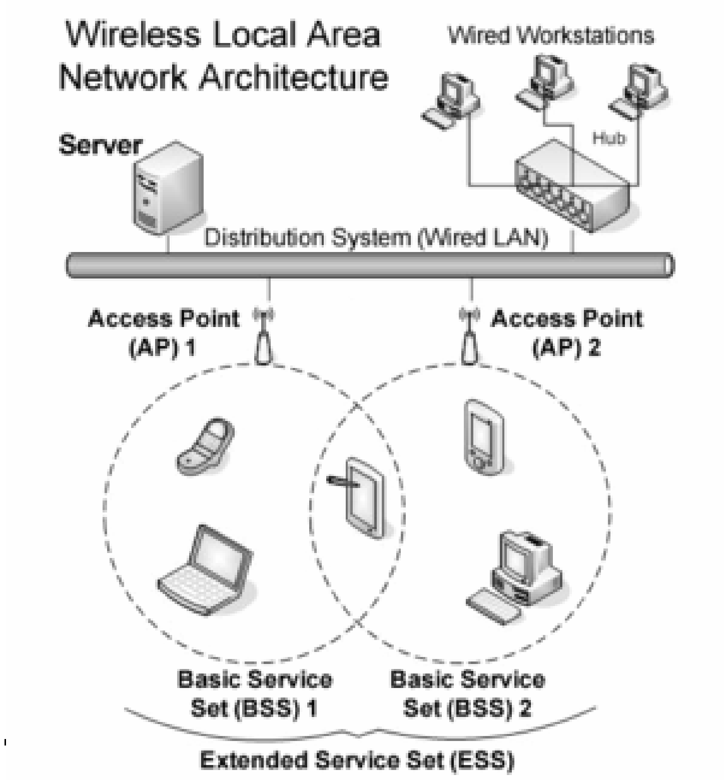
IEEE 802.11 WLAN

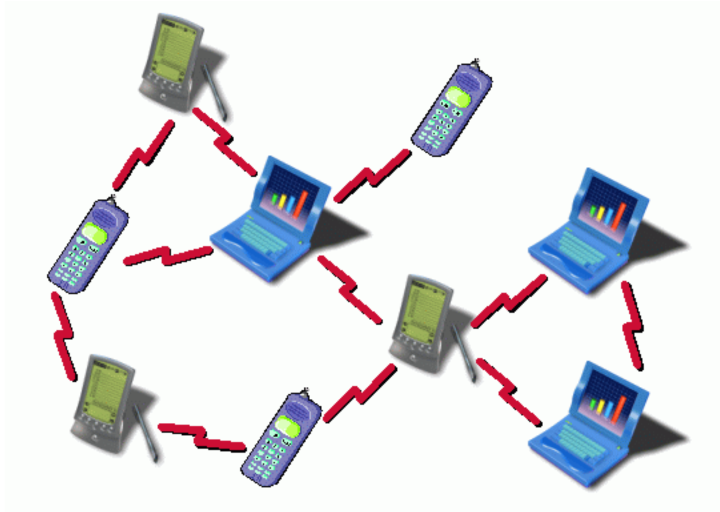
Wireless LANs

- Infrastructure based
  - Access points
  - Mobile hosts
- Connected to Internet
- Industrial standard
  - IEEE 802.11 protocols
    - De facto industrial standard
  - HiperLAN
    - European standard. Obsolete.



Ad Hoc Networks

- Formed by wireless hosts which may be mobile
- Without (necessarily) using a pre-existing infrastructure
- Routes between nodes may potentially contain multiple hops
- No standards yet, many possible solutions



Ad hoc networks

- Collection of wireless mobile nodes dynamically forming a temporary network without the use of any existing network infrastructure or centralized administration.
- Hop-by-hop routing due to limited range of each node
- Nodes may enter and leave the network
- Usage scenarios:
  - Military
  - Disaster relief
  - Temporary groups of participants (conferences)

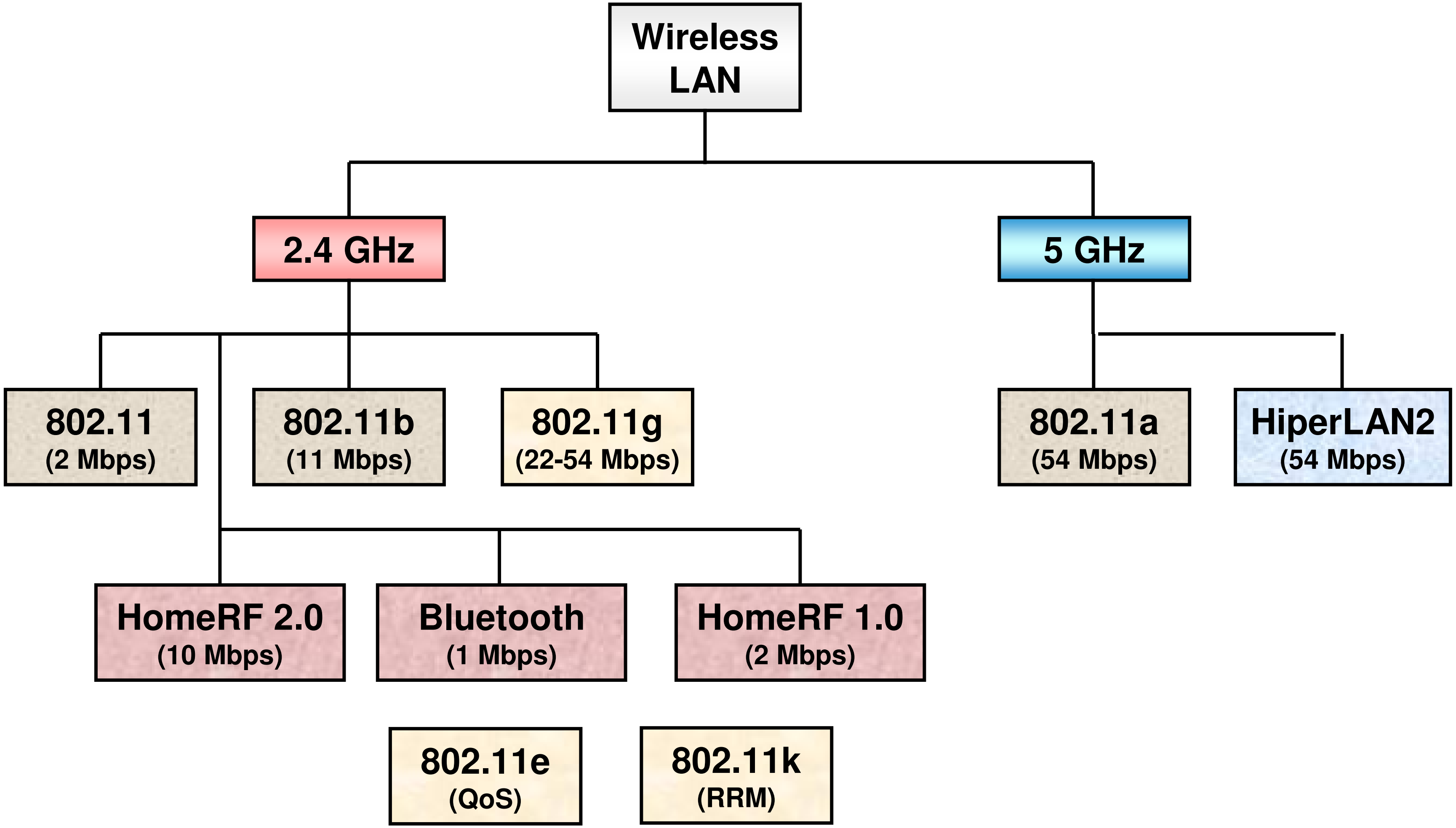
Ad hoc networks, continued

- Very mobile – whole network may travel
- Applications vary according to purpose of network
- No pre-existing infrastructure. Do-it-yourself infrastructure
- Coverage may be very uneven

Issues in ad hoc networks

- Routing performance
  - Routes change over time due to node mobility
  - Would like to avoid long delays when sending packets
  - But would like to avoid lots of route maintenance overhead
  - Want as many participating nodes as possible for greater aggregate throughput, shorter paths, and smaller chance of partition
- Medium Access Control
  - Admission control
  - Collision avoidance
  - Mobility
  - QoS

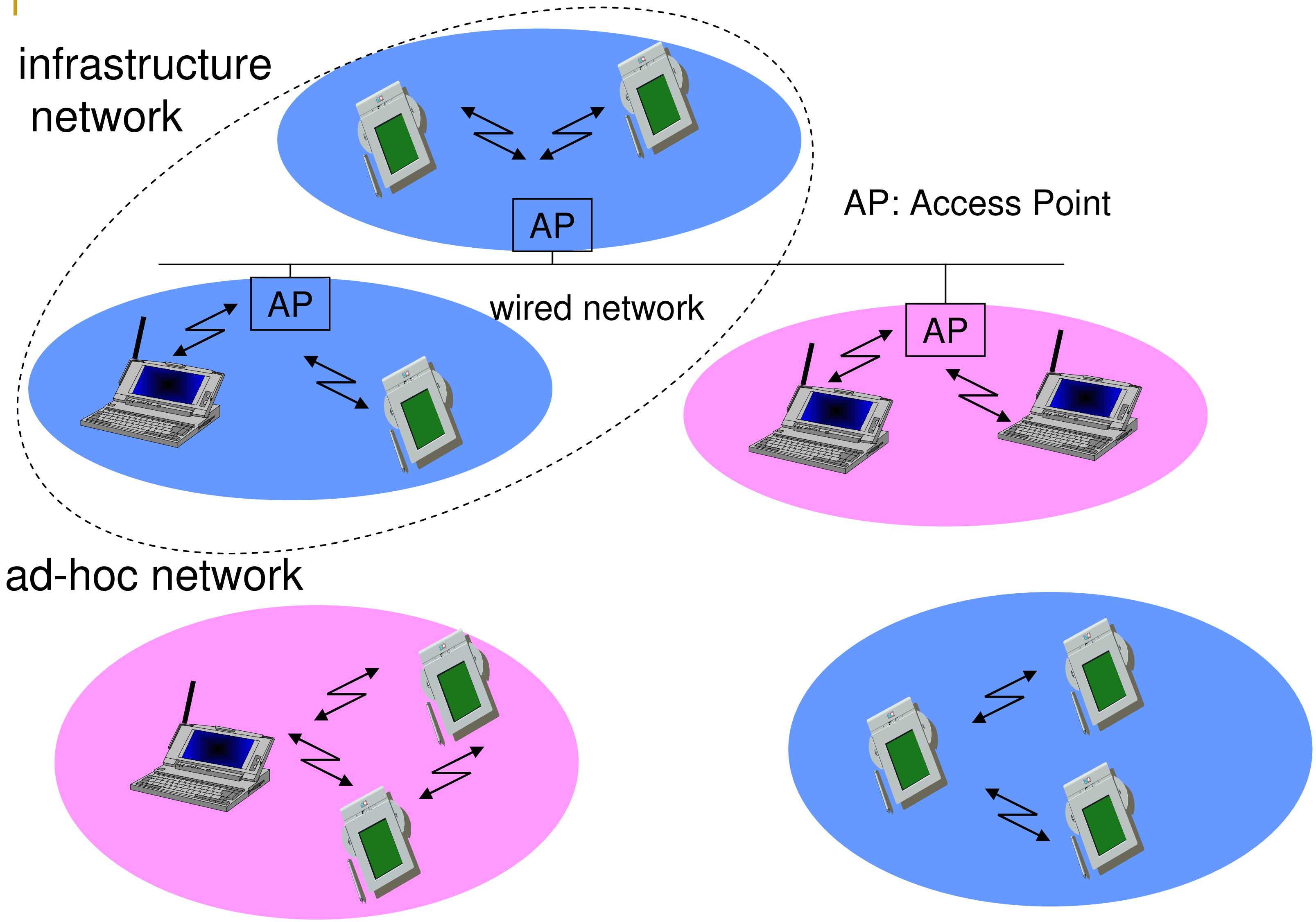
WLAN: Standards



Requirements

- Collision avoidance
  - Basic task — medium access control
- Energy efficiency
- Scalability and adaptivity
  - Number of nodes changes overtime
- Latency
- Fairness
- Throughput
- Bandwidth utilization

Infrastructure and Adhoc Networks



Source: Schiller

Multi-channel Protocols

- Fixed assignment approaches
  - Allocate channels to a fixed number of transceivers
  - Central server (AP) makes allocation assignment
  - Great for cellular networks
- Examples
  - TDMA — each channel has different time slot
  - FDMA — each channel has different frequency
  - CDMA — each channel has different code

Fixed Assignment MACs

- Given a static number of users
  - Can schedule each user evenly across available spectrum
- Advantage
  - Efficiently assign spectrum evenly to users
  - Fair
  - "guaranteed" slice of spectrum
  - Minimal interference and conflicts
- Disadvantages
  - Requires single (central) entity to perform assignment
  - Does not adapt well to changing network
    - Assumes equal use of B/W by each transceiver
- No contention
  - Scales to large # of users (hence ideal for cellular)

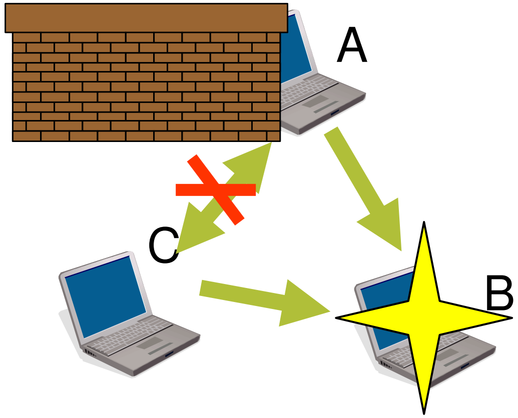
Problem with Fixed Assignment

- Assignment for given set of users
  - Can be recomputed over time by central entity
- Assumes uniform traffic model across users
  - Every user has same “slice” of bandwidth
- What about data networks such as Wireless LAN?
  - # of users changes quickly over time
  - Each user’s bandwidth requirement varies over time
  - No central entity to compute assignment
  - Need distributed approach to media access

Cotention-based Protocols

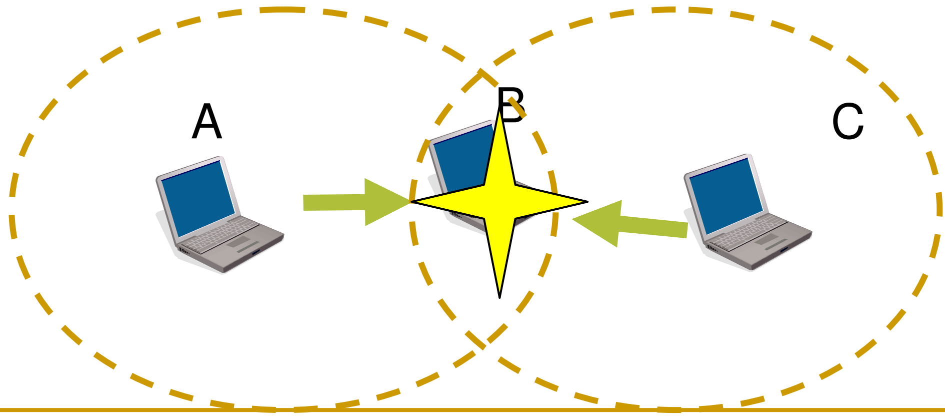
- Random assignment approaches
  - Dynamic number of transceivers contend for medium
  - Distributed (peer-to-peer) algorithms for contention
  - Great for dynamic / unplanned or distributed networks
  - Problem: Hidden and Exposed Terminal Problems

Hidden Terminal Problem

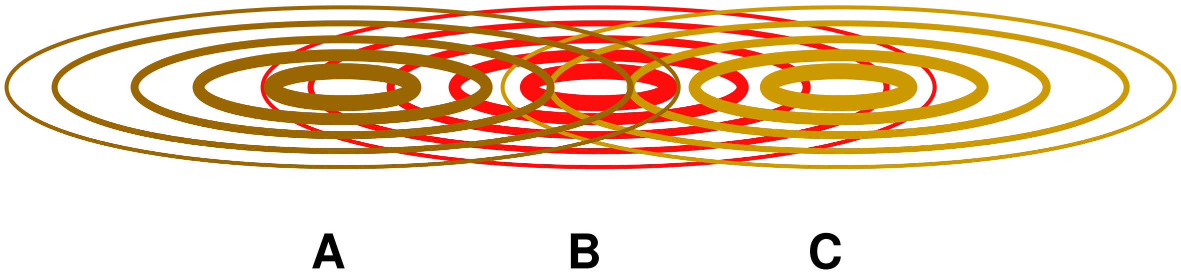


Senders A and C separated by obstacle. Each thinks the medium is free.

Senders A and C out of range of each other. Each thinks medium is free.

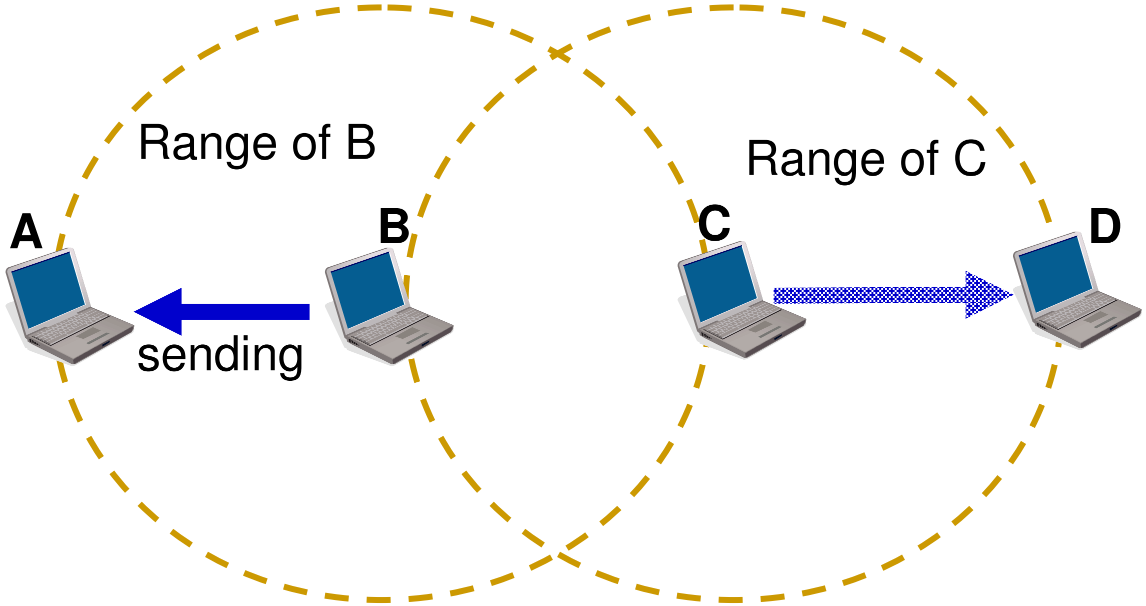


Hidden Terminal Problem

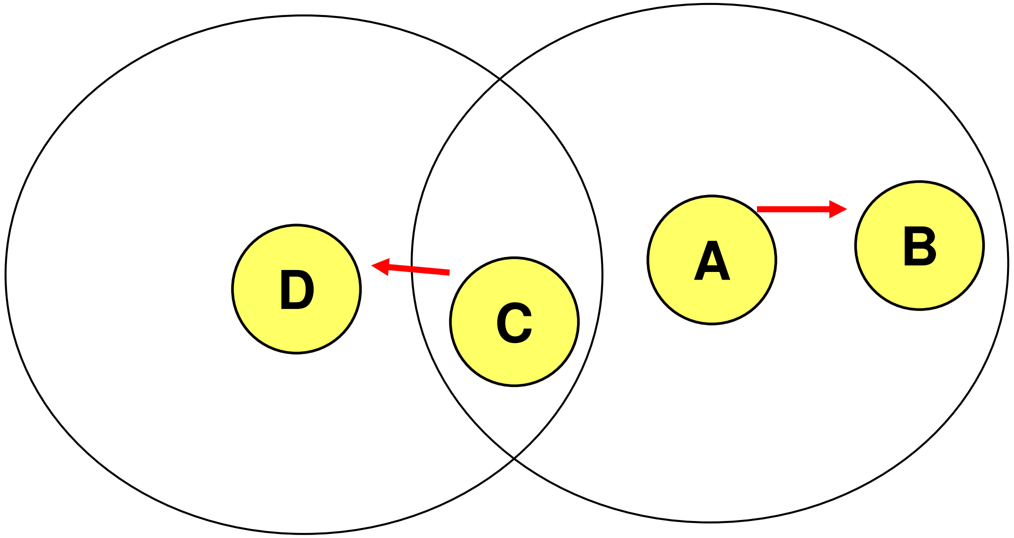


- A and C cannot hear each other.
- A sends to B, C cannot receive A.
- C wants to send to B, C senses a “free” medium (CS fails)
- Collision occurs at B.
- A cannot receive the collision (CD fails).
- A is “hidden” for C.

Exposed Terminal Problem



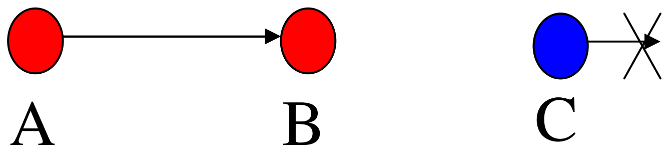
Exposed Terminal Problem



- A starts sending to B.
- C senses carrier, finds medium in use and has to wait for A->B to end.
- D is outside the range of A, therefore waiting is not necessary.

Contention-based Protocols -Examples

- CSMA — Carrier Sense Multiple Access
  - Ethernet
  - Not enough for wireless (collision at receiver)



Hidden terminal: A is hidden from C's CS

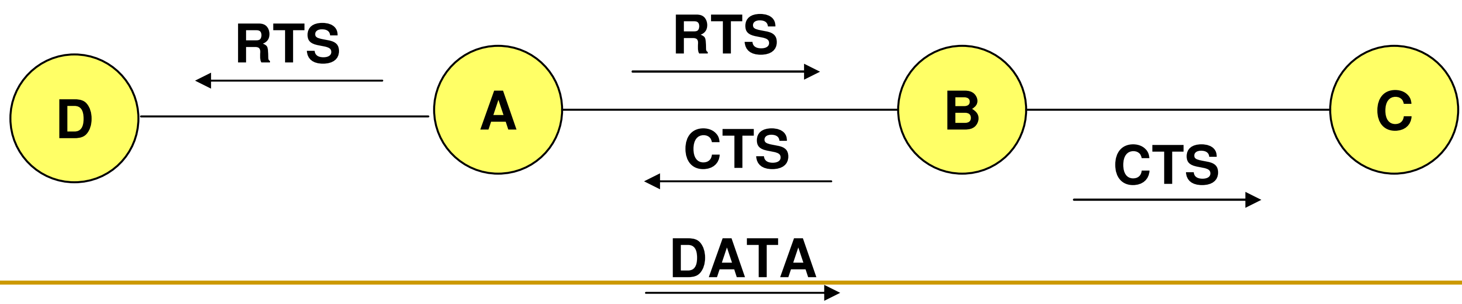
- MACA — Multiple Access w/ Collision Avoidance
  - RTS/CTS for hidden terminal problem
  - RTS/CTS/DATA

Contention-based Protocols -Examples

- MACAW — improved over MACA
  - RTS/CTS/DATA/ACK
  - Fast error recovery at link layer
- IEEE 802.11 Distributed Coordination Function (DCF)
  - Largely based on MACAW

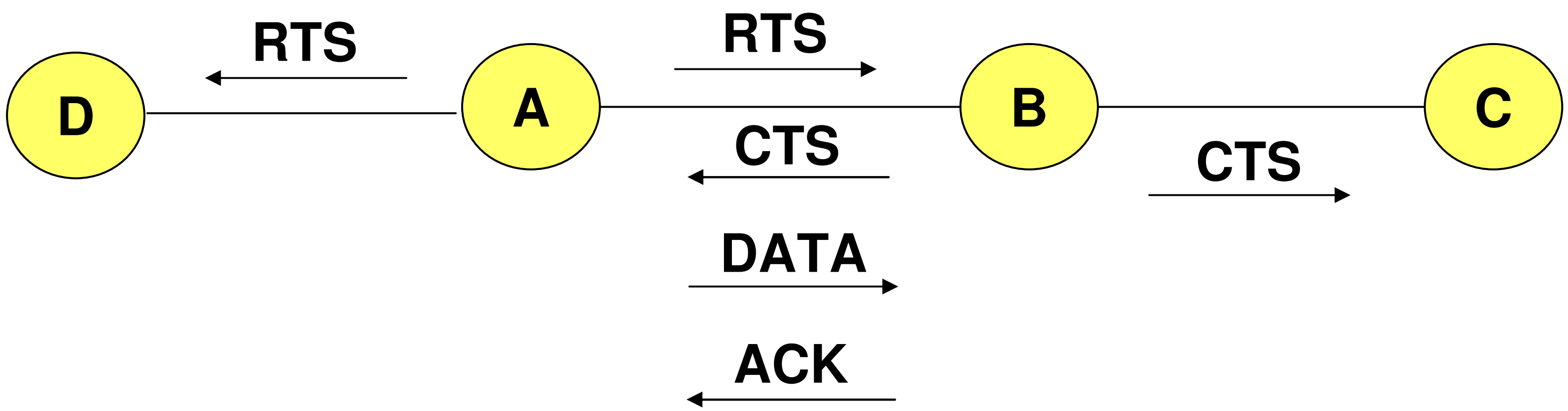
Solution for Hidden Terminals

- A first sends a *Request-to-Send (RTS)* to B
- On receiving RTS, B responds *Clear-to-Send (CTS)*
- Hidden node C overhears CTS and keeps quiet
  - Transfer duration is included in both RTS and CTS
- Exposed node overhears a RTS but not the CTS
  - D's transmission cannot interfere at B



802.11 – Reliability: ACKs

- When B receives DATA from A, B sends an ACK
- If A fails to receive an ACK, A retransmits the DATA
- Both C and D remain quiet until ACK (to prevent collision of ACK)
- Expected duration of transmission+ACK is included in RTS/CTS packets

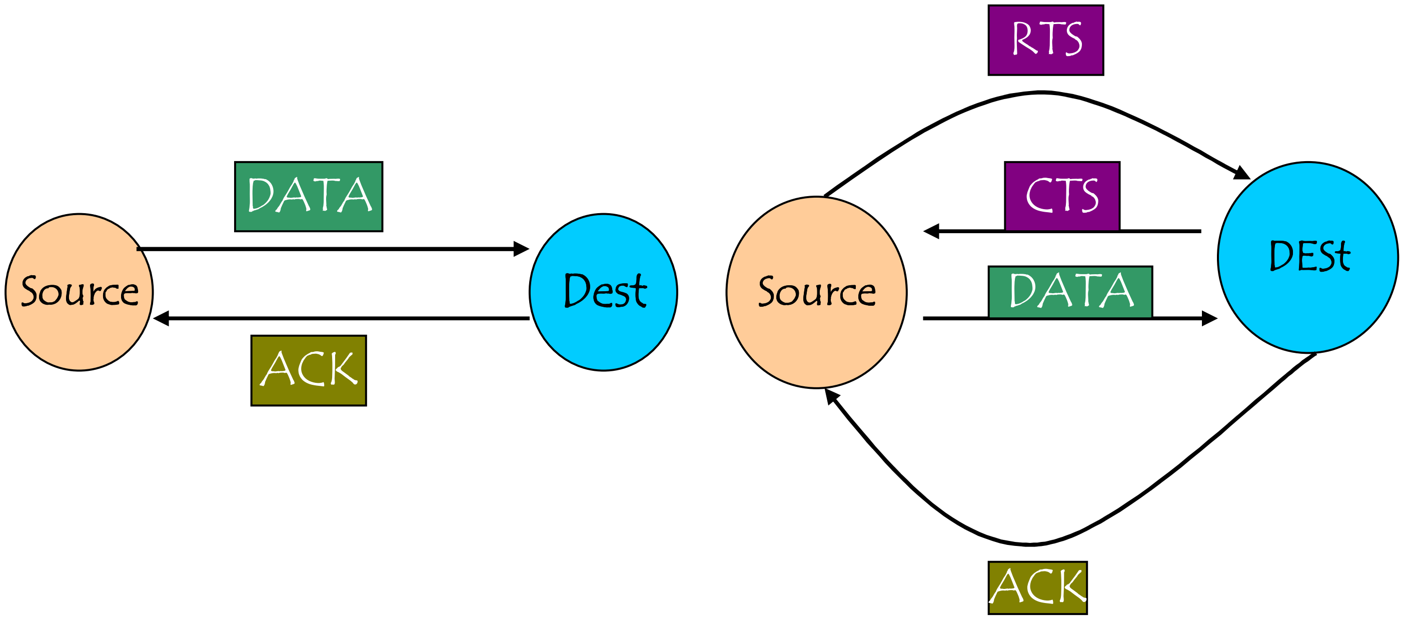


IEEE 802.11 DCF

- Distributed coordinate function: ad hoc mode
  - Virtual and physical carrier sense (CS)
    - Network allocation vector (NAV), duration field
  - Binary exponential backoff
  - RTS/CTS/DATA/ACK or DATA/ACK for unicast packets
  - Broadcast packets are directly sent after CS
  - Fragmentation support
    - RTS/CTS reserve time for first (frag + ACK)
    - First (frag + ACK) reserve time for second…
    - Give up tx when error happens

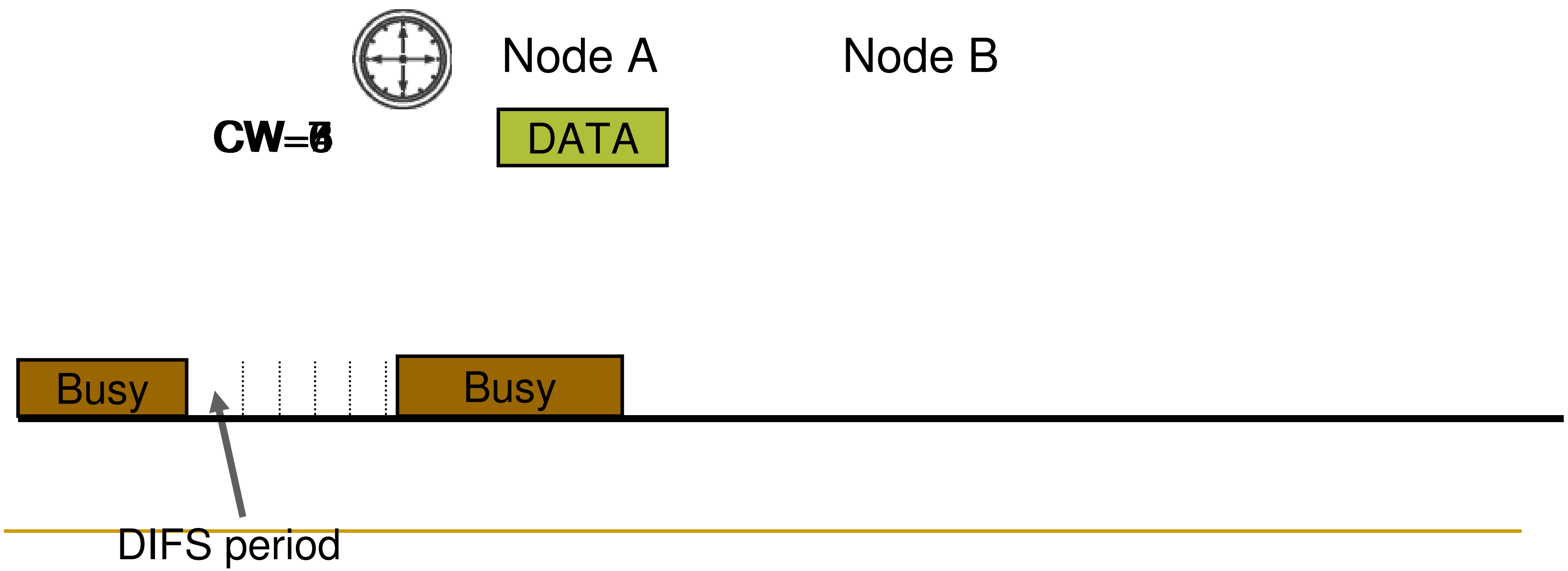
IEEE 802.11 Handshake

- Basic mechanism: 2 way handshaking
- RTS/CTS mechanism: 4 way handshaking



IEEE 802.11 DCF (2)

- Carrier-sensing until channel idle for DIFS period
- If channel not idle, random backoff based on contention window
- If channel idle, RTS-CTS-DATA-ACK or DATA-ACK handshake
- If transmission unsuccessful, double contention window size



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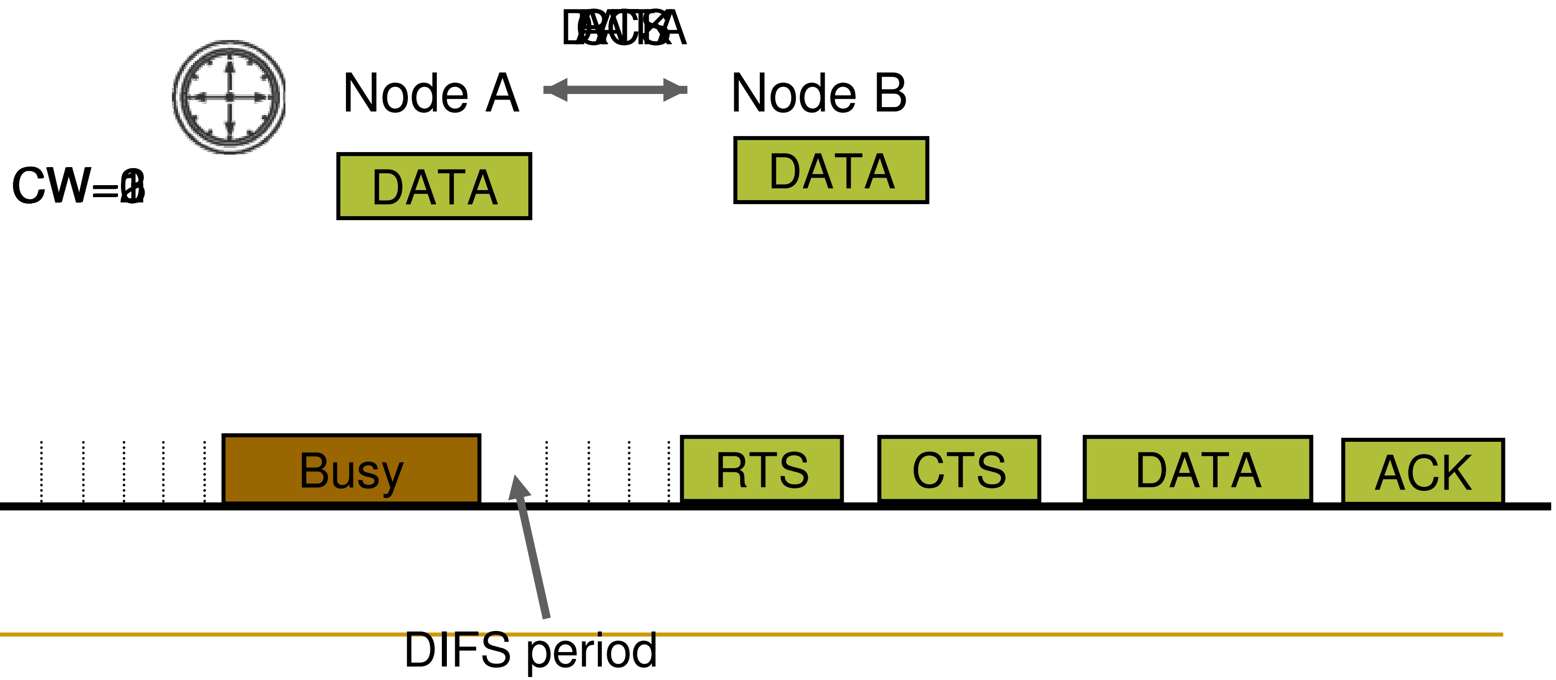
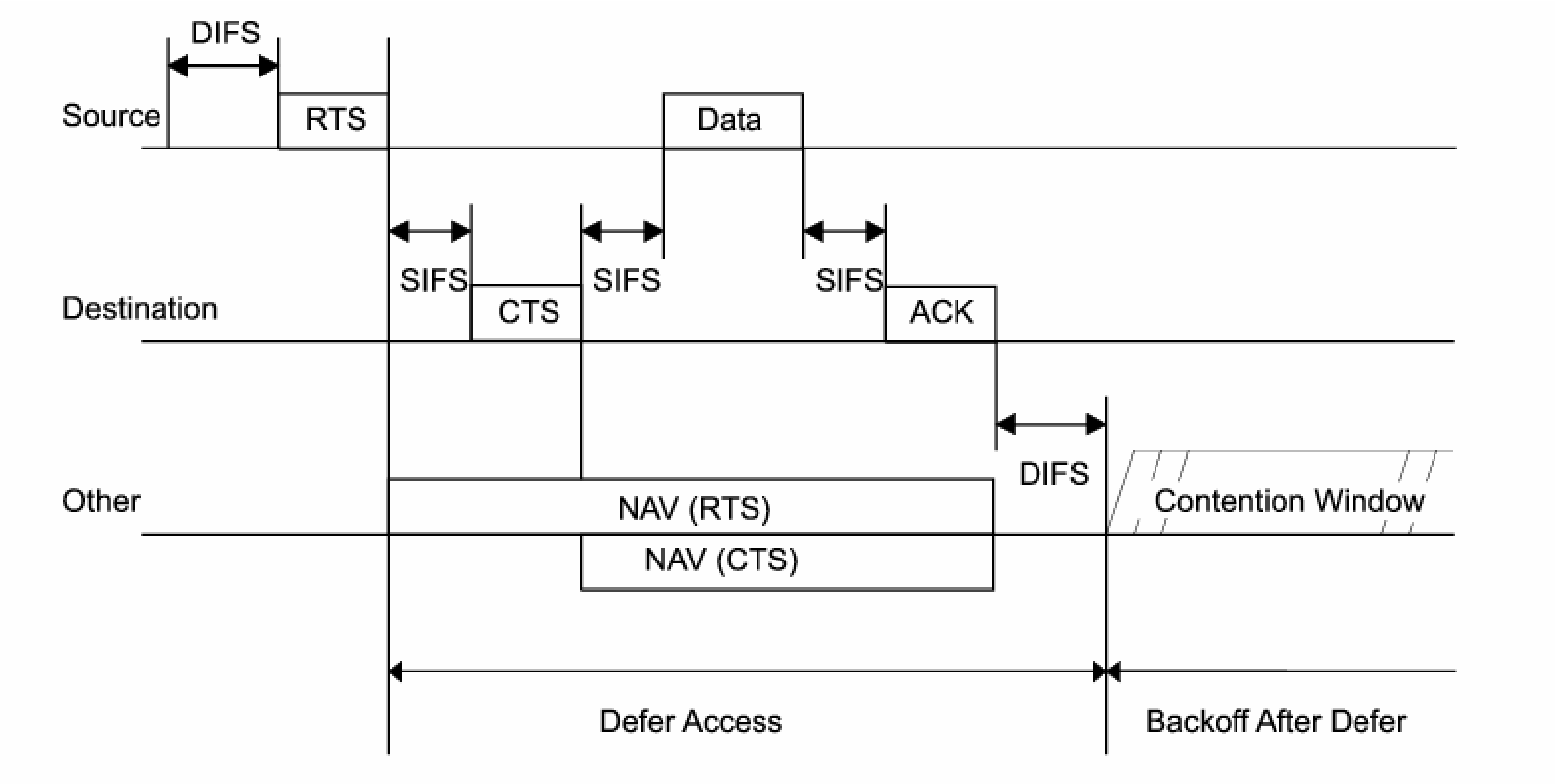


IEEE 802.11 DCF (3)

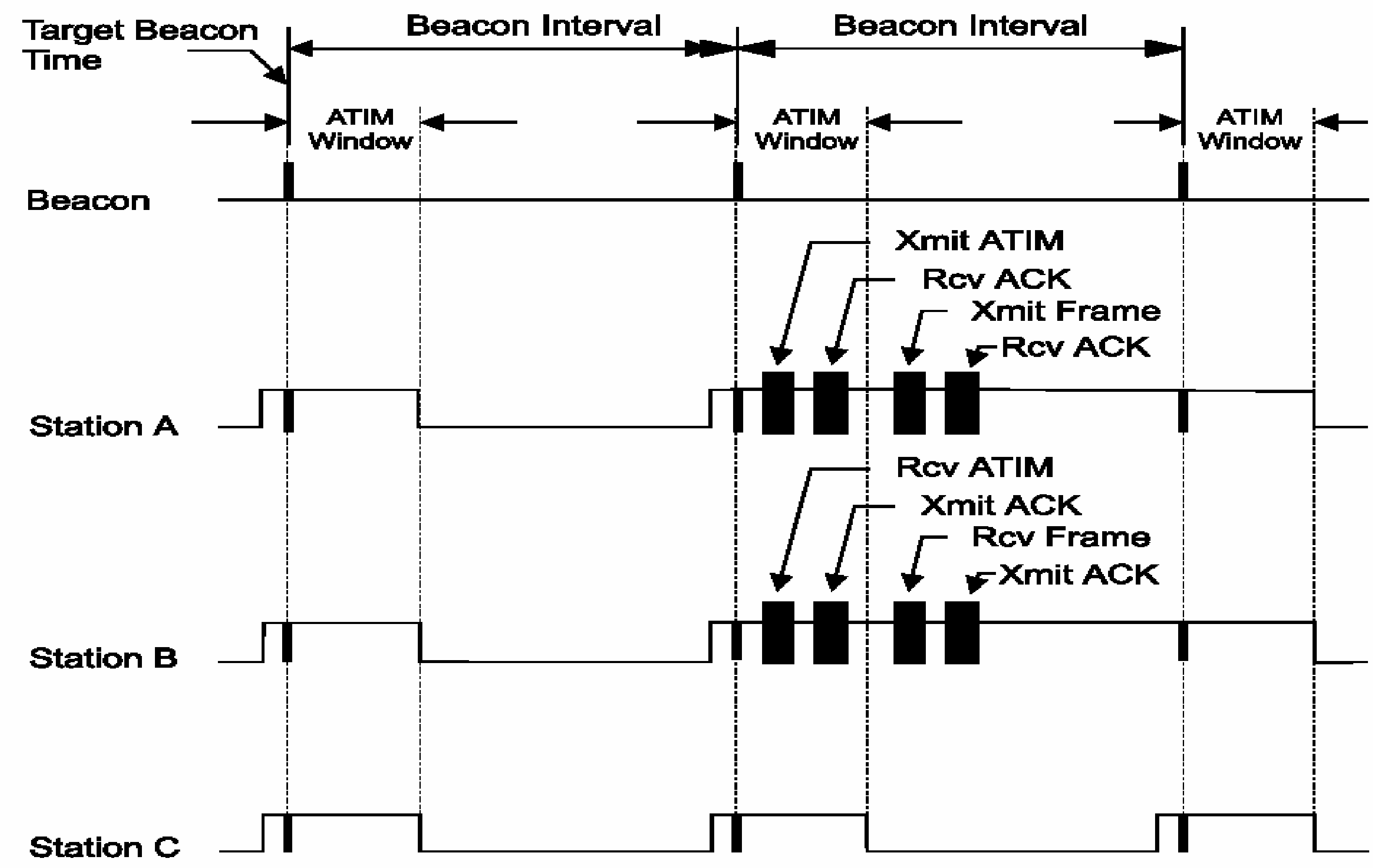
- Timing relationship

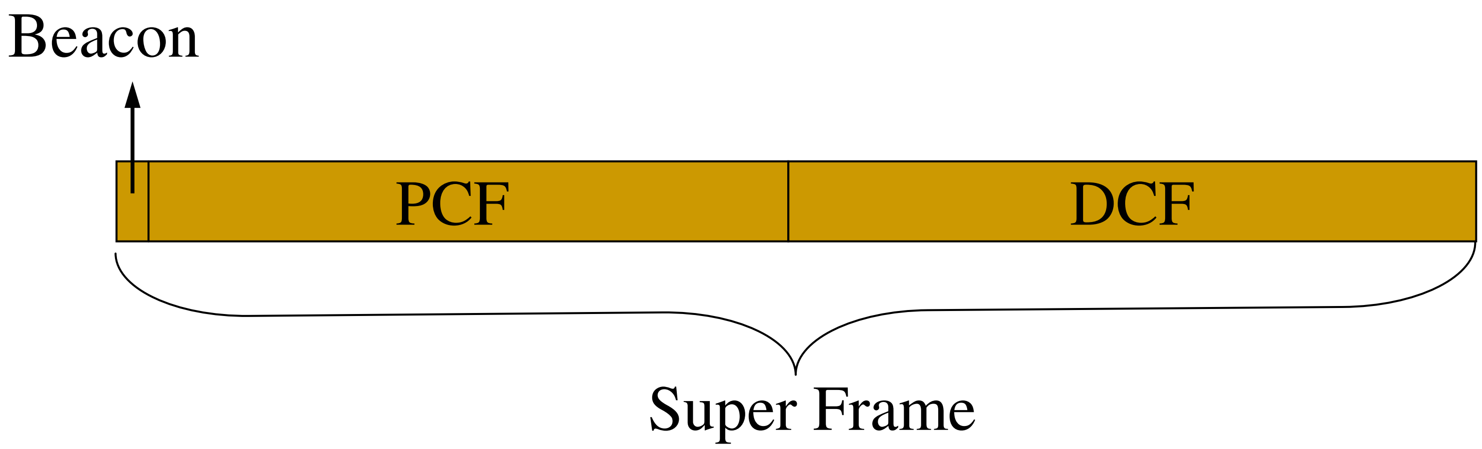


Power save (PS) mode

- Assumption: all nodes are synchronized and can hear each other (single hop)
- Nodes in PS mode periodically listen for beacons & ATIMs (ad hoc traffic indication messages)
- Beacon: timing and physical layer parameters
  - All nodes participate in periodic beacon generation
- ATIM: tell nodes in PS mode to stay awake for Rx
  - ATIM follows a beacon sent/received
  - Unicast ATIM needs acknowledgement
  - Broadcast ATIM wakes up all nodes — no ACK

Example of PS mode





DCF - Distributed Coordinated Function

(**Contention Period** - *Ad-hoc Mode*)

PCF - Point Coordinated Function

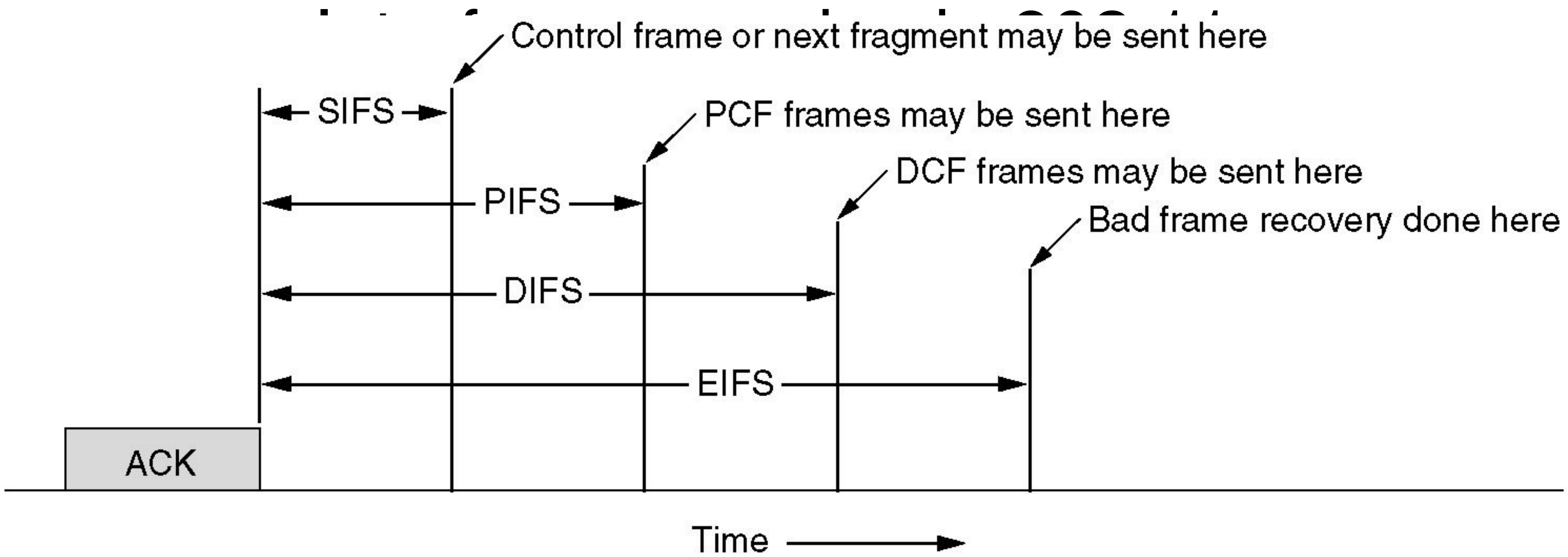
(**Contention Free Period** – *Infrastructure BSS*)

Beacon - Management Frame

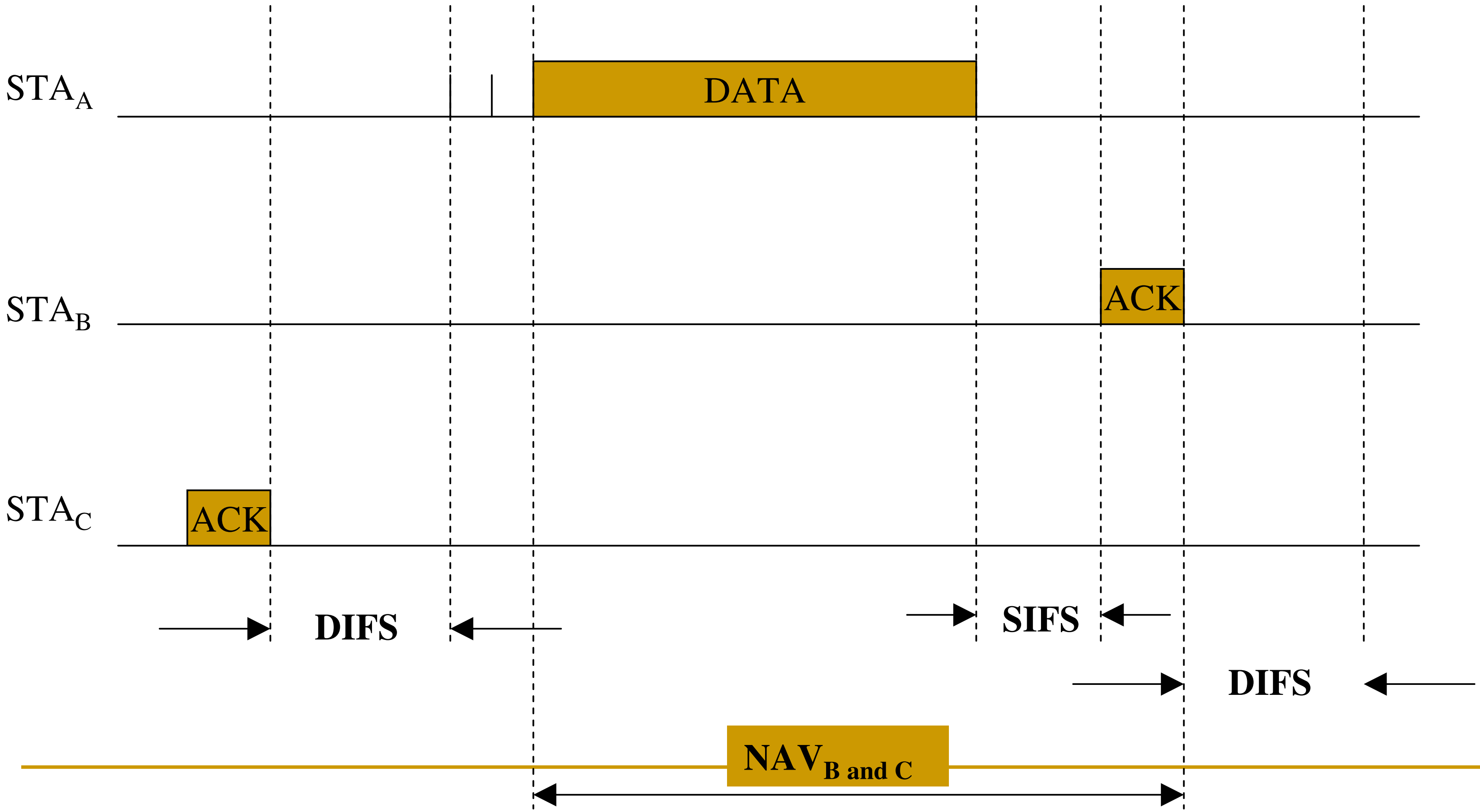
Synchronization of Local timers

Delivers protocol related parameters

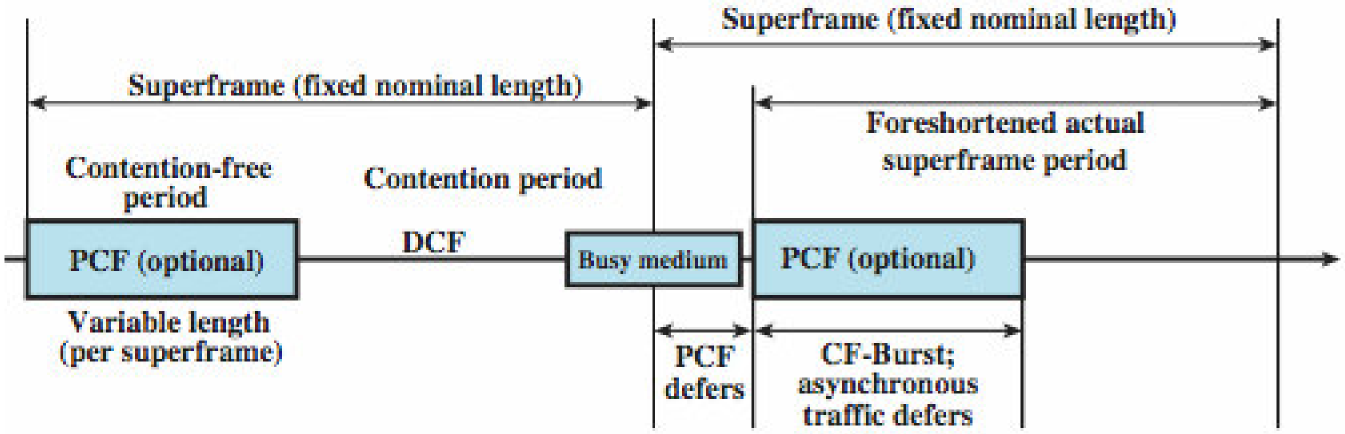
The 802.11 MAC Sublayer Protocol



NAV – Network Allocation Vector

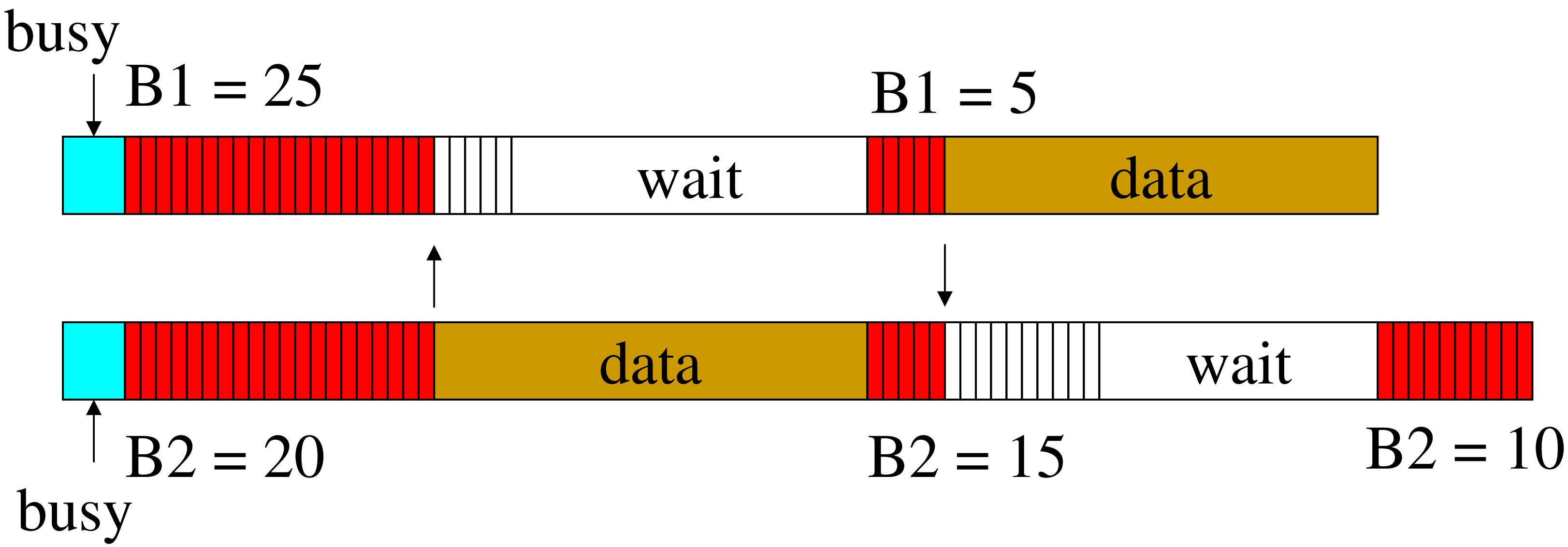


PCF Superframe Timing



(b) PCF Superframe Construction

Congestion Avoidance: Example



cw = 31

B1 and B2 are backoff intervals at nodes 1 and 2

Backoff Interval

- The time spent counting down backoff intervals is a part of MAC overhead
  - large CW ➔ large overhead
  - however, small CW ➔ may lead to many collisions (when two nodes count down to 0 simultaneously)

- Since the number of nodes attempting to transmit simultaneously may change with time, we need some mechanism to manage contention

- IEEE 802.11: contention window CW is adapted dynamically depending on collision occurrence
  - after each collision, CW is doubled

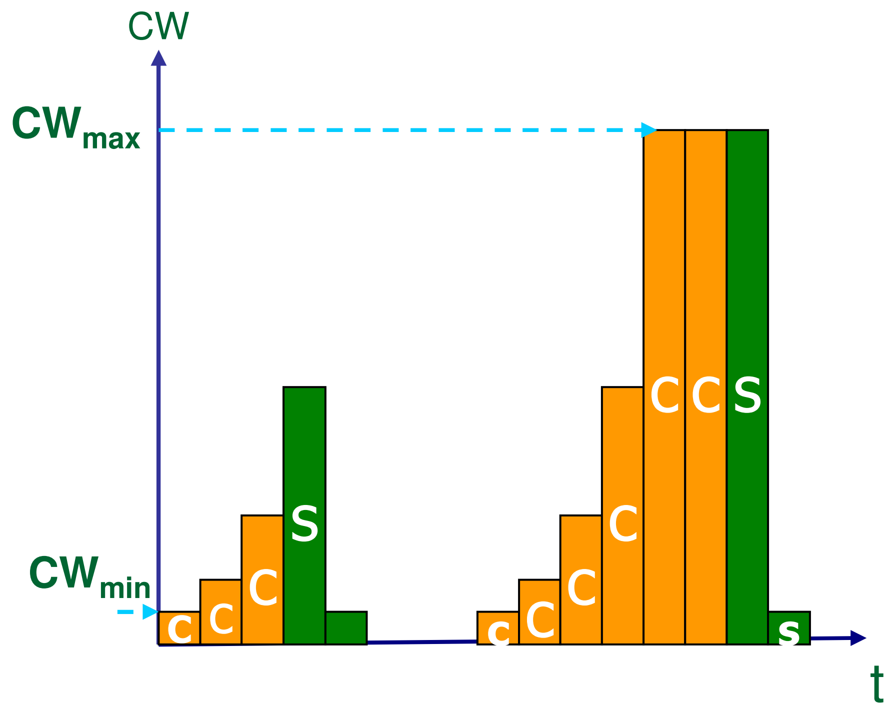
Performance Analysis of the IEEE 802.11 Distributed Coordination Function

Overview of IEEE 802.11 DCF

Backoff procedure—BEB algorithm

Backoff counter:

- **Initial: uni~[0,CW-1]**
- **Non zero: decremented for each idle slot**
- **Zero: transmit**



Problem Formulation

- Saturation Throughput
  - Asymptotic throughput
  - Limit reached by the system throughput as the offered load increases. Maximum load that the system can carry in stable conditions.
- Assumptions
  - Ideal Channel Condition (No Hidden Terminal, No Channel Capture)
  - Finite Number of Stations
  - Constant & Independent Collision Probability
  - Overload Condition

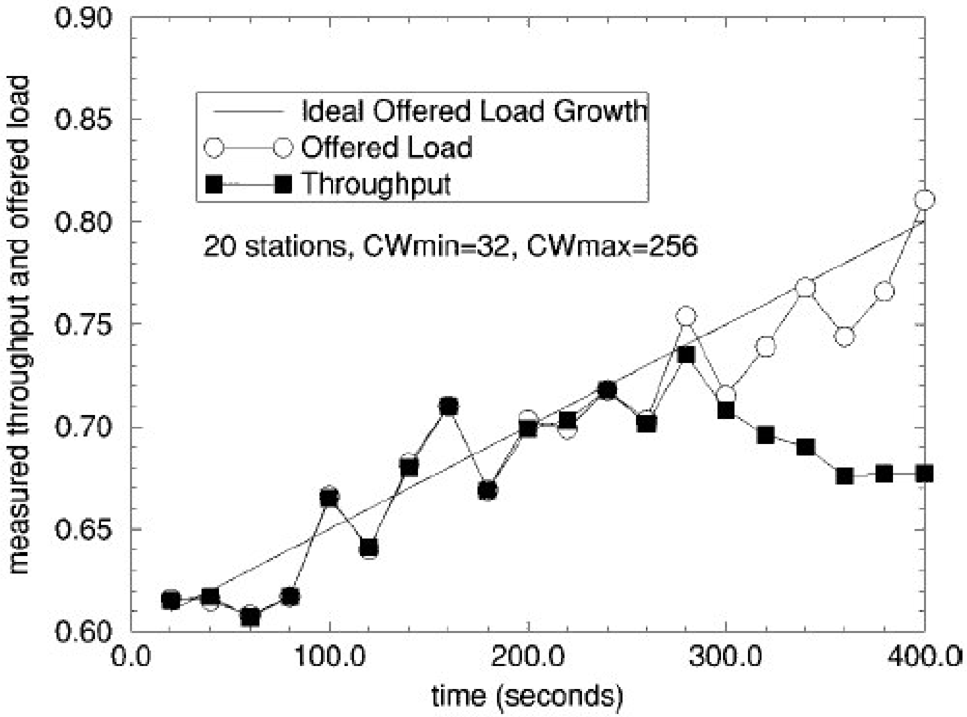
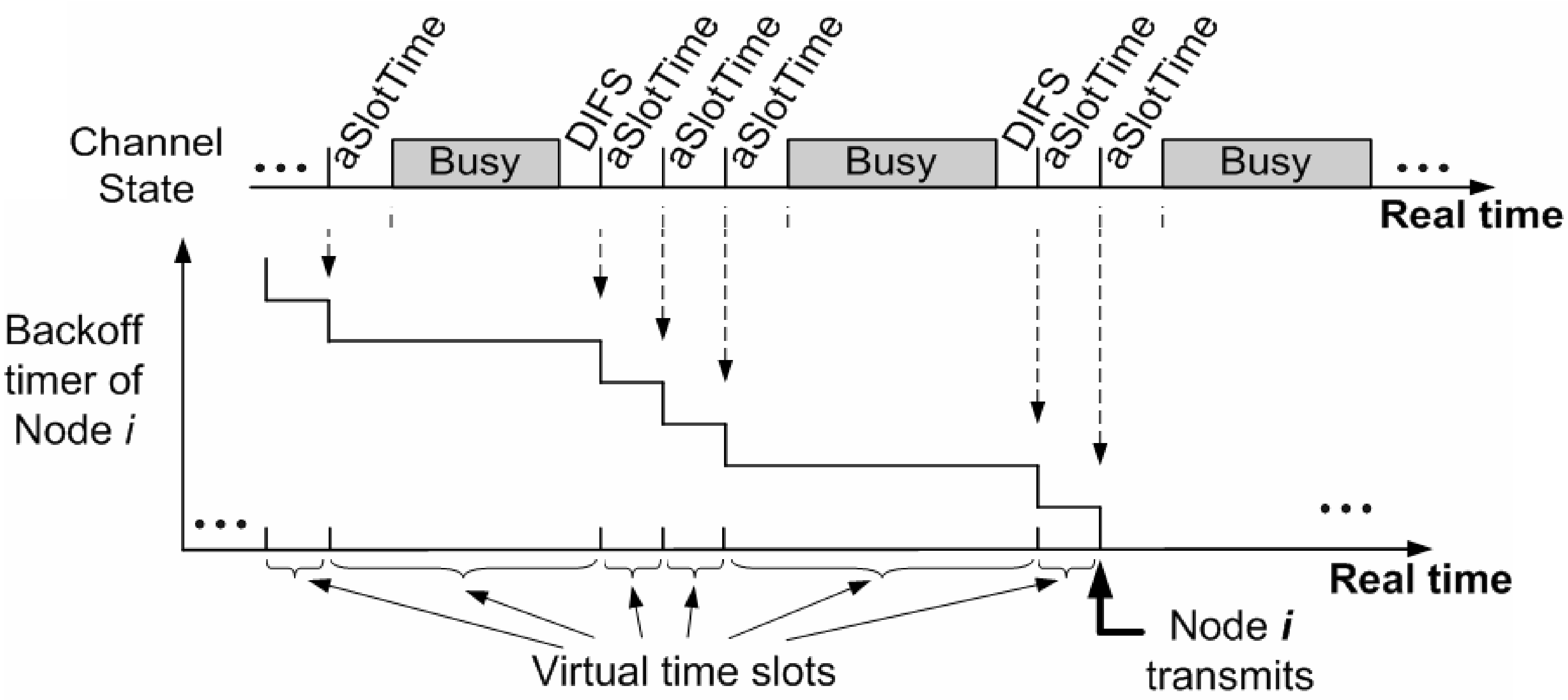


Fig. 3. Measured Throughput with slowly increasing offered load.

Discrete Time Model

- Discrete and integer time scale
- At beginning of a slot time, backoff time counter decrements or regenerated
- [t, t+1], interval between 2 consecutive slot time, can be variable length



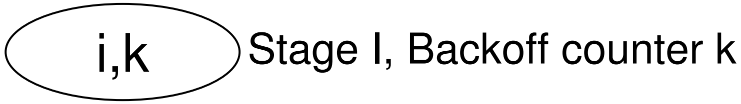
Notation

- b(t): stochastic process representing the backoff counter
- s(t): stochastic process representing the backoff stage (0..m)
- $W = CW_{min}$ and $CW_{max} = 2^m W$
- $W_i = 2^i W$ at stage $i \in (0,m)$
- {s(t), b(t)}: bidimensional process with discrete-time Markov Chain
- Conditional Collision Probability p
- Transmission Probability τ

In the middle of Backoff

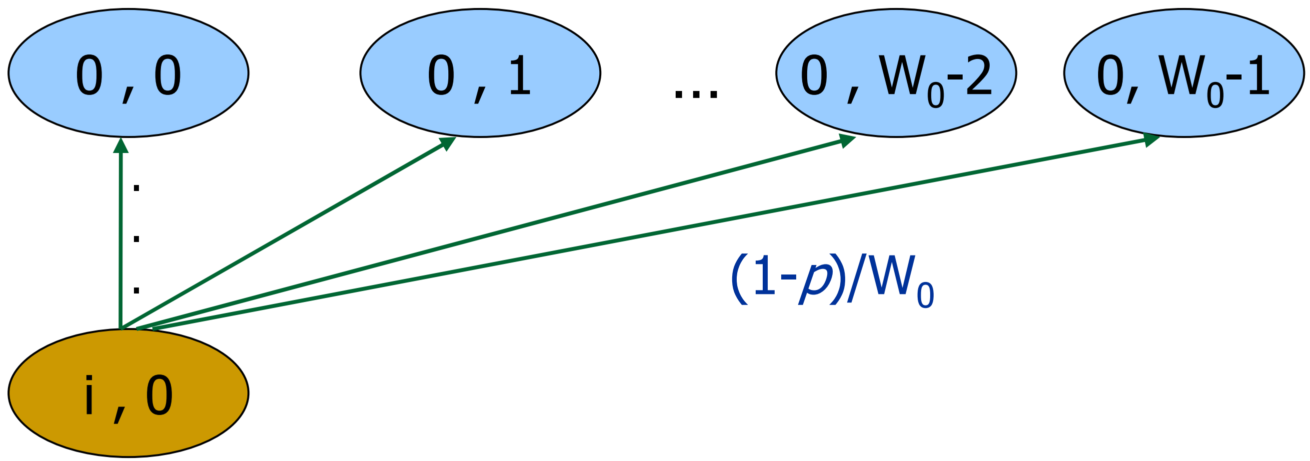
$$P\{i_1, k_1 / i_0, k_0\} = P\{s(t+1) = i_1, b(t+1) = k_1 / s(t) = i_0, b(t) = k_0\}$$

- b(t): stochastic process representing the backoff counter
- s(t): stochastic process representing the backoff stage (0..m)
- P{i,k|i,k+1}=1, k : [0,Wi-2], i : [0,m]
  - At beginning of t
    - Backoff counter not reach zero, no transmission
    - Channel sensed idle for 1 mini-slot till t+1
  - At beginning of t+1
    - Backoff counter is decremented by 1



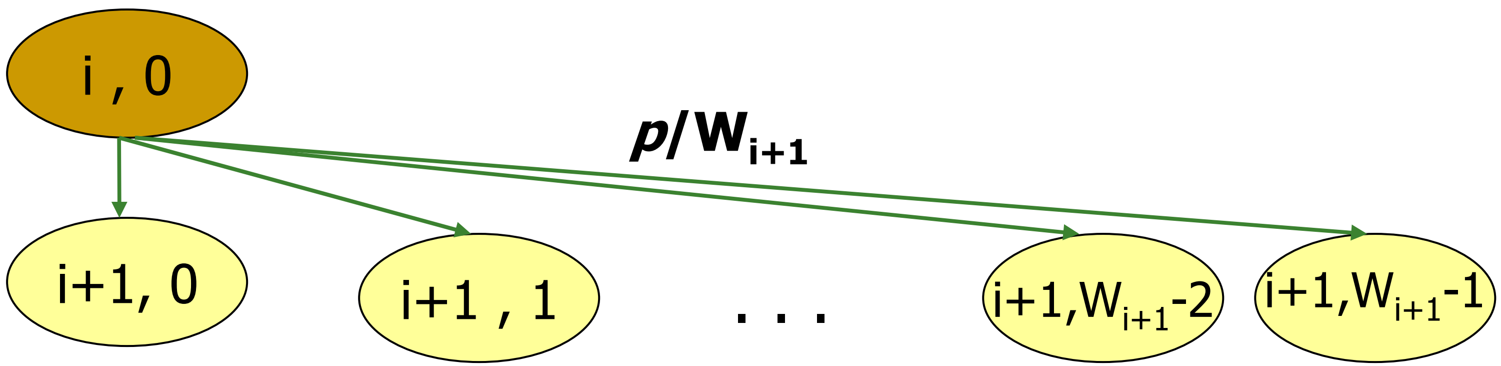
Successful Transmission

- $P\{0,k|i,0\}=(1-p)/W_0$, $k : [0,W_0-1]$, $i : [0,m]$
  - At beginning of t
    - Backoff counter reaches zero, successful transmitted [t,t+1]
  - At beginning of t+1
    - Contention window reset to CWmin (backoff stage = 0)
    - Backoff counter chosen randomly in $[0,W_0-1]$
    - Conditional Collision Probability p



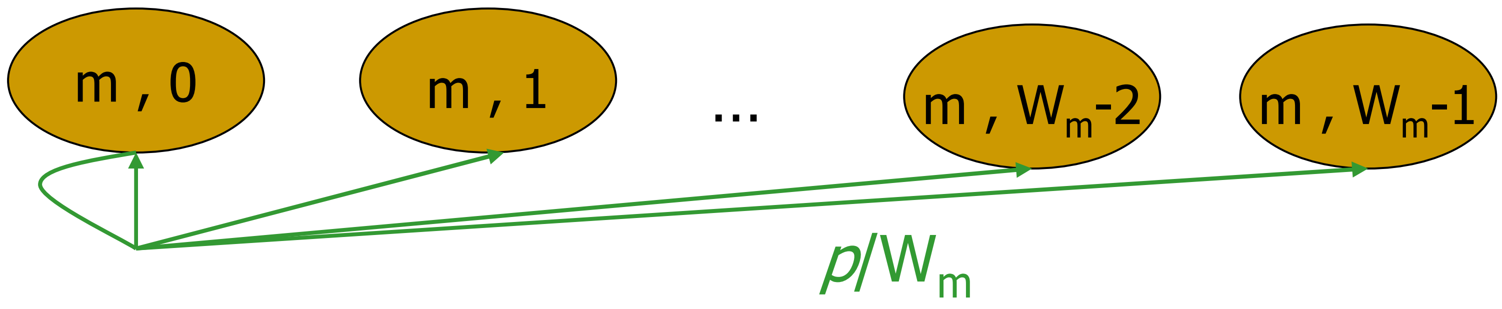
Failed Transmission

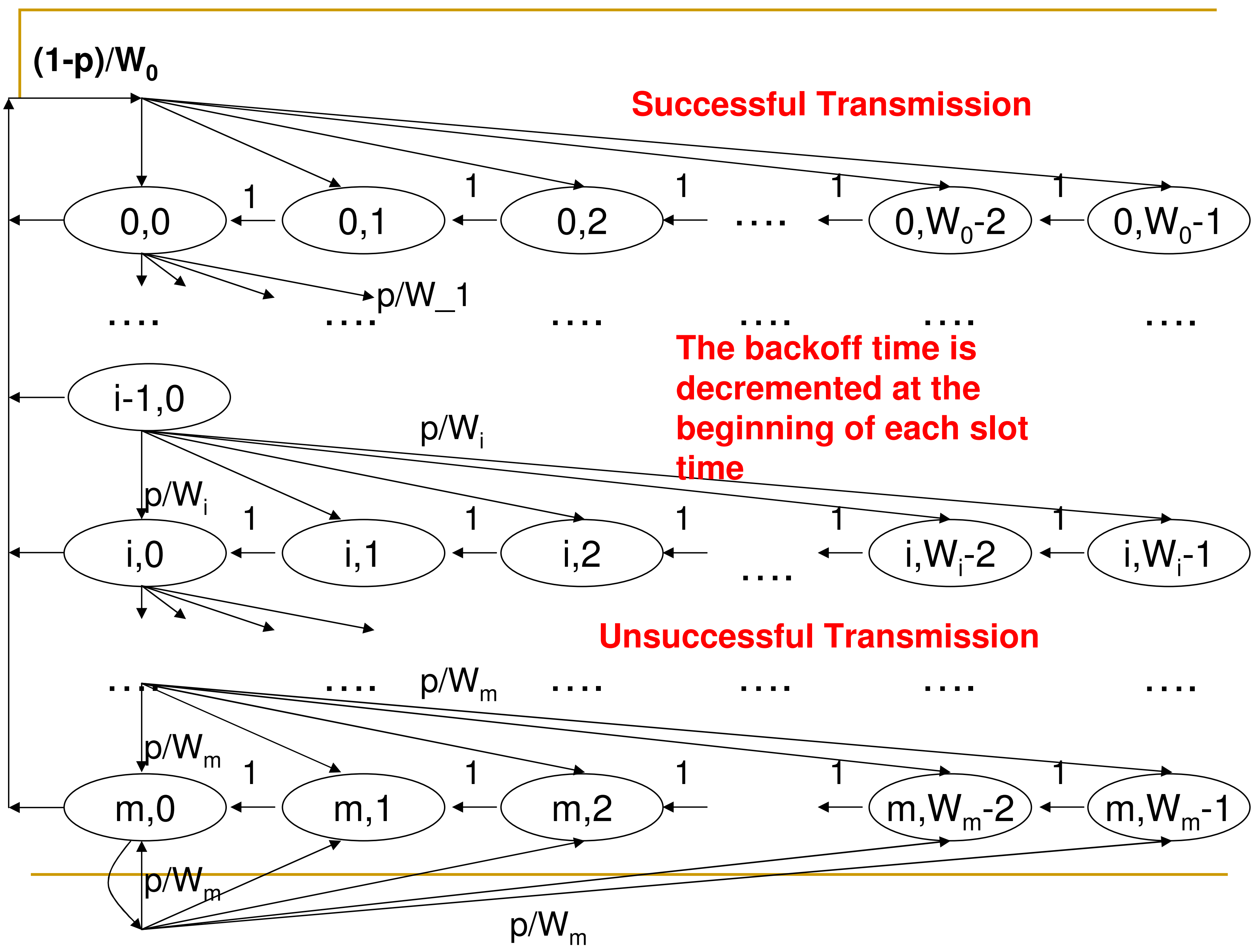
- $P\{i+1,k|i,0\} = p/W_{i+1}$, k : $[0,W_{i+1}-1]$, i : [1,m-1]
  - At beginning of t
    - Backoff counter reaches zero, transmit in [t,t+1], collision
    - Contention window < CWmax
  - At beginning of t+1
    - contention window doubled
    - Backoff counter chosen randomly in $[0,W_{i+1}-1]$



Failed Transmission when CW Reaching CWmax

- $P\{m,k|m,0\} = p/W_m$, $k : [0, W_m-1]$, $i = m$
  - At beginning of t
    - Backoff counter reaches zero, transmit in [t,t+1], collision
    - Contention Window = CWmax
  - At beginning of t+1
    - Contention Window remains at CWmax
    - Backoff time counter chosen randomly in $[0, W_m-1]$





(1-p)/W0
Successful Transmission
0,0
0,1
0,2
0,W0-2
0,W0-1
1
p/W_1
The backoff time is decremented at the beginning of each slot time
i-1,0
p/Wi
i,0
i,1
i,2
i,Wi-2
i,Wi-1
Unsuccessful Transmission
p/Wm
m,0
m,1
m,2
m,Wm-2
m,Wm-1