# Self-organizing Energy Efficient M2M Communications

Hung-Yu Wei
National Taiwan University

# M2M communications

- Challenges
  - A large number of devices
  - Energy source
    - Limited battery capacity
      - difficult to change battery in many scenarios
    - Energy harvesting
      - Solar panel
      - Vibration
      - Piezoelectric
  - Configuration

# Energy-Efficient M2M Communications with WiFi

- Why WiFi?
  - Low cost
  - Widely used
  - Low energy consumption ?
- There are other M2M communication solutions
  - Short-range solutions: 802.15.4 based
    - Zigbee
    - 802.15.4g for smart meter
  - Long-range solution: cellular based
    - Machine-Type-Communications in LTE
    - 802.16p for WiMAX M2M
    - SMS in GSM system

# About 802.11

- IEEE standard
  - http://www.ieee802.org/11/
  - A long history 802.11-1997 → 802.11-2007
- Also known as Wifi
  - Wi-Fi Alliance (http://www.wi-fi.org)
- Widely deployment
  - NTU wireless access on campus
  - Wifly in Taipei city
  - Built-in in your laptop
    - Intel Centrino
  - In your home
    - Wireless router (ADSL-WiFi router)
  - You will see more and more WiFi phones

# What 802.11 really is?

- A wireless access standard which defines
  - Physical layer
  - MAC layer
- Not about network layer and above
- Facts
  - Several physical layer technologies
    - Modulation and coding
    - Frequency bands
  - MAC
    - CSMA/CA
    - A few extensions
  - A lot of enhancement

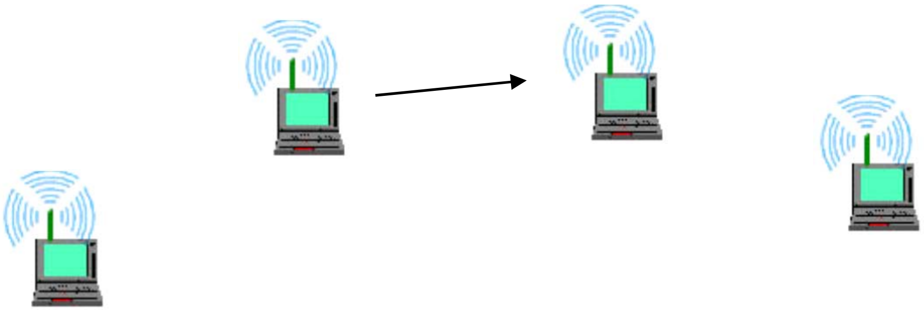
# 123 & ABC

- 802
  - 802.3
  - 802.11
  - 802.15
  - 802.16
  - …
  - 802.20
  - 802.21
  - 802.22
  - And more
- 802.11
  - 802.11a
  - 802.11b
  - …
  - 802.11l ???
  - 802.11x ???
  - 802.11y
  - 802.11z
  - And more

# Basics of 802.11 MAC

# MAC

- Medium Access Control
  - Who and when to access the channel
- Shared channel
  - Distributed operation
  - Random access design



# MAC

- CSMA/CA
  - Carrier sense multiple access with collision avoidance
- Random backoff
- RTS/CTS
  - RTS (Request to Send)
  - CTS (Clear to Send)

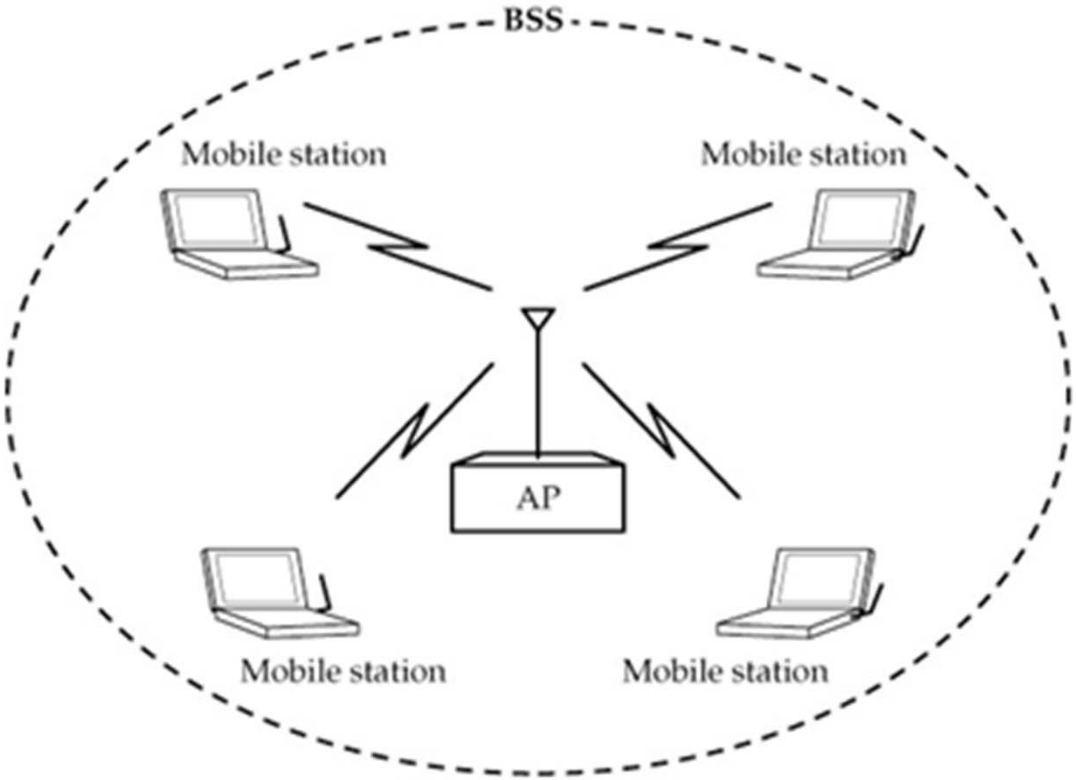
# More About 802.11

# 802.11 Network Terminologies

- BSS
- BSA
- ESS
- IBSS

# BSS

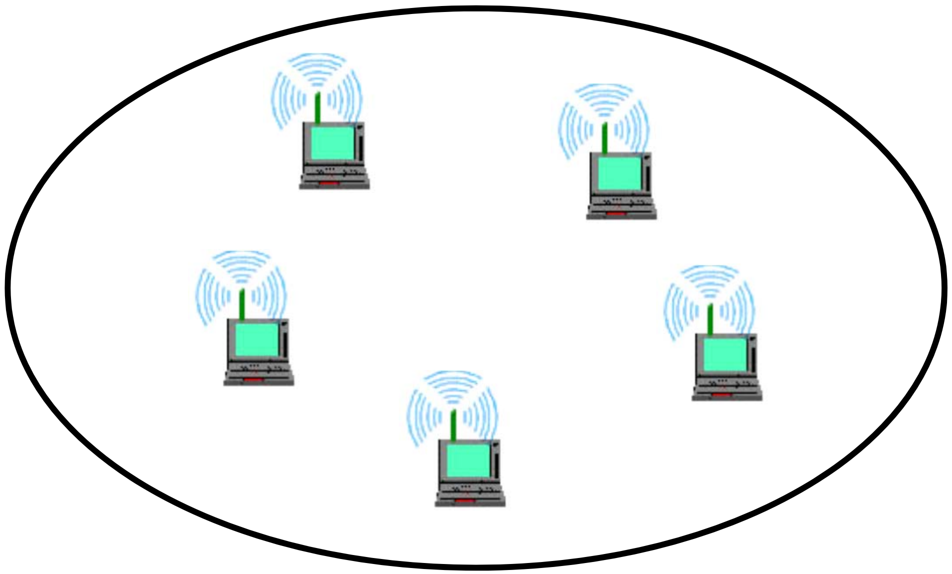
- basic service set (BSS): A set of stations controlled by a single coordination function
  - [concept] A cell with 1 AP and some MSs




BSA (basic service area): cell

# IBSS

- **Independent basic service set (IBSS): stand-alone BSS**
  - [concept] Ad hoc network

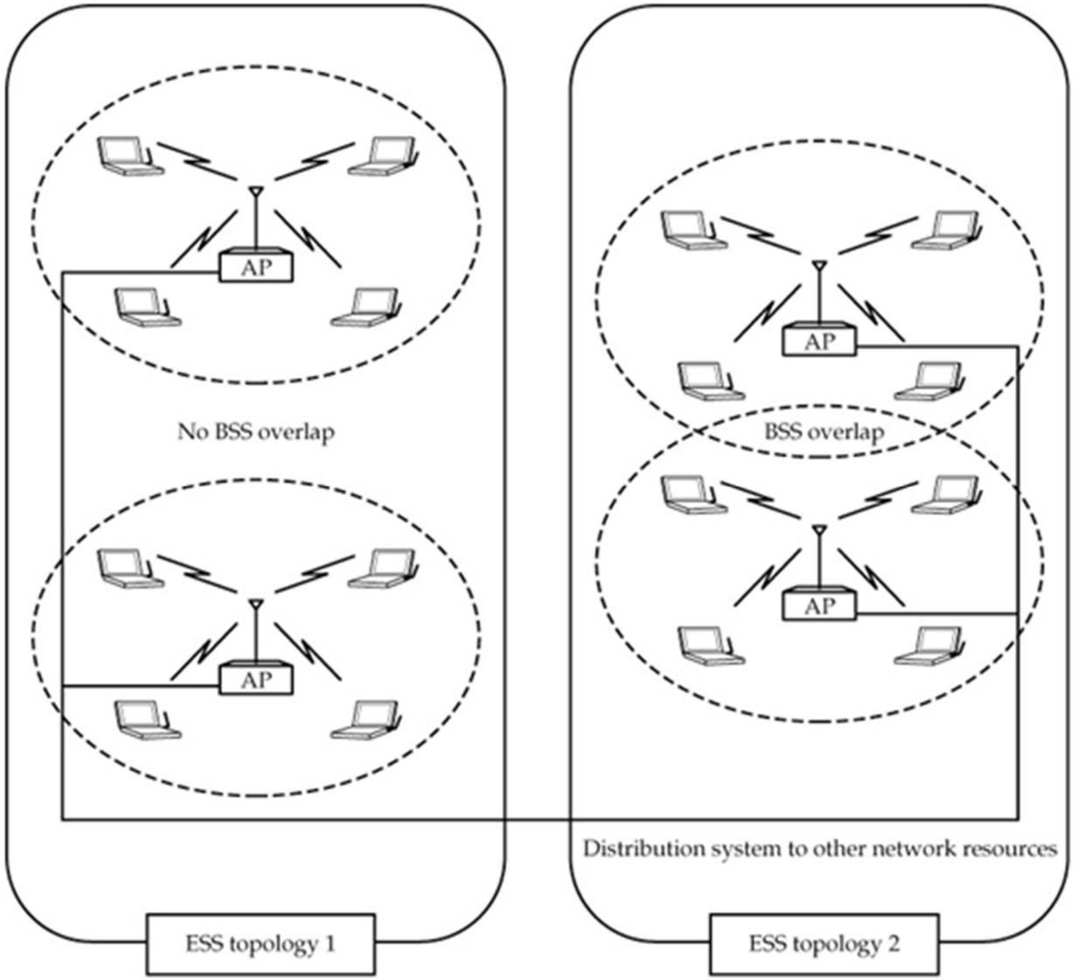


# ESS

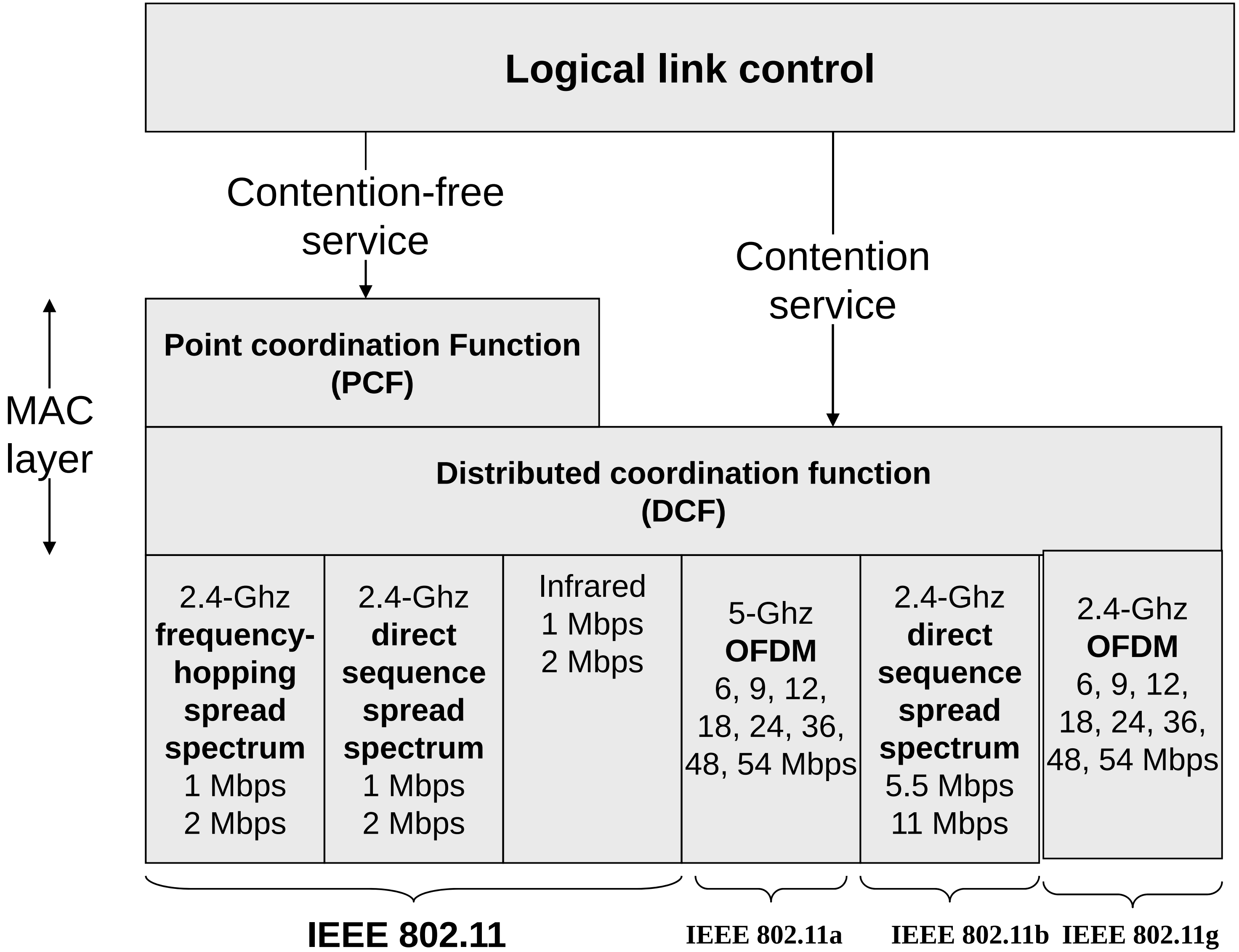
- Extended service set (ESS): A set of one or more interconnected basic service sets (BSSs) and integrated local area networks (LANs)
  - [concept] Cellular system with multiple cells and multiple BSs
- Identifier
  - ESSID: network name
  - BSSID: MAC address of AP
  - Several BSSID with 1 ESSID

# ESS

- Two topologies
  - No overlap
  - With overlap



# 802.11: L2/L1 Protocol Stack



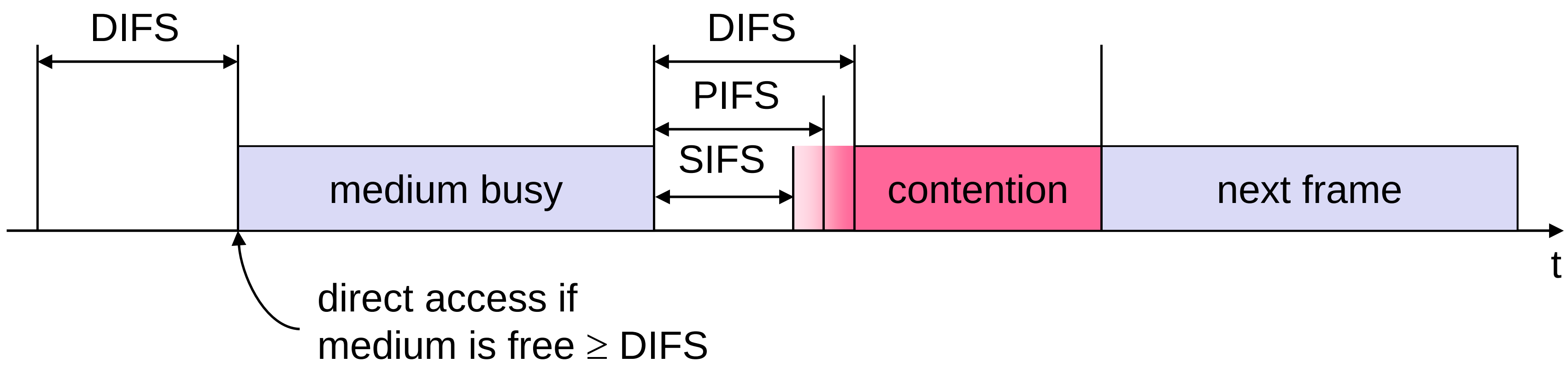
# IEEE 802.11 operations

# 802.11 - MAC layer

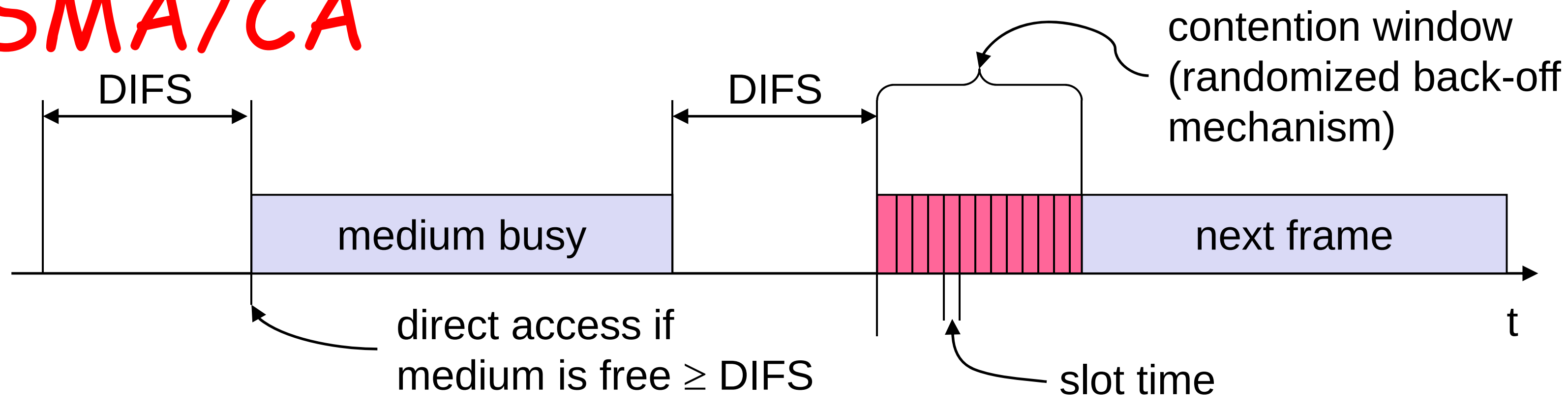
- Traffic services
  - **Asynchronous Data Service (mandatory)**
    - exchange of data packets based on "best-effort"
    - support of broadcast and multicast
  - **Time-Bounded Service (optional)**
    - implemented using PCF (Point Coordination Function)
- Access methods
  - **DCF CSMA/CA (mandatory)**
    - collision avoidance via randomized „back-off" mechanism
    - minimum distance between consecutive packets
    - ACK packet for acknowledgements (not for broadcasts)
  - **DCF w/ RTS/CTS (optional)**
    - Distributed Foundation Wireless MAC
    - avoids hidden terminal problem
  - **PCF (optional)**
    - access point polls terminals according to a list

# Transmission Priorities -- IFS

- Defined through different inter frame spaces (IFS)
- No guaranteed, or hard priorities
- SIFS (Short Inter Frame Spacing)
  - highest priority, for ACK, CTS, polling response
- PIFS (PCF IFS)
  - medium priority, for time-bounded service using PCF
- DIFS (DCF, Distributed Coordination Function IFS)
  - lowest priority, for asynchronous data service

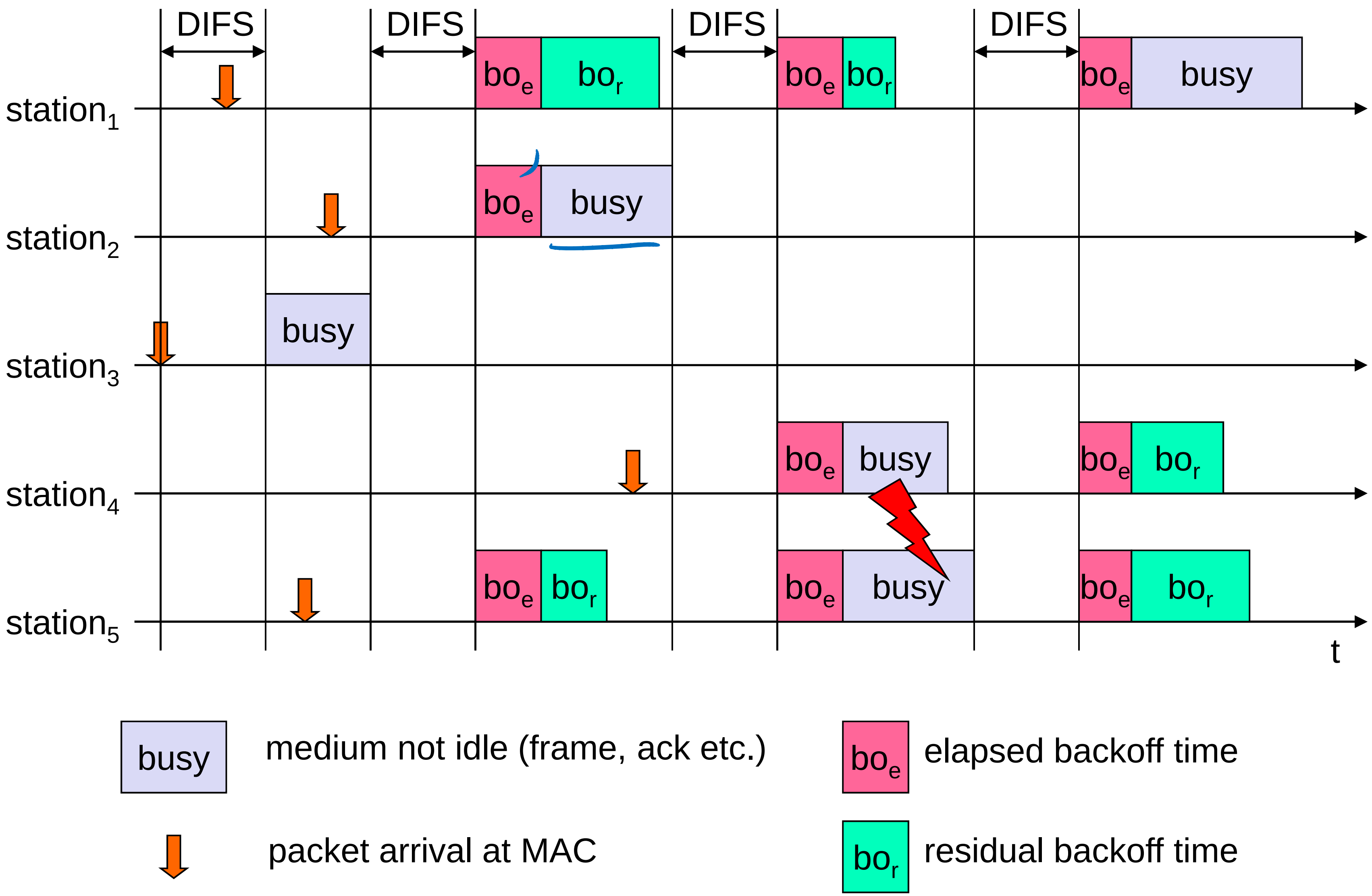


# CSMA/CA



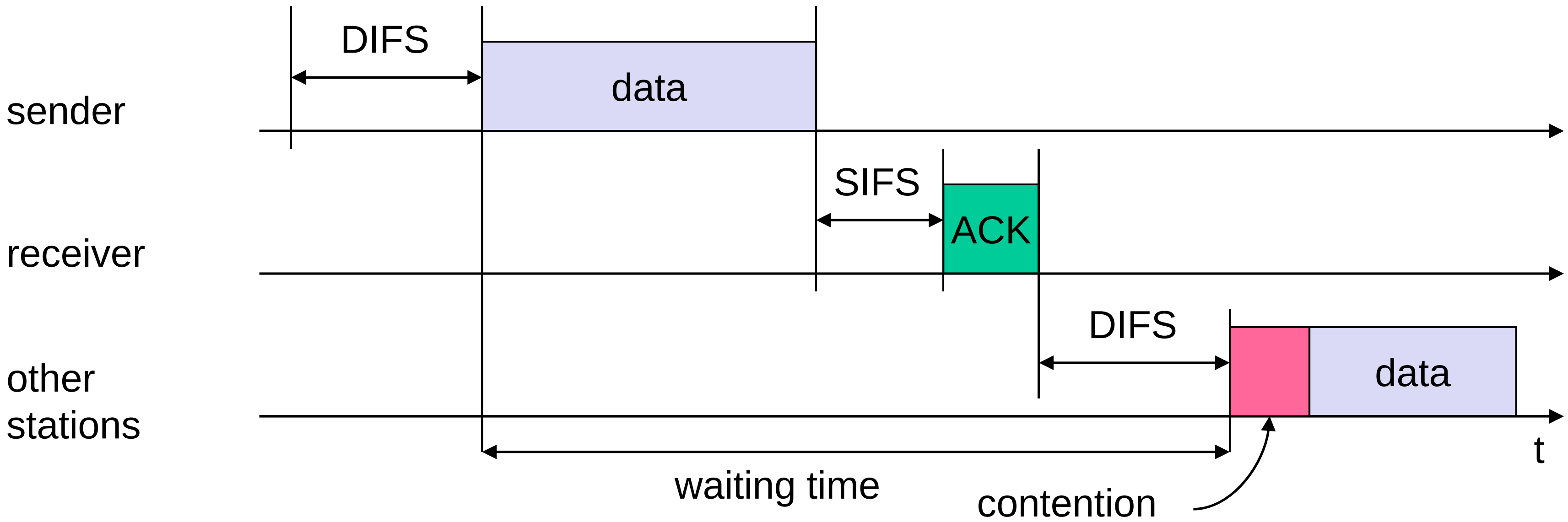

- Station ready to send starts sensing the medium (Carrier Sense based on CCA, Clear Channel Assessment)
  - if the medium is free for the duration of an Inter-Frame Space (IFS), the station can start sending
  - if the medium is busy, the station has to wait for a free IFS, then the station must additionally wait a random back-off time (collision avoidance, multiple of slot-time)
- if another station occupies the medium during the back-off time of the station, the back-off timer stops (fairness)

# 802.11 example



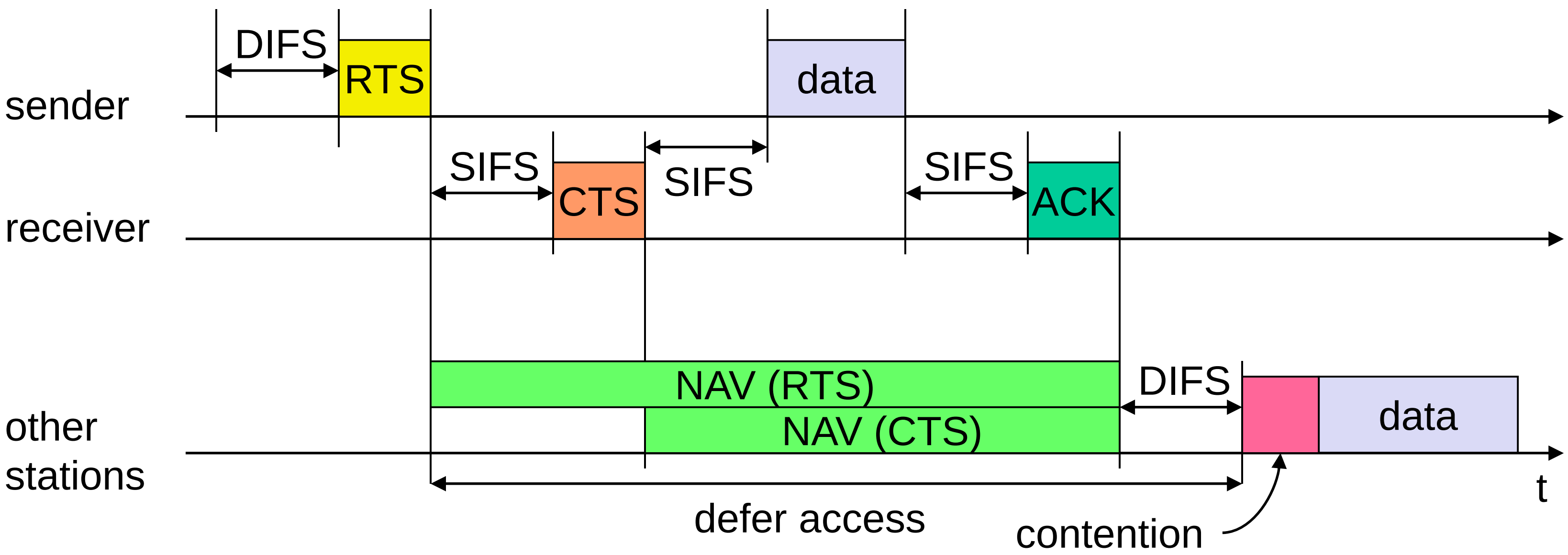
# 802.11 - CSMA/CA

- Sending unicast packets
  - station has to wait for DIFS before sending data
  - receivers acknowledge at once (after waiting for SIFS) if the packet was received correctly (CRC)
  - automatic retransmission of data packets in case of transmission errors



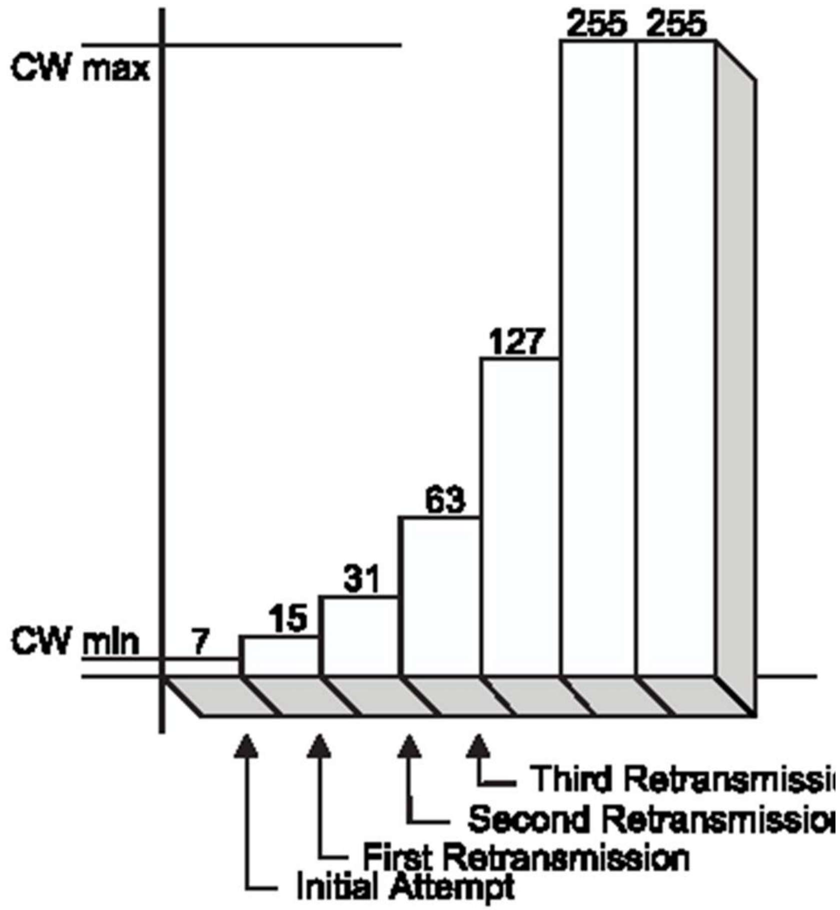
# 802.11 with RTS/CTS

- Sending unicast packets
  - station can send RTS with reservation parameter after waiting for DIFS (reservation determines amount of time the data packet needs the medium)
  - acknowledgement via CTS after SIFS by receiver (if ready to receive)
  - sender can now send data at once, acknowledgement via ACK
  - other stations store medium reservations distributed via RTS **and** CTS



# 802.11: Contention Window

- Increment of CW
  - In 802.11, $CW=2^n-1$
  - Initialization, CW=CWmin
  - CW increases with every retry
  - CW increases up to CWmax
  - CW is reset to CWmin after successful transmission
- (truncated) binary exponential backoff



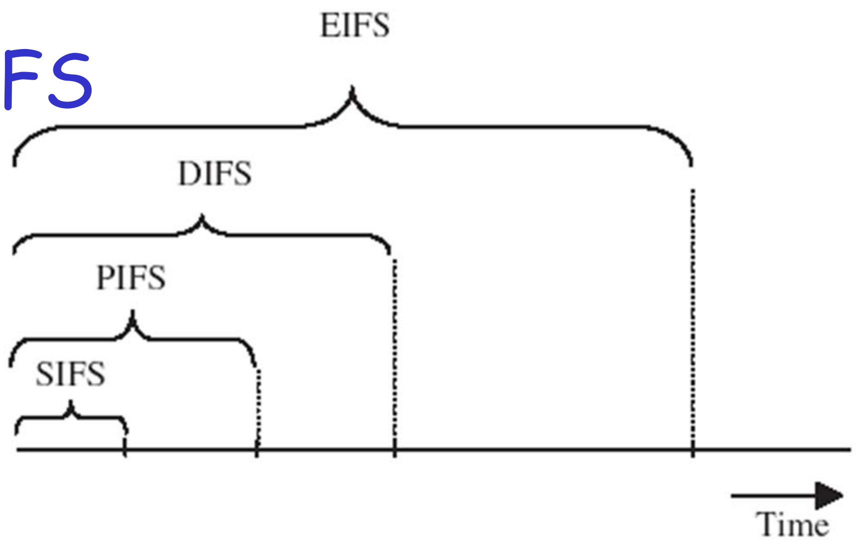

Example: CWmin=7, CWmax=255

# 802.11: Random Backoff

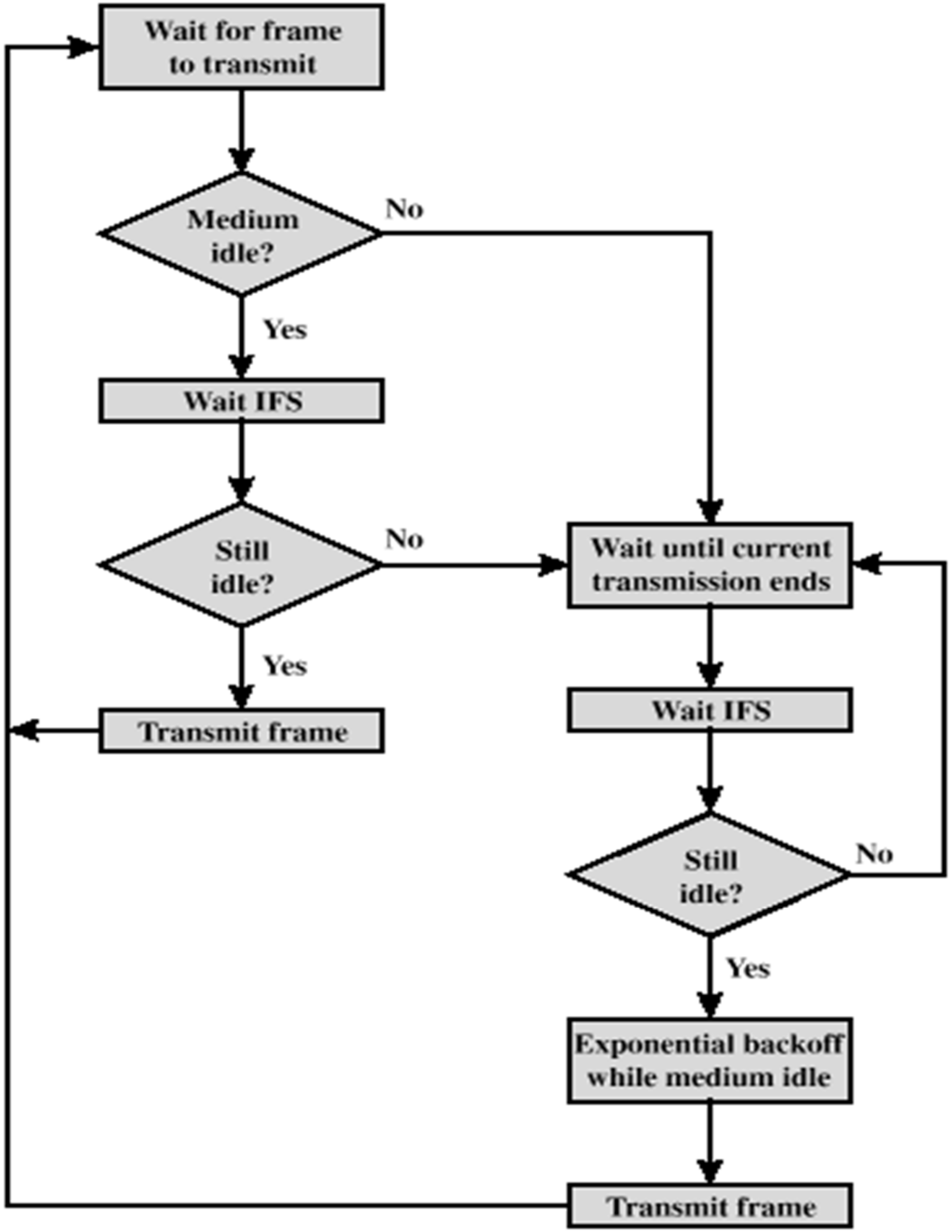
- Backoff Time = random() * Slot_Time
  - Slot_Time is the PHY basic time unit
    - PHY layer parameter
      - (e.g. 20 μs in 802.11-1999 DSSS PHY)
  - random() is a random integer number drawn uniformly from [0,CW]
    - CW is the contention window size
    - CWmin≤ CW ≤CWmax
  - CWmin and CWmax are PHY-dependent parameters
    - E.g. 802.11-1999 DSSS PHY
      - CWmin=31; CWmax=1023

# Prioritize IFSs

- interframe spacing (IFS)
  - SIFS: short IFS
  - PIFS: point (coordinated function) IFS
    - PCF IFS
  - DIFS: distributed (coordinated function) IFS
    - DCF IFS
  - EIFS: extended IFS
- SIFS < PIFS< DIFS < EIFS



# MAC State Diagram



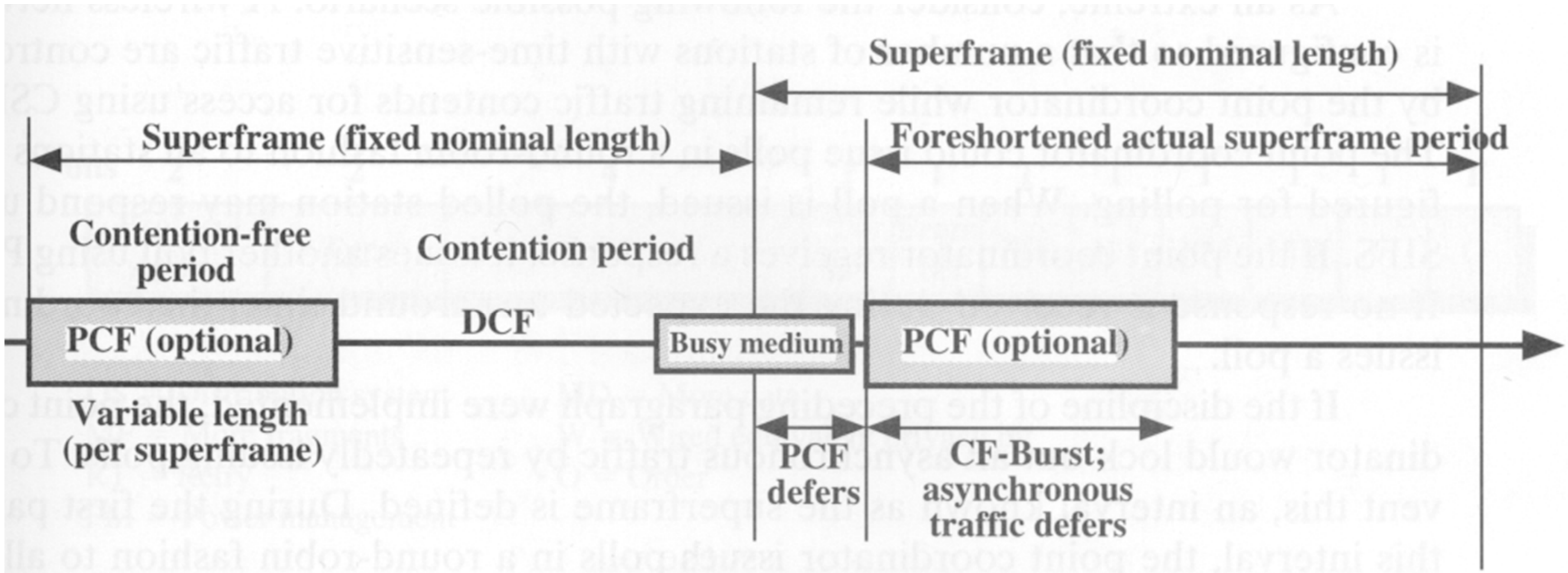
# 802.11 Coordinated Functions: DCF and PCF

# 802.11: Coordinated Functions

- 2 types of coordinated functions
  - DCF: distributed coordinated function
  - PCF: point Coordination Function
    - Built upon DCF
    - Optional
      - Not always implemented in products
    - Centralized coordination
      - More like cellular BS

# MAC Timing: PCF Operation

- Two periods
  - Contention free interval
  - Contention interval




(b) PCF superframe construction

# PCF Examples

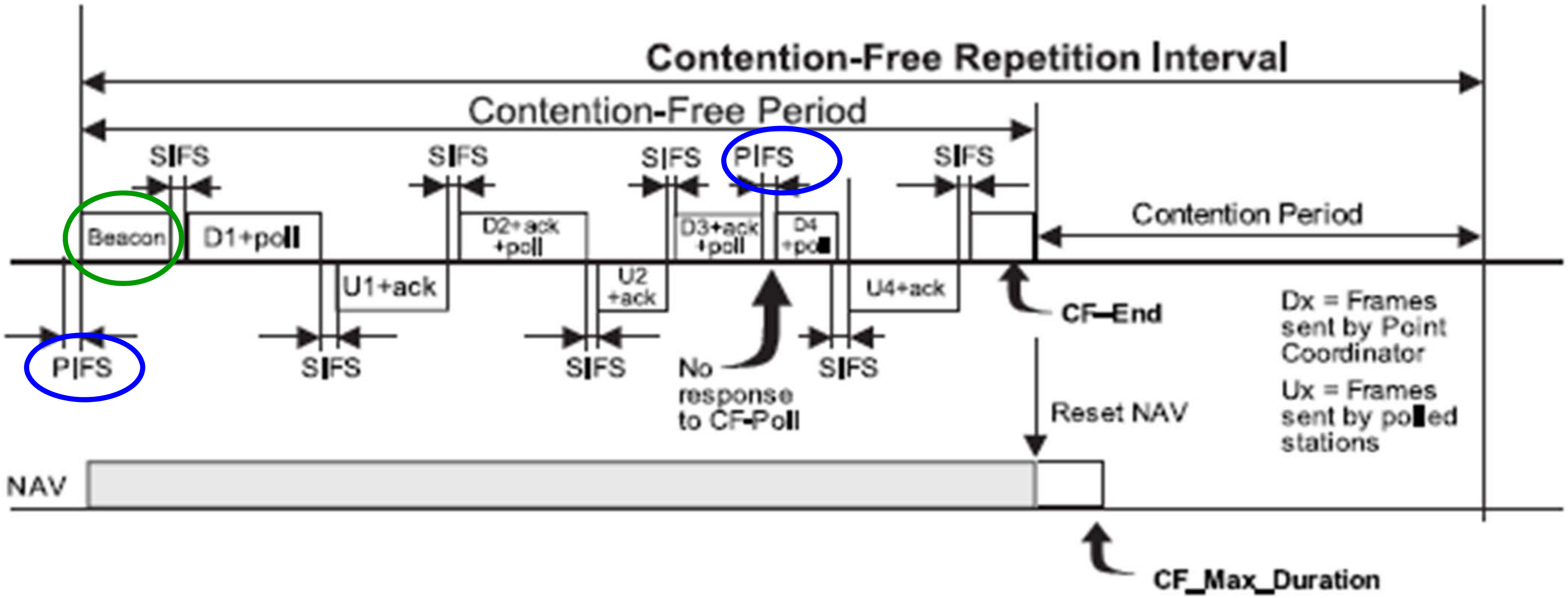



Figure 62—Example of PCF frame transfer

# 802.11: Power Management

# Power Management Overview

- Why power management?
  - Most of the time mobile devices receive data in burst and then are idle for the rest of the time.
  - Can exploit that by going into a power saving idle mode – "powering off". However, need to maintain on-going sessions
- Basic idea
  - Mobile sleeps, AP buffers downlink data, and sends the data when the mobile device is awakened
  - Using the Timing Sync Function all mobiles are synchronized and they will wake up at the same time to listen to the beacon.
    - Check the beacon to see if the mobile needs to wake up
- Compare to cellular network power control
  - In comparison to the continuous power control in cellular networks this power conservation is geared towards burst data

# Power Management in 802.11

- MS has 2 modes
  - Active mode (AM)
  - power-save (PS) mode
- MS enters power-save (PS) mode
  - Notify AP with "Power Management bit" in Frame Control field
  - PS mode MSs listen for beacons periodically
- MS enters active mode
  - The MS sends a power-save poll (PS-Poll) frame to the AP and goes active

# Power Management in 802.11

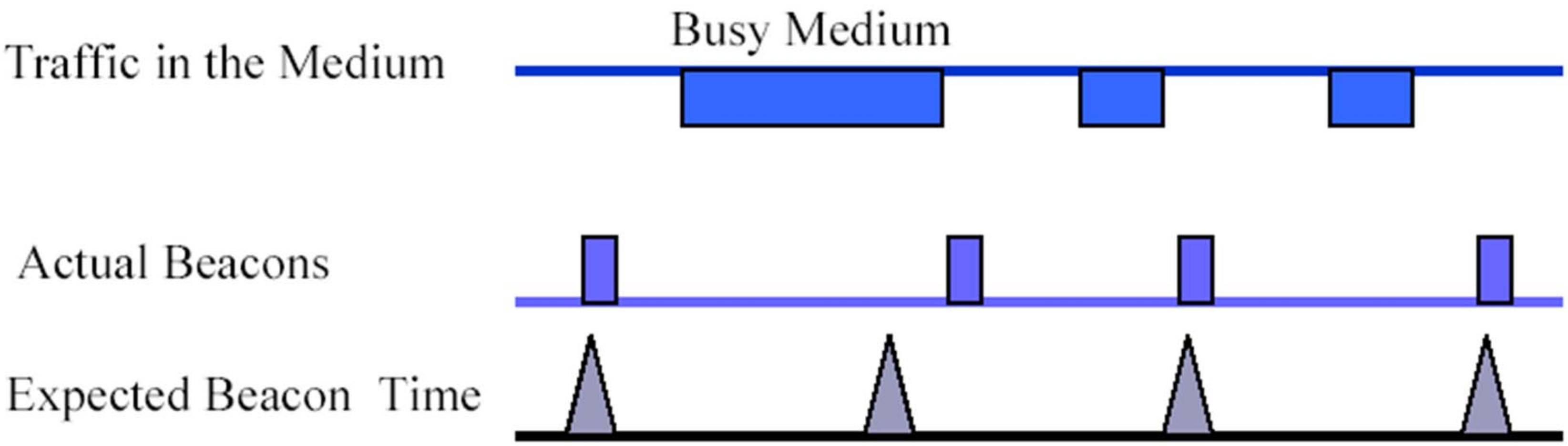
- AP operations (when MS is in PS mode)
  - Does not arbitrarily sends MSDU to MS in PS mode
  - Buffer MSDUs at AP until MS "wake up"
  - MSs with buffered MPDUS at AP are identified with traffic indication map (TIM).
    - TIM is included in periodic beacons
    - MS learns that it has data buffered by checking the beacon/TIM
- AP operations when MS goes into active mode
  - The AP then sends the buffered data to the mobile in active mode

# Concept: Paging and Sleep mode

- Sleep mode (dormant mode)
  - Save power
- Wake up mechanism
  - Paging
- Combine with location management mechanism (in cellular networks not in 802.11)
  - Paging area V.S. location area
  - Frequency of location area update
  - Savings
    - Power consumption
    - Signaling overhead
- Paging + IP → IP Paging

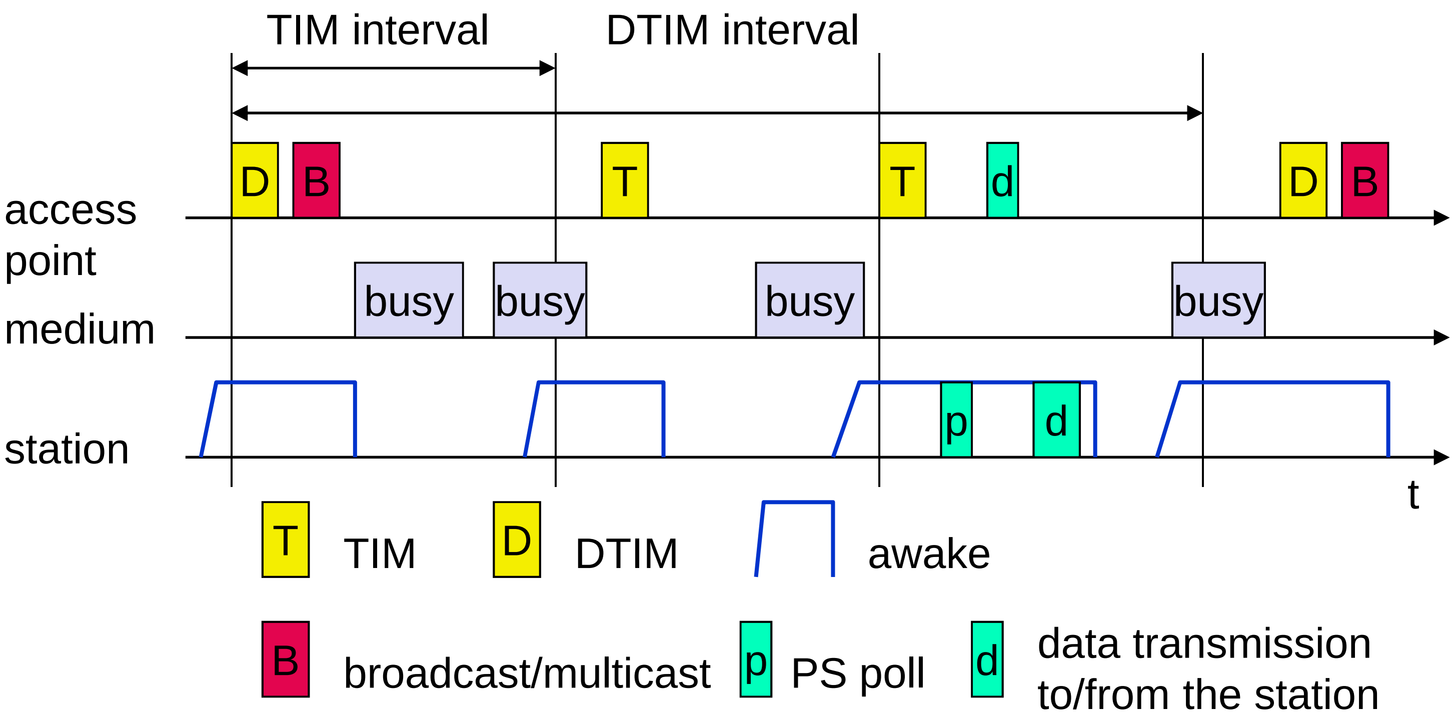
# Listening to the beacon for power management

- Beacon for synchronization
  - Quasi-periodic
  - Might be deferred due to busy medium



# TIM and DTIM

- TIM (traffic indication map)
  - Contain the info of PS mode stations with data buffered at AP
  - TIM interval: transmit TIM (quasi) periodically
    - TIM might be deferred due to busy medium
- DTIM (delivery traffic indication map)
  - Similar to TIM, DTIM is used for multicast/broadcast
  - DTIM interval = multiple TIM interval



# Summary: Power Management Function

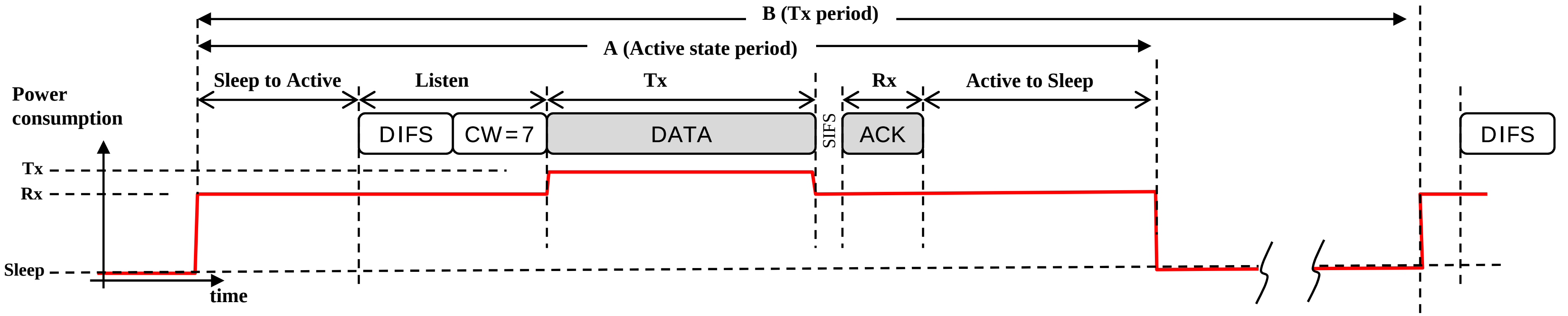
- Idea: switch the transceiver off if not needed
- States of a station: sleep and awake
- Timing Synchronization Function (TSF)
  - stations wake up at the same time
- Infrastructure
  - Traffic Indication Map (TIM)
    - list of unicast receivers transmitted by AP
  - Delivery Traffic Indication Map (DTIM)
    - list of broadcast/multicast receivers transmitted by AP
- Ad-hoc
  - Ad-hoc Traffic Indication Map (ATIM)
    - announcement of receivers by stations buffering frames
    - more complicated - no central AP
    - collision of ATIMs possible
  - Scalability issues!

# Solutions for energy-efficient WiFi and 802.11ah

# IEEE 802.11ah

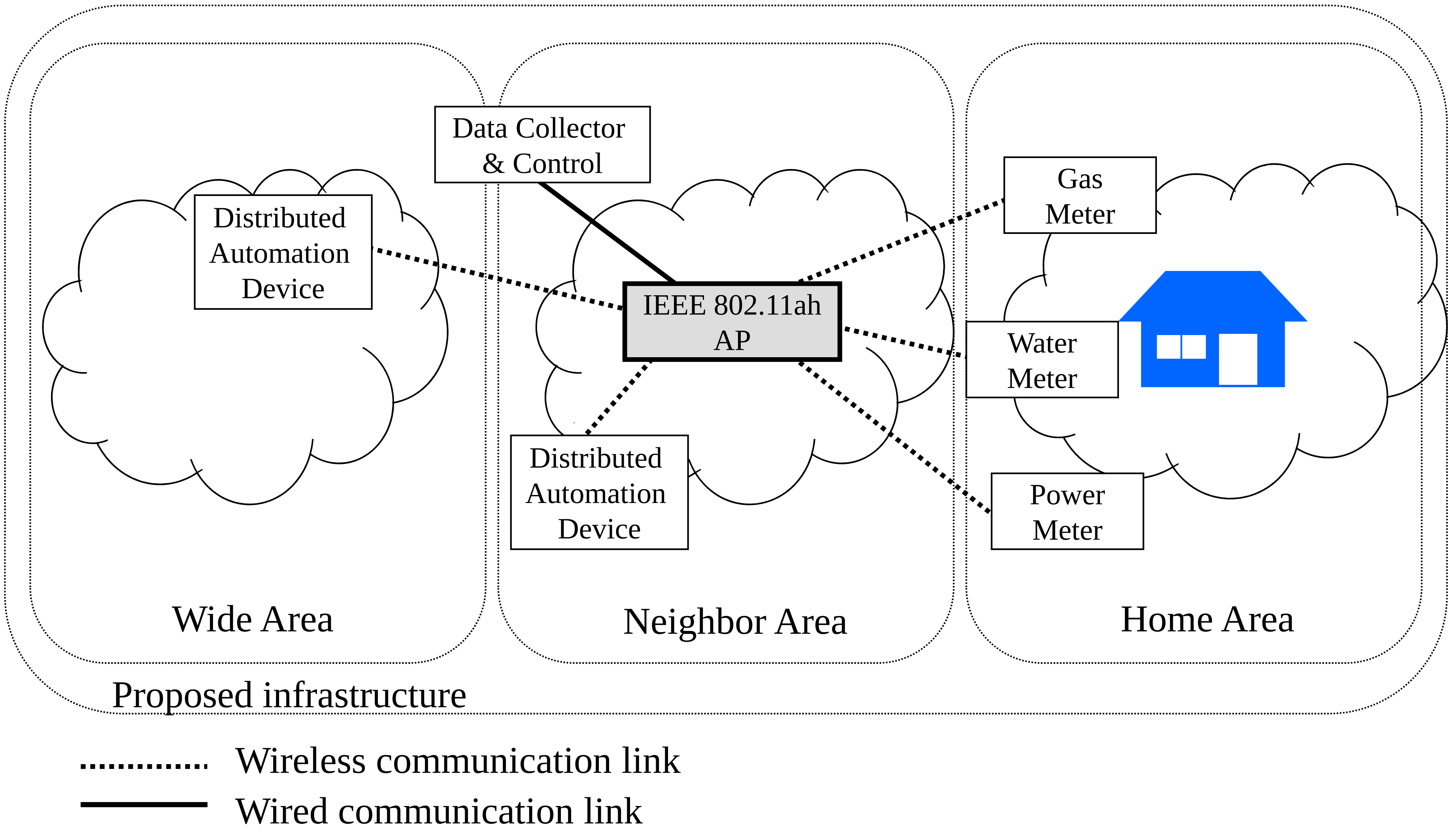
- WiFi in Sub 1GHz band
  - Longer transmission range
    - Signal loss (pathloss) is lower for low frequency carrier
  - Narrowband transmission
    - Due to channel availability and regulation (e.g. FCC)
  - Lower data rate
- M2M is the key use case for 802.11ah

# Energy Consumption



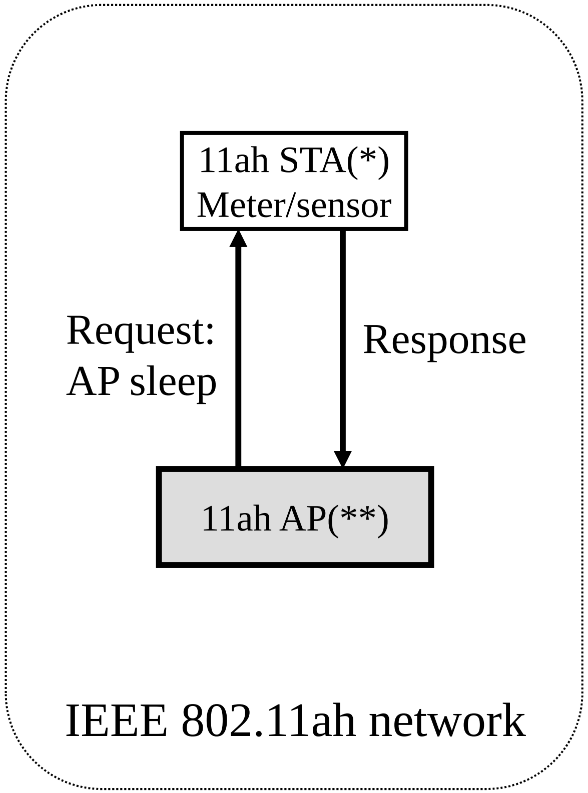

From: 11-10-1268-00-00ah-low-power-consumption-opportunity-in-sub-1-ghz

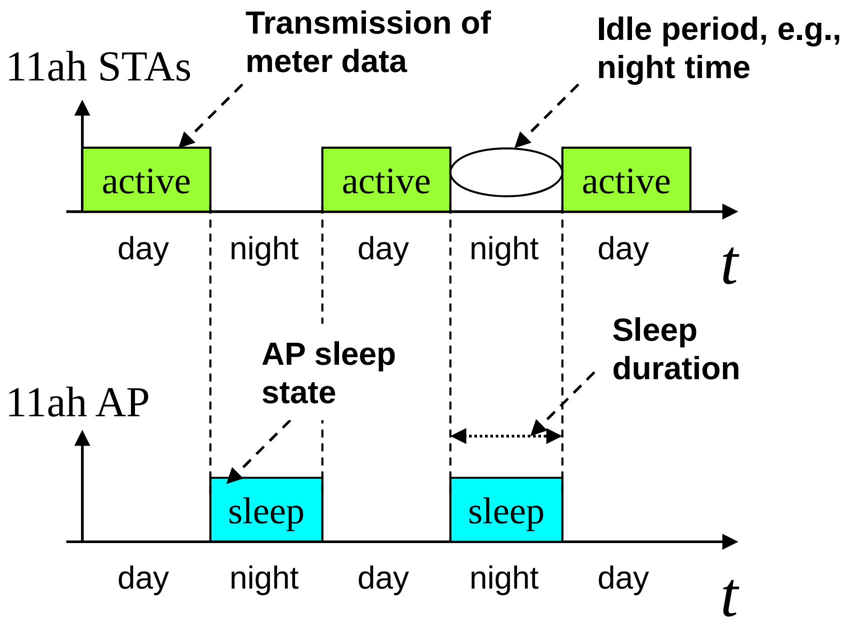
# Use Case 1a: Smart Grid – Meter to Pole




From: 11-11-0457-00-00ah-potential-compromise-of-802-11ah-use-case-document

# Use Case: AP Power Saving in Smart Grid




(*) = IEEE 802.11ah STA with proposed AP power saving support

(**) = IEEE 802.11ah AP with proposed AP power saving support

From: 802.11ah contribution 11-11-0273-00-00ah-tgah-use-case-ap-power-saving-in-smart-grid

# BSS Max Idle Period

- BSS Max idle period management enables an AP to indicate a time period during which the AP does not disassociate a STA due to non-receipt of frames from the STA.
  - This supports improved STA power saving and AP resource management.
- If dot11MaxIdlePeriod is a non-zero, the STA shall include the BSS Max Idle Period element in the (Re)Association Response frames
- BSS Max Idle Period element
  - The Max Idle Period field is a 16-bit unsigned integer. The time period is specified in units of 1000 TUs.
  - Bit 0 (the Protected Keep-alive Required) in Idle Options field set to 1 indicates that the STA sends an RSN protected frame to the AP to reset the Idle Timer at the AP for the STA

| | **Element ID** | **Length** | **Max Idle Period** | **Idle Options** |
|---|---|---|---|---|
| **Octets:** | **1** | **1** | **2** | **1** |

From: 11-10-1326-00-00ah-bss-max-idle-period-and-sleep-interval

# WNM-Sleep Mode

- WNM-Sleep Mode enables a non-AP STA to signal to an AP that it will be sleeping for a specified length of time. This enables a non-AP STA to reduce power consumption and remain associated while the non-AP STA has no traffic to send to or receive from the AP.
- WNM-Sleep mode is an extended power save mode for non-AP STAs in which a non-AP STA need not listen for every DTIM Beacon frame, and need not perform GTK/IGTK updates.
- WNM-Sleep Mode element
  - The WNM-Sleep Interval field indicates to the AP how often a STA in WNM-Sleep Mode wakes to receive Beacon frames, defined as the number of DTIM intervals. The value set to 0 indicates that the requesting non-AP STA does not wake up at any specific interval.

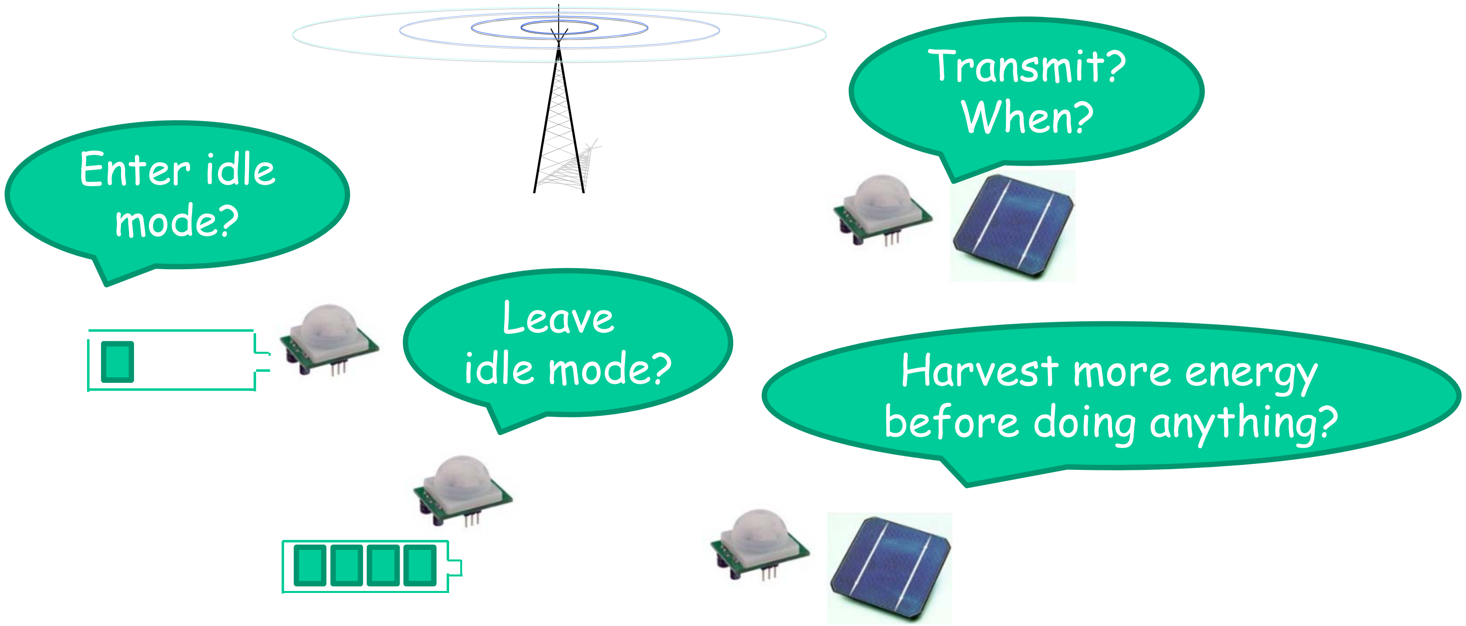
| | Element ID | Length | Action Type | WNM-Sleep Mode Response Status | WNM-Sleep Interval |
|---|---|---|---|---|---|
| Octets: | 1 | 1 | 1 | 1 | 2 |

From: 11-10-1326-00-00ah-bss-max-idle-period-and-sleep-interval

# Discussions

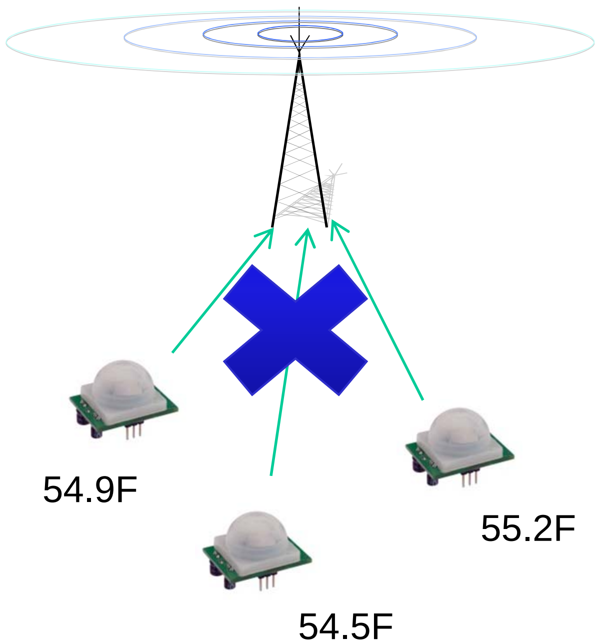
# Energy Harvesting and Application Sceanrios

# Some Decisions to Make

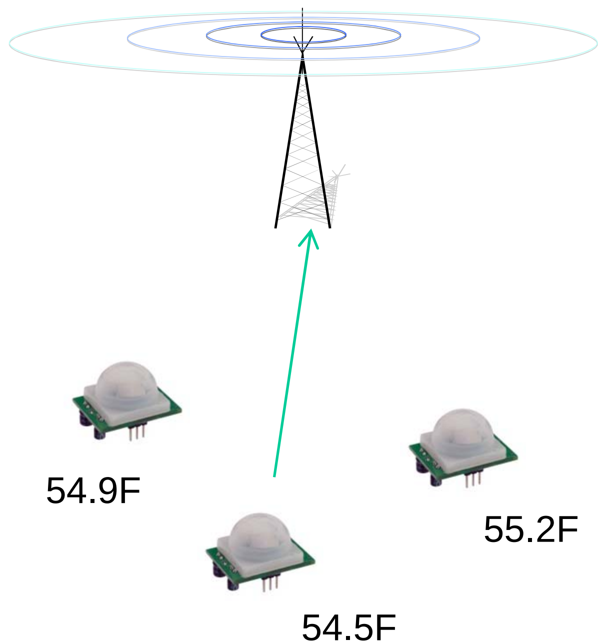


# Collision causes problem

- Large number of M2M devices cause serious problem




- Transmission fails
- Waste communications resource
- Waste battery energy




- Transmission is successful
- Other two devices could enter idle mode to save energy

# Questions 1

- What might be the energy issue for M2M devices in the following scenarios?
  - Agricultural monitoring
  - Bridge structure monitoring
  - Industrial automation
  - Earthquake monitoring
  - Healthcare

# Question 2

- What are the design tradeoffs for energy-efficient M2M communications?
  - Energy consumption
  - Delay
  - More ….

- Will your answers change in different deployment scenarios (agricultural monitoring, bridge structural monitoring, etc.)?

# Question 3

- How will you design an energy-efficient M2M communication system?
  - How will you improve WiFi system for M2M?
  - How will you improve cellular communication system for M2M?