ΕΛΛΗΝΙΚΗ ΔΗΜΟΚΡΑΤΙΑ
ΠΑΝΕΠΙΣΤΗΜΙΟ ΚΡΗΤΗΣ

Ασύρματα Δίκτυα και Κινητοί Υπολογισμοί

Μαρία Παπαδοπούλη
Τμήμα Επιστήμης Υπολογιστών
Πανεπιστήμιο Κρήτης

Χρηματοδότηση

- Το παρόν εκπαιδευτικό υλικό έχει αναπτυχθεί στα πλαίσια του εκπαιδευτικού έργου του διδάσκοντα.
- Το έργο «**Ανοικτά Ακαδημαϊκά Μαθήματα στο Πανεπιστήμιο Κρήτης**» έχει χρηματοδοτήσει μόνο τη αναδιαμόρφωση του εκπαιδευτικού υλικού.
- Το έργο υλοποιείται στο πλαίσιο του Επιχειρησιακού Προγράμματος «Εκπαίδευση και Δια Βίου Μάθηση» και συγχρηματοδοτείται από την Ευρωπαϊκή Ένωση (Ευρωπαϊκό Κοινωνικό Ταμείο) και από εθνικούς πόρους.

Ευρωπαϊκή Ένωση
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ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ ΚΑΙ ΘΡΗΣΚΕΥΜΑΤΩΝ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

Σημείωμα αδειοδότησης

IEEE 802.11 Family

- IEEE802.11b:

Direct Sequence Spread Spectrum (DSSS) or **Frequency Hopping (FH),** operates at 2.4GHz, 11Mbps bitrate

- IEEE802.11a: between 5GHz and 6GHz uses **orthogonal frequency-division multiplexing (OFDM)**, up to 54Mbps bitrate

- IEEE802.11g: operates at 2.4GHz up to 54Mbps bitrate

- **All have the same architecture & use the same MAC protocol**

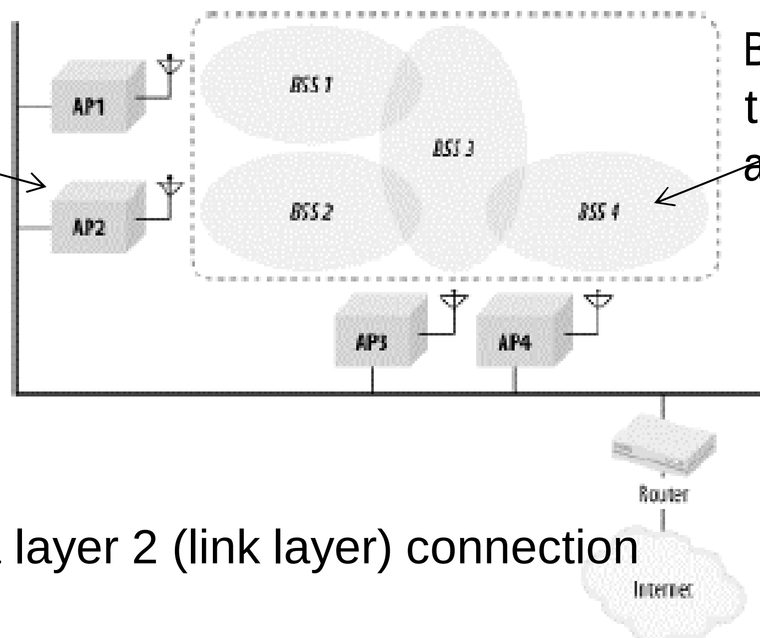
Networks of Arbitrarily Large size

- Chain BSSs together with a backbone network
- Several APs in a single area may be connected to a single hub or switch or they can use virtual LAN if the link=layer connection

Figure 2-5. Extended service set

APs act as bridges

APs are configured to be part of the ESS



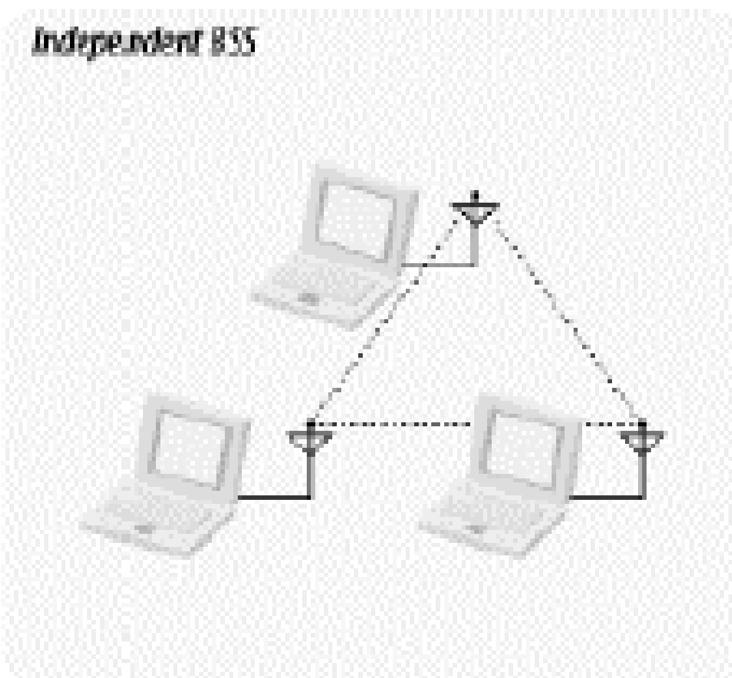
Basic Service Set: the network around one AP

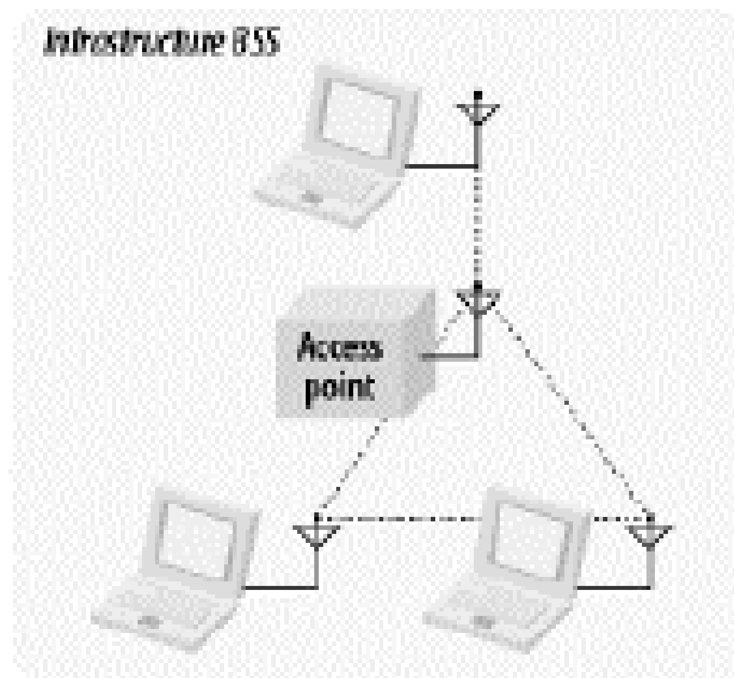
Backbone network is a layer 2 (link layer) connection

Modes of Operation of IEEE 802.11 Devices

- *Infrastructure*: A special STA, the *Access Point (AP),* mediates all traffic mediates all traffic
- *Independent*: Stations speak directly to one another

(**ad hoc networks**)





Inter-Access Point Communication

- If a client is associated with one AP, all the other APs in the ESS need to learn about that client

- If a client associated with an AP sends a frame to a station associated with a different AP, the bridging engine inside the first AP must send **the frame over the backbone Ethernet** to the second AP so it can be delivered to its ultimate destination

- No standardized method for communication

  Major project in the IEEE802.11 working group the standardization of the IAPP

A Network of Socialites

Our 802.11 station (STA) would like to

- Join the community (i.e., a network)
- Chat for a while (send and receive data)
- Take a nap (rest, then wake up)
- Take a walk ("roam" to a new area)
- Leave the network

Note: the word "roam" is using in a non-technical way.
In wireless networks, roaming is the handoff between base stations of
different providers/operators.

Steps to Join a Network

1. ***Discover*** available networks (aka *BSSs*)
2. ***Select*** a BSS
3. ***Authenticate*** with the BSS
4. ***Associate***

Discovering Networks

Each AP ***broadcasts periodically*** beacons announcing itself

Beacon includes:

- AP’s MAC address
- AP’s clock
- Beacon interval (100ms typical)
- Network Name (*SSID*); eg “UoC-1”

Associations

- Exclusive:

  A device can be associated with **only one AP**

- ***Client-initiated***:

The client initiates the association process

- AP may choose to grant or deny access based on the content of the association request

Reasons to Deny Access

- Memory
- Traffic load

Infrastructure Mode: Handoff Re-association

- When a station leaves one BSS and enters another BSS, it can re-associate with a new AP
- Re-association request is like association plus:
  - Previous AP MAC address
  - Old association id
- **New AP can contact old AP to get buffered frames**

Infrastructure mode: Leaving the network

- If a station is inactive, AP may disassociate it automatically; 30 seconds is typical
- Station may indicate its de-association politely

Coordination Functions for Channel Access

- **Distributed Coordination function**
  - ***Contention*-based** access
  - DIFS (ms) sensing channel
  - 4-way handshaking protocol for data transmissions
  - ***Backoff*** process
- **Point Coordination function**
  - Contention-free access

Infrastructure Mode: Joining a network
1. Discovering Network (active)

1. Instead of waiting for beacon, clients can send a probe request which includes

- STA MAC address
- STA's supported data rates
- May specify a SSID to restrict search

2. AP replies with proble response frame

Infrastructure Mode: Joining a network
2. Choosing a Network

- The user selects from available networks; common criteria:
  - User choice
  - Strongest signal
  - Most-recently used
- OS Driver indicates this selection to the STA

Infrastructure Mode: Joining a network 3. Authentication

- Open-system ‘authentication’; no password required
- Often combined with MAC-address filtering

Infrastructure Mode: Joining a network 3. Authentication

- Shared-key ‘ authentication’ called “Wired Equivalency Protection”, *WEP*

Infrastructure Mode: Joining a network 4. Association

- Station requests association with one AP
- Request includes includes
  - STA MAC address
  - AP MAC address
  - SSID (Network name)
  - **Supported data rates**
  - *Listen Interval* (described later)

We have now joined the network …

- Next: sending data

Carrier-Sensing Functions

IEEE 802.11 to **avoid collisions**

Carrier Sense Multiple Access/***Collision Avoidance*** (CSMA/CA)

MAC layer

- ***RTS, CTS, ACK***
- **Network allocation vector (NAV)** to ensure that atomic operations are ***not interrupted***
- **Different types of delay**

Short Inter-frame space (SIFS):

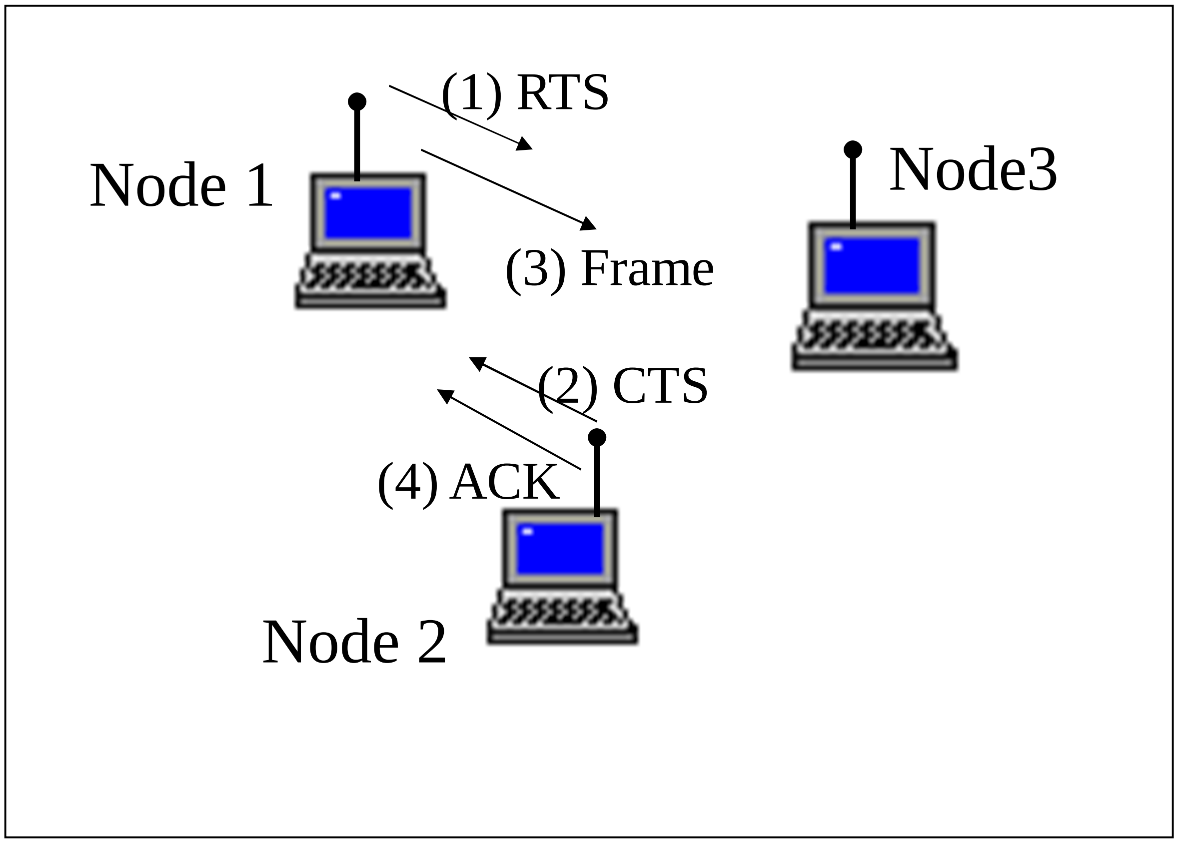
highest priority transmissions (RTS, CTS, ACK)

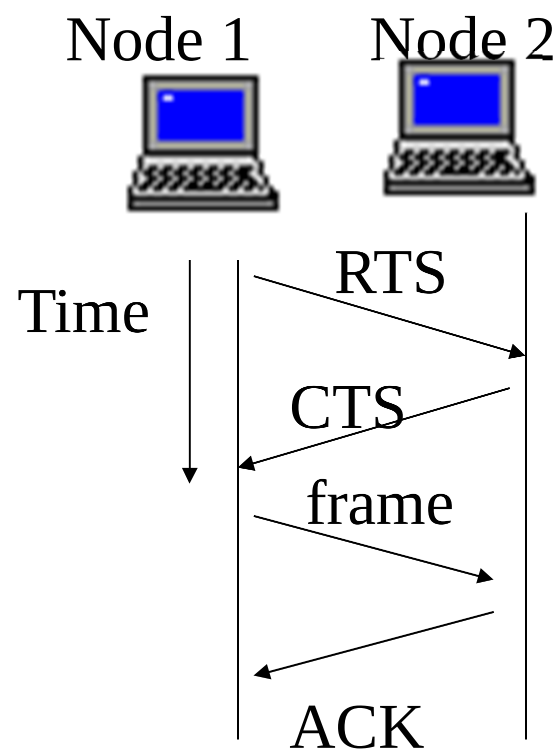
DCF inter-frame space (DIFS):

minimum idle time for contention-based services

EIFS: minimum idle time in case of “erroneous” past transmission

RTS/CTS Clearing

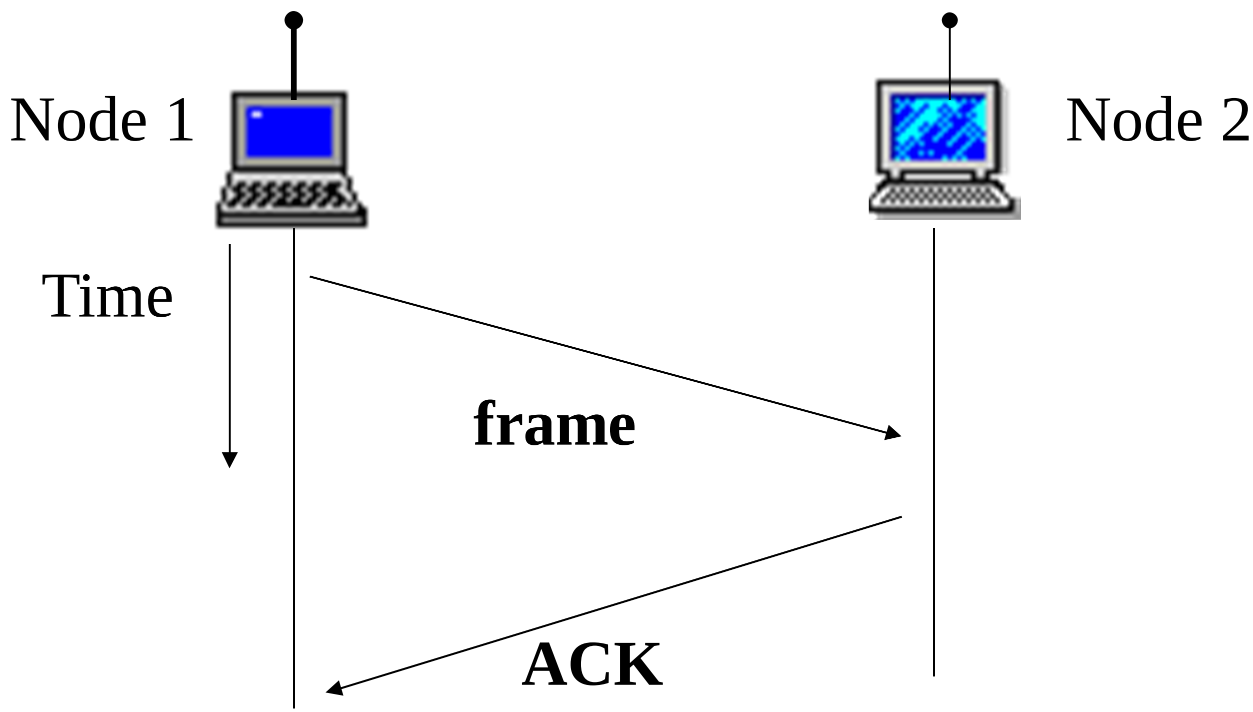




RTS: reserving the radio link for transmission

RTS, CTS: Silence any station that hear them

Positive Acknowledgement of Data Transmission



☞IEEE 802.11 allows stations to **lock out contention during atomic operation so that atomic sequences are not interrupted by other hosts attempting to use the transmission medium**

Sending a Frame

1. Request to Send – Clear to send

   Used to reserve the full coverage areas of both sender and receiver

1. Send frame
2. Get acknowledgement

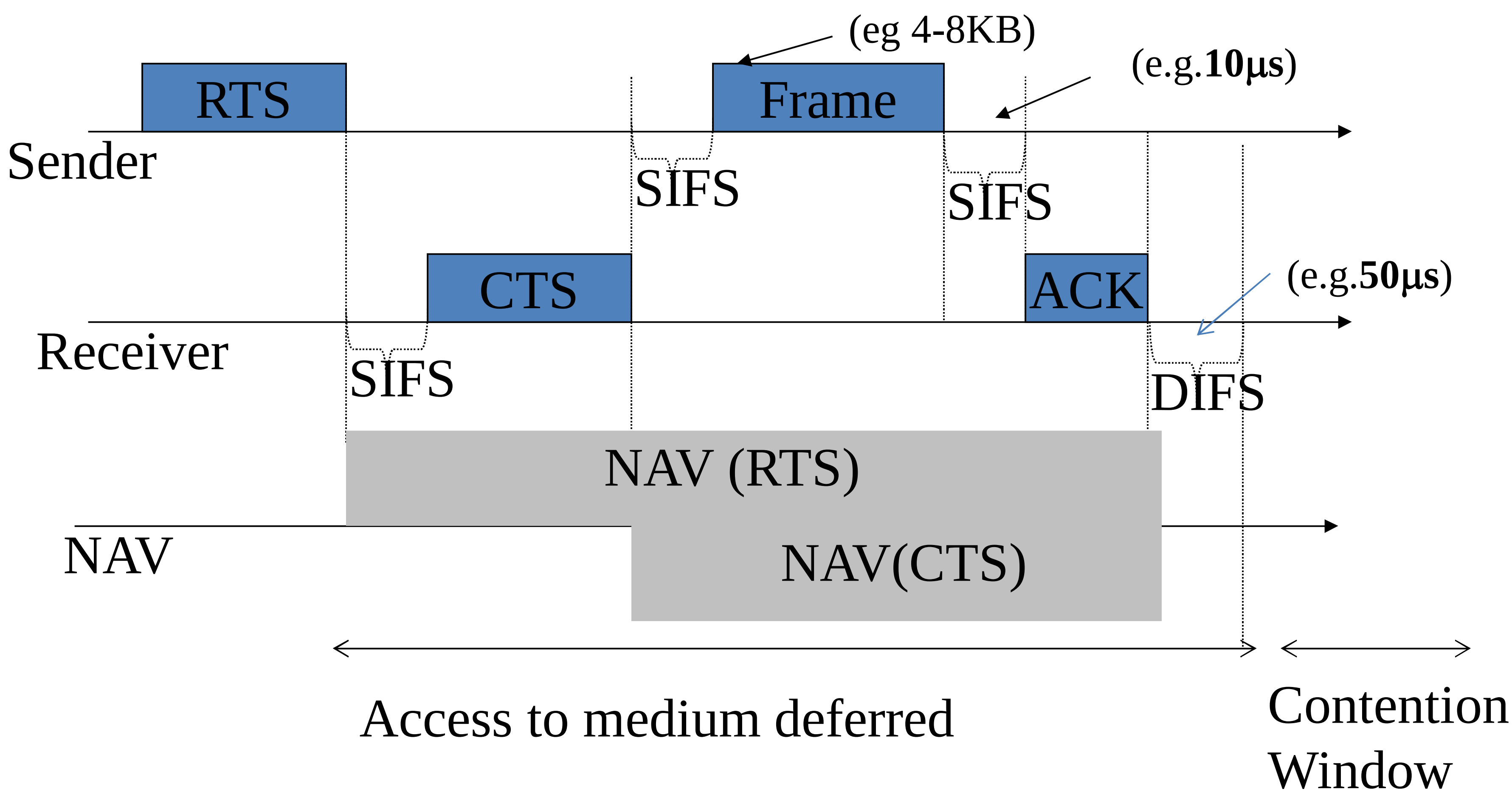
Infrastructure mode: Sending Data 1. RTS/CTS

- RTS announces the intent to send a pkt; it includes:
  – Sender’s MAC address
  – Receiver’s MAC address
  – Duration of reservation (ms)
- CTS inidcates that medium is available; includes:
  – Receiver’s MAC address
  – Duration of reservation remaining (ms)

Infrastructure mode: Sending Data 2. Transmit frame

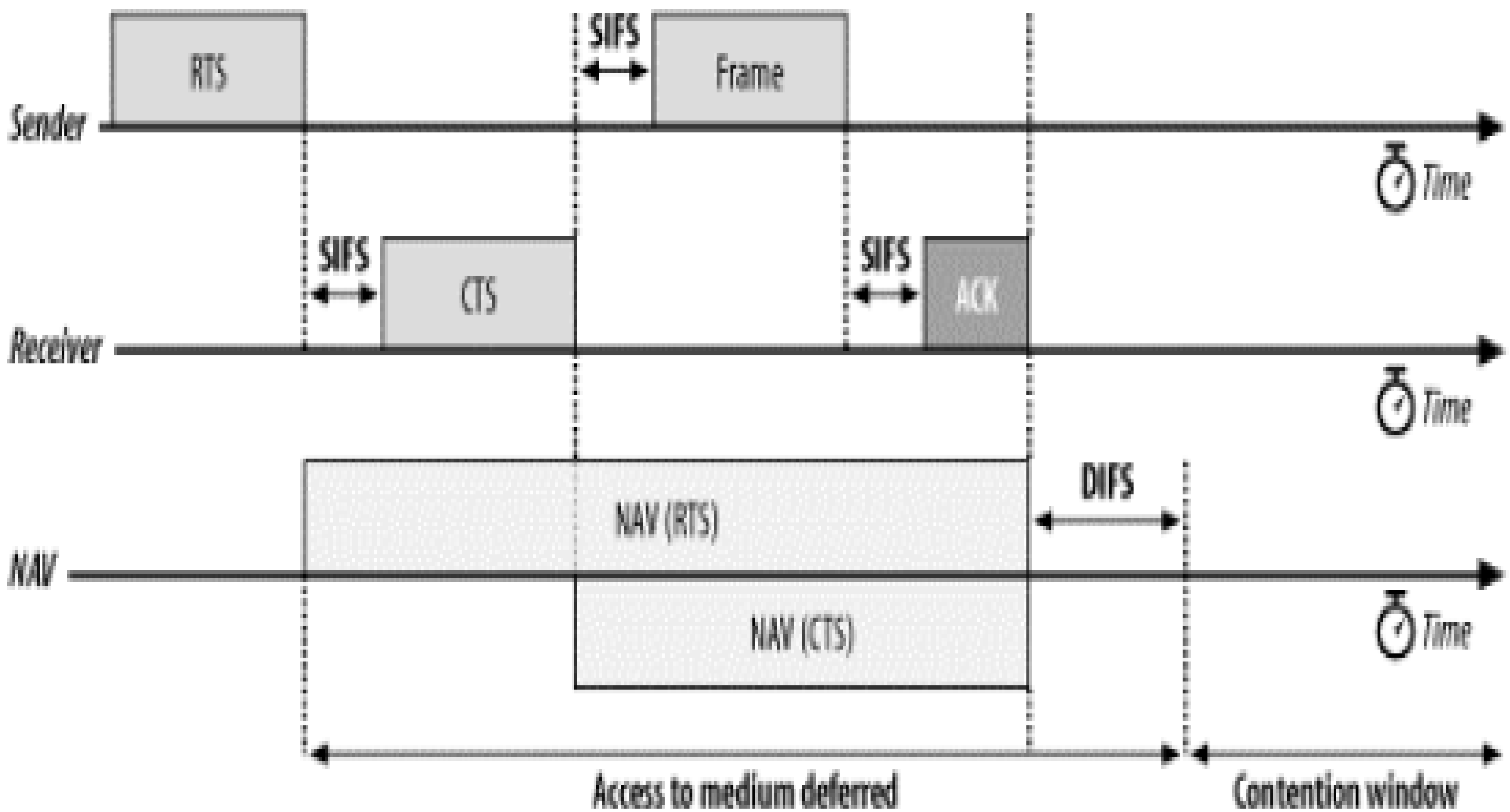
- Normal ethernet frame has two addresses: sender and receiver
- 802.11 data frame has four possible addresses:
  - Sender (SA) originated the data
  - Destination (DA): should ultimately receive the data
  - Receiver (RA): receives the transmission from the sender
  - Transmitter (TA) transmits the frame
- Data frame includes also
  - Duration remaining in fragment burst
  - More-fragments ? Indicator
  - Data

Using the NAV for virtual carrier sensing



NAV is carried in the headers of CTS & RTS

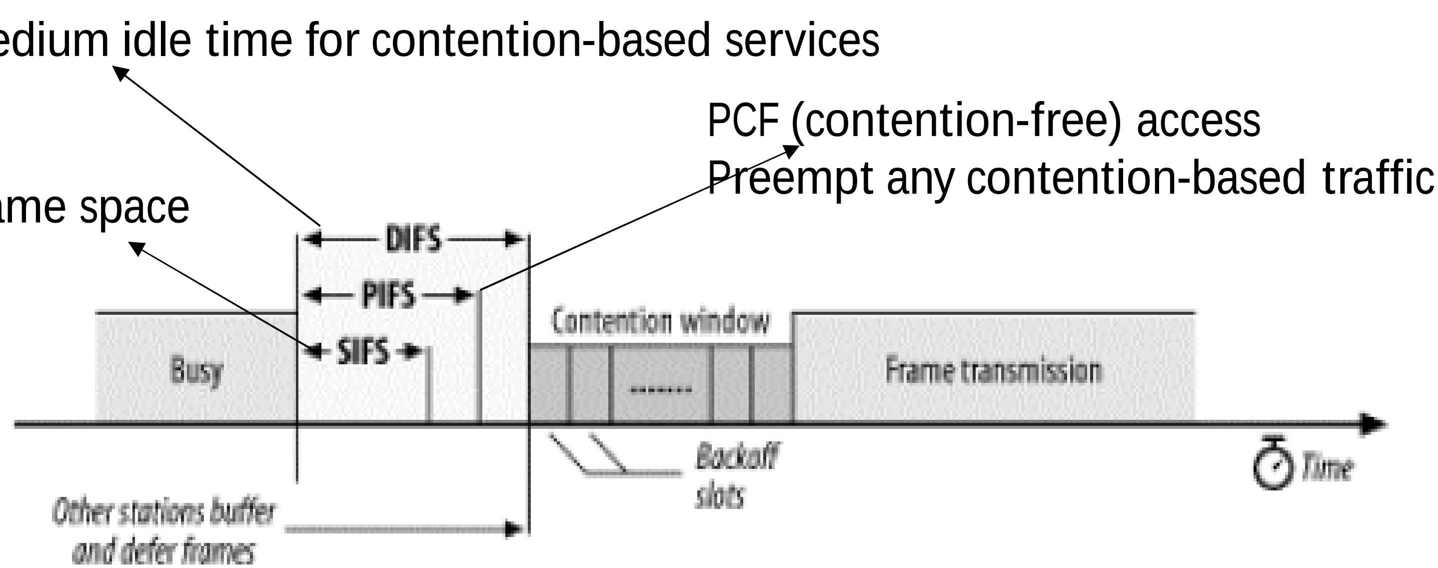
Using the NAV for Virtual Carrier Sensing



Every host that receives the **NAV differs the access**, even if it is configured to be in **a different network**

Inter-frame Spacing

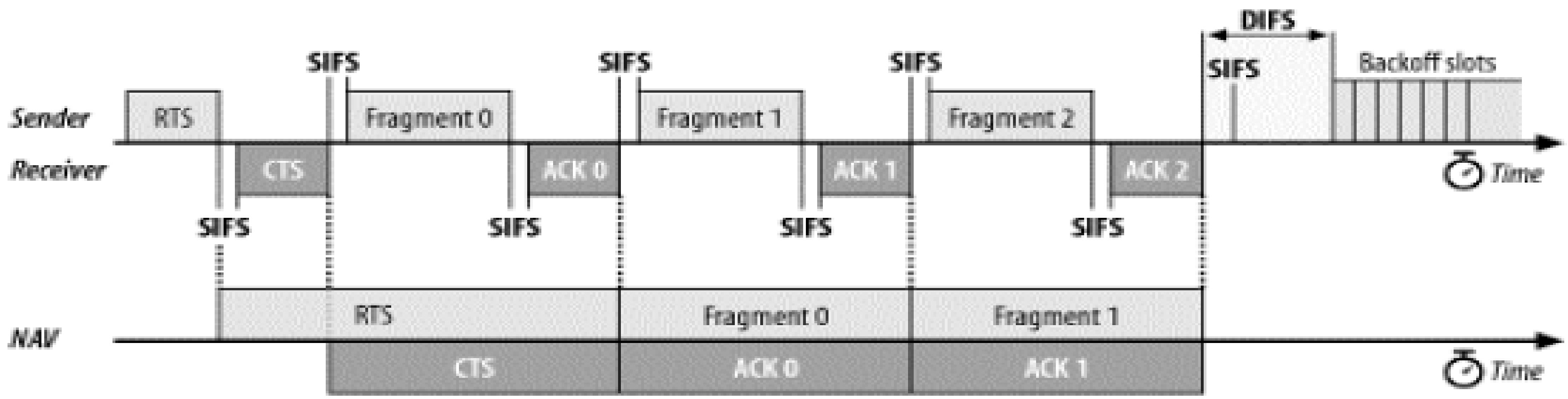
- Create **different** **priority levels** for different types of traffic
- The higher the priority the smaller the wait time after the medium becomes idle



Interframe Spacing & Priority

- Atomic operations start like regular transmissions
  - They must **wait for the DIFS** before they can begin
  - However the **second and any subsequent steps in an atomic operation take place using SIFS** rather than DIFS
  - Second and subsequent parts of the atomic operation will grab the medium before another type of frame can be transmitted.
- By using the SIFS and the NAV stations can seize the medium as long as necessary

Fragmentation burst



Data sent ...

- Next: Take a nap

IEEE802.11

- **Point Coordination Function (PCF)**

Provides un-contended access via arbitration by a Point Coordinator which resides at the AP

☞ **Guarantees a time-bounded service**

- **Distributed Coordination Function (DCF)**

Uses **CSMA/CA** to share channel in a "***fair way***":

☞ Guarantees **<u>long-term</u> channel access probability to be equal among all hosts**

Note:

- there is short-term and long-term fairness
- Fairness in the long-term probability for accessing the channel

IEEE802.11 Media Access Protocol with DCF (1/2)

- **Coordinates the access & use of the shared radio frequency**
- Carrier Sense Multiple Access protocol with collision avoidance (**CSMA/CA**)
- Physical layer **monitors the energy level** on the radio frequency to determine whether another station is transmitting and provides this carrier-sensing information to the MAC protocol

☞ If **channel is sensed idle** for **DIFS**, a station can transmit

- When receiving station has correctly & completely received a frame for which it was the addressed recipient, it waits a short period of time **SIFS** and then **sends an ACK**

IEEE802.11 Media Access Protocol with DCF (2/2)

- If channel is sensed busy **will defer its access** until the channel is later sensed to be idle
- Once the channel is sensed to be **idle for time DIFS**, the station computes an **additional random backoff time** and **counts down this time *as the channel is sensed idle***
- When the random backoff timer reaches zero, the station transmits its frame
- Backoff process to avoid having multiple stations immediately begin transmission and thus collide

Distributed Coordination Function (DCF)

A host wishing to transmit:

- **Senses the channel**
- Waits for a period of time (DIFS), and then
- Transmits, if the medium is still free

Receiving host:

- Sends ACK, after SIFS time period, if packet is correctly received

Sending host:

- Assumes a collision, if this ACK is not received
- Attempts to send the packet again, when the channel is free for DIFS period augmented of a random amount of time

Backoff with DCF

- Contention (backoff) window follows DIFS
- Window is divided in **time slots**
- Slot length & window length are medium-dependent
- Window length limited and medium-dependent

A **host that wants to transmit a packet**:

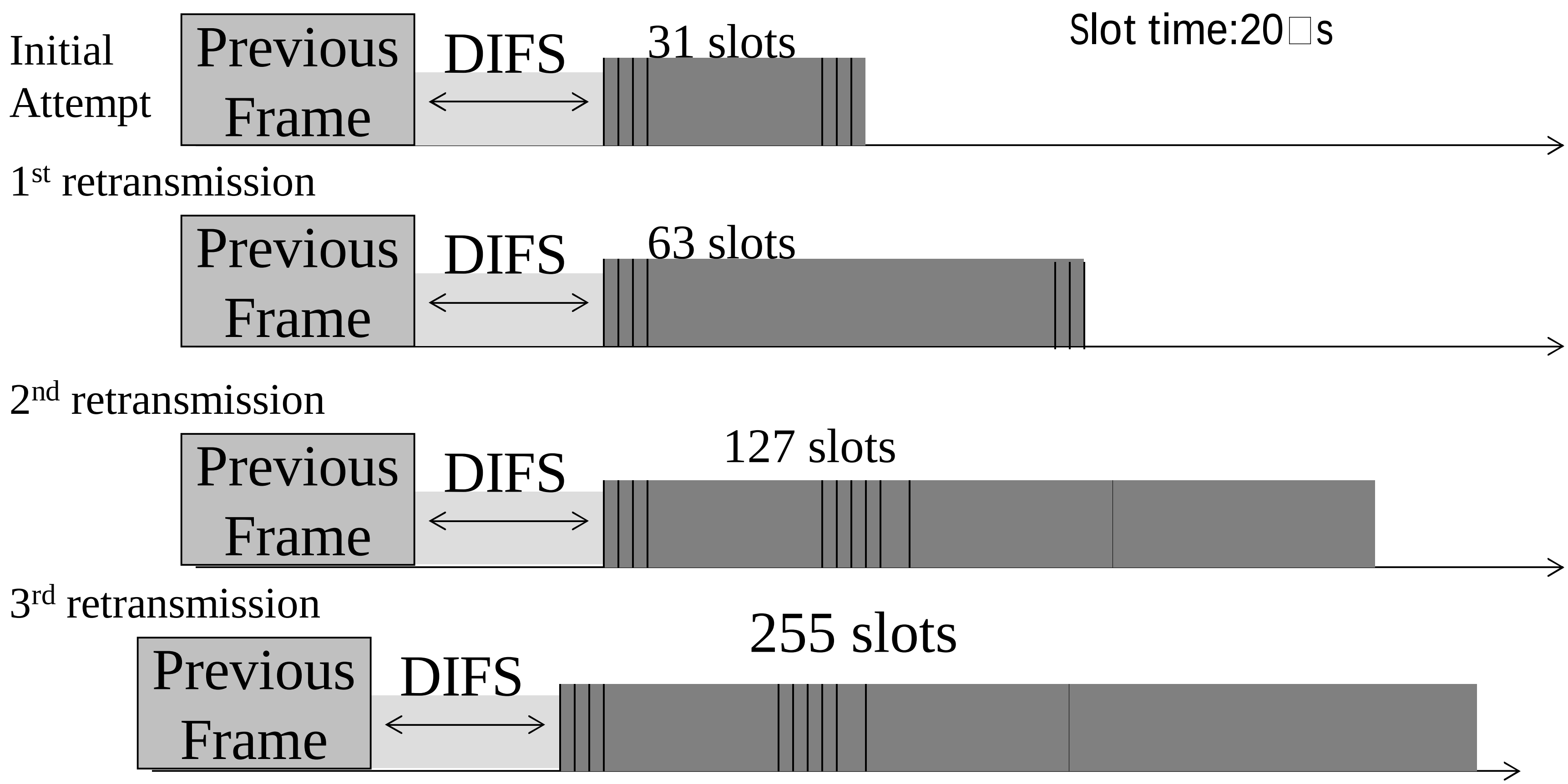
1. **picks a random** number with uniform probability from the contention window

   (All slots are equally likely selections)

2. **waits for this amount of time before attempting to access the medium**
3. **freezes the counter when it senses the channel busy**

- The host that picks the earlier number wins
- Each time the **retry counter increases**, for a ***given host and packet (to be retransmitted),*** the contention window is doubled

Contention Window Size

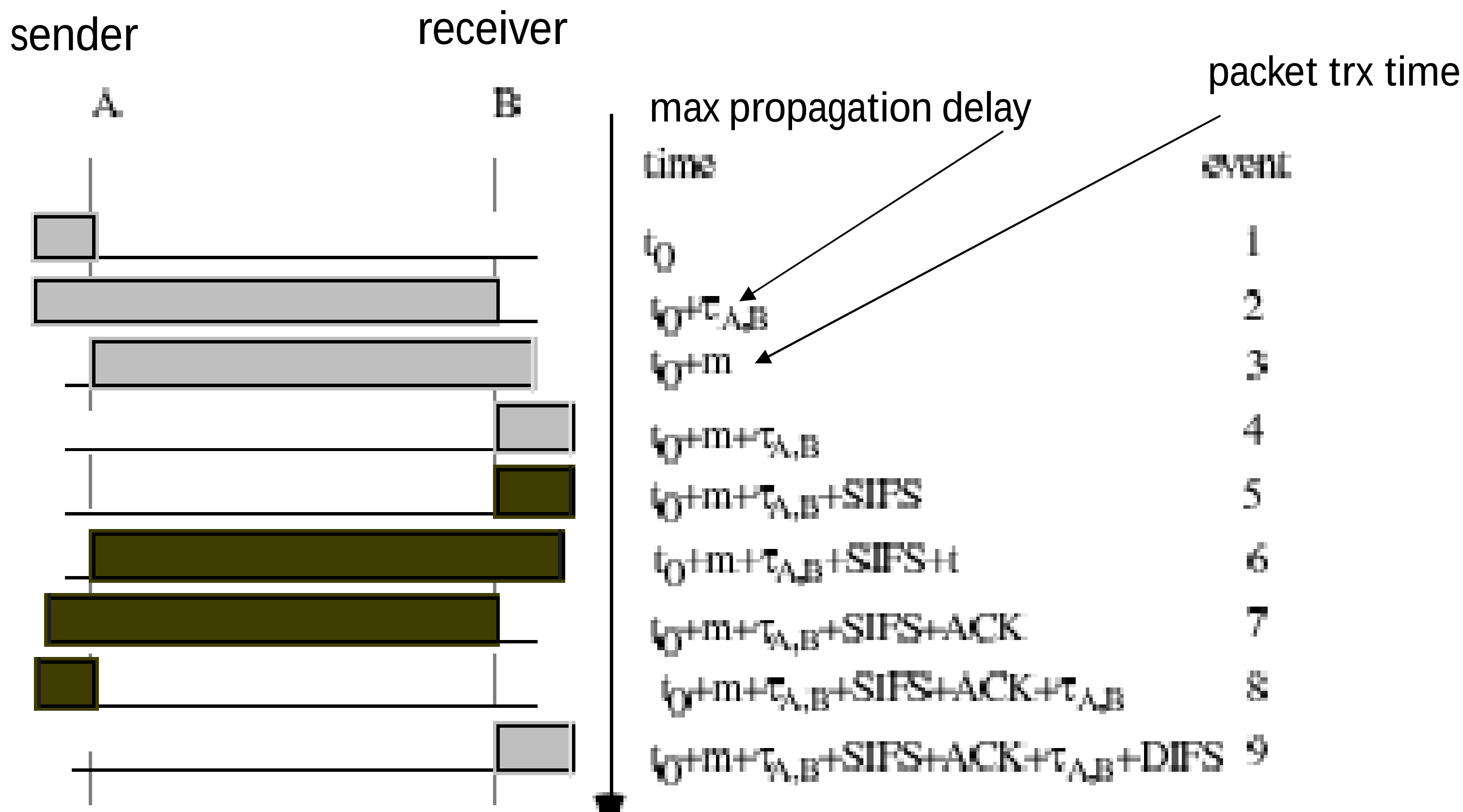


The contention window is reset to its minimum size when frames are transmitted successfully, or the associated retry counter is reached and the frame is discarded

Simple Exercise

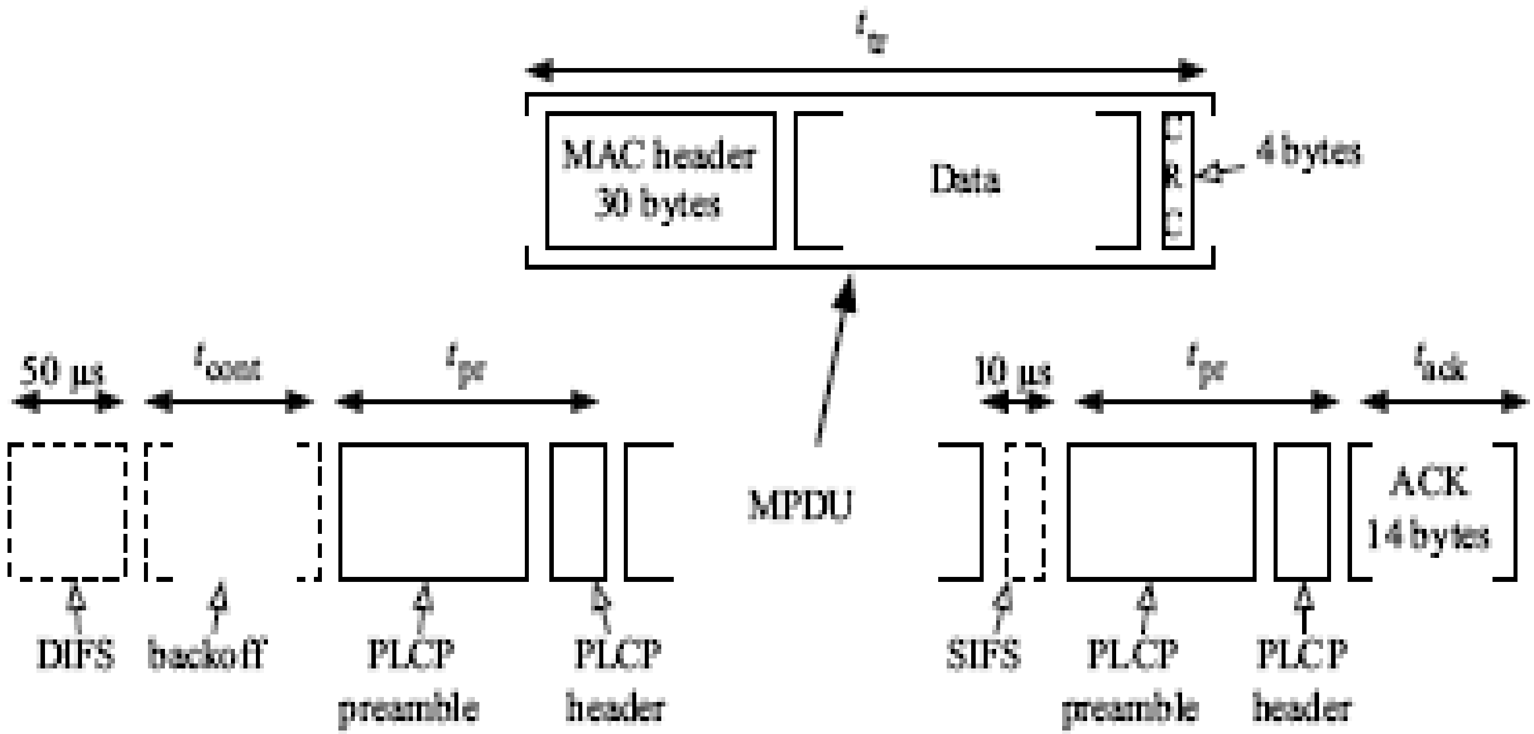
- ☞Compute the **utilization of the wireless LAN** when there is only one transmitting device

Sequence of Events (1/2)



Note, that in this example, the RTS/CTS messages are disabled.
In case that they were enabled, the total time should also include:
$2xSIFS + \tau_{RTS} + \tau_{CTS}$

Successful transmission of a single frame



Performance of DCF

Overall Transmission time (T) :

$$T = t_{\mathrm{tr}} + t_{\mathrm{ov}}$$

Constant Overhead (t_{ov}) :

$$t_{\mathrm{ov}} = DIFS + t_{\mathrm{pr}} + SIFS + t_{\mathrm{pr}} + t_{\mathrm{ack}}$$

Proportion of useful throughput (p):

$$p = \frac{t_{\mathrm{tr}}}{T} \times \frac{1500}{1534} = 0.70.$$

Note: to compute the throughput you estimate the ratio: message size/T

Performance of DCF

Assuming that multiple successive collisions are negligible,

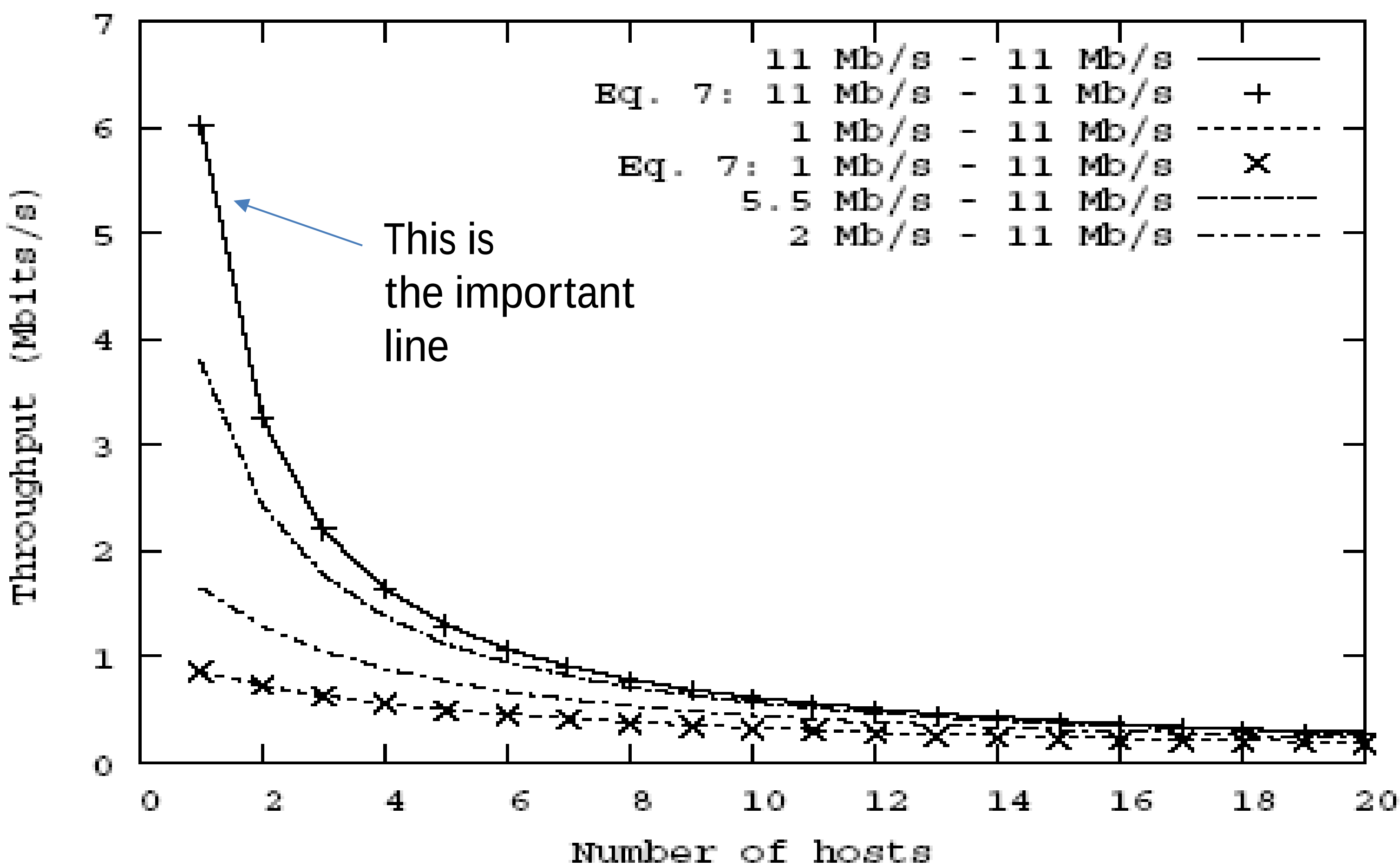
Proportion of collisions ($P_c(N)$) experienced for each packet acknowledged successfully :

$$P_c(N) = 1 - (1 - 1/CW_{\min})^{N-1}$$

Proportion (p) of useful throughput obtained by a host:

$$p(N) = t_{\text{tr}}/T(N)$$

Throughput as a function of the number of hosts in the WLAN.



Throughput experienced by a 802.11b host when all hosts except one transmit at 11Mb/s

Metrics for characterizing the performance (QoS)

- **Delay**

e.g., **end-to-end**, **roundtrip**, o**ne-way**

- **Jitter**

measures the **variance of the packet interarrival times**

- **Packet loss**

e.g., distribution, **total number**, **burstiness**, and position of these bursts in the session

- **Energy consumption**

Point Coordination Function (PCF)

- Point-coordinator **cyclically polls all stations** which are assigned to the network and added to the PC polling table
- Assign a time slot to them in which they are **exclusively allowed to send data**
- Resides in APs

☹ Drawbacks: **Higher bandwidth waste** under normal load

☞ Correction for reducing overhead for polling idle stations
Embedded Round Robin: dynamic classification of stations as busy or clear

Infrastructure mode: Saving Power

1. STA indicates power management mode is on to AP and waking interval
2. STA goes to sleep (turns off radio)
3. STA wakes later;

   Listens for traffic conditions (e.g., first 10ms of the beacon interval)
4. STA may request buffered frames
5. AP sends buffered frames

Steps 2-5 repeat

Power Savings: Basic Principle

- Whenever a wireless node has noting to send or receive it should fall asleep: turn off the MAC processor, the base-band processor, and RF amplifier to save energy
- Easy in an infrastructure wireless network
- APs responsible for timing synchronization (through beacons)

1. STA indicates

- Most frames include power-management (PM) bit

  PM=1 means STA is sleeping

- STA indicates

  Listen Interval & length of its naps (in beacon intervals)

Tradeoffs:

- Larger listen interval requires more **AP memory for buffering**
- **Interactivity** issues

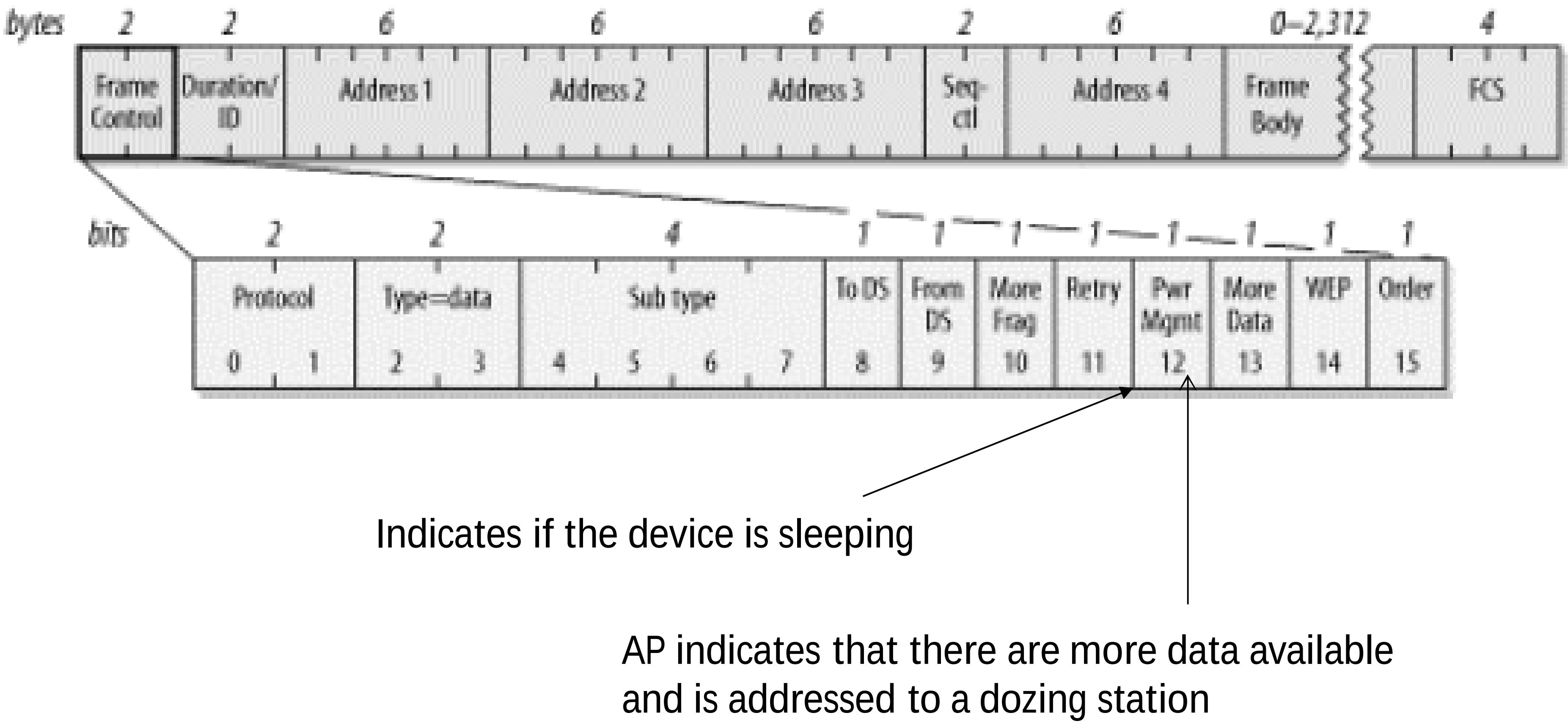
Infrastructure Mode
2. Check for waiting traffic

- Station wakes to listen for a beacon, which includes the Traffic-Indication Map (TIM)
- TIM is 2,007-bit-long map;
- TIM[j]=1 means that station with Associated ID=j has traffic buffered

Infrastructure Mode
3. Get buffered traffic

- Station sends **Power-Saving-Poll** to indicate that it is **awake and listening**
- **AP sends buffered packets**
- Station stays awake until it has retrieved all buffered packets

Frame Control Field



Wireless network topologies can be controlled by

- **Data rate**
- **Channel allocation: different devices communicate at different channels**

In some cases, there is a channel dedicated for the control (management) and message exchange

- **Transmission power (power control)**
- **Carrier sense threshold**
- **Directional antennas**
- **Cognitive intelligent radios & software defined radios**
- **Node placement**

Spectrum Utilization (1/2)

- Studies have shown that there are frequency bands in the spectrum **largely unoccupied most of the time** while others are heavily used

☞ **Cognitive radios** have been proposed to **enable a device to access a spectrum band unoccupied by others at that location and time**

Spectrum Utilization (2/2)

Cognitive radio: intelligent wireless communication system that is

- **Aware** of the environment
- **Adapt to changes** aiming to achieve:
  - **reliable communication** whenever needed
  - **efficient utilization** of the radio spectrum

Their commercialization has not yet been fully realized

- Most of them still in research & development phases
- Cost, complexity, and compatibility issues

Improvement at MAC layer

- To achieve **higher throughput** and **energy-efficient** access, devices may use **multiple channels** instead of only one fixed channel

Depending on the number of radios & transceivers, wireless network interfaces can be classified:

1. **Single-radio MAC**
   - **Multi-channel single-transceiver**
   - **Multi-channel multi-transceiver**

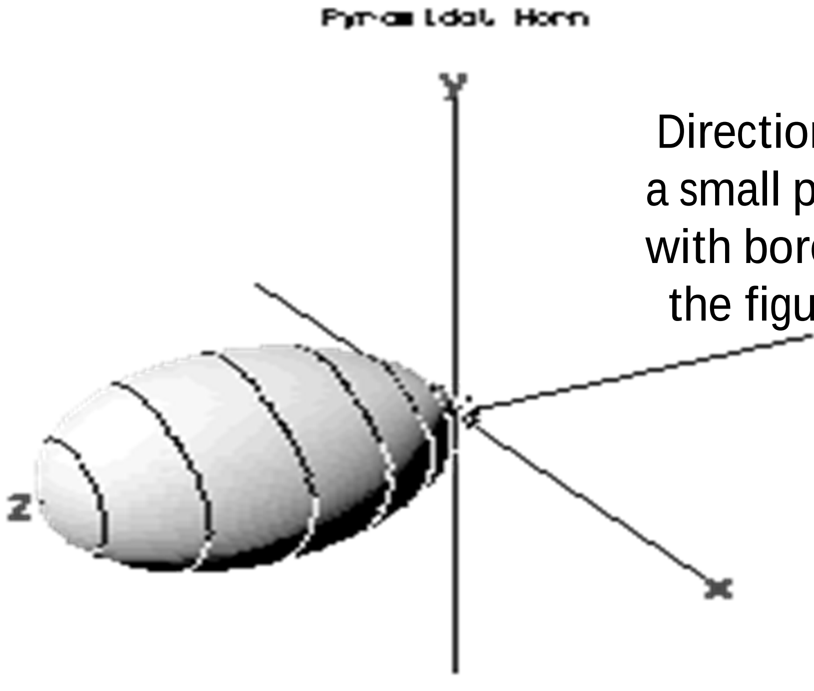
2. **Multi-radio MAC**

Multiple Radio/Transceivers

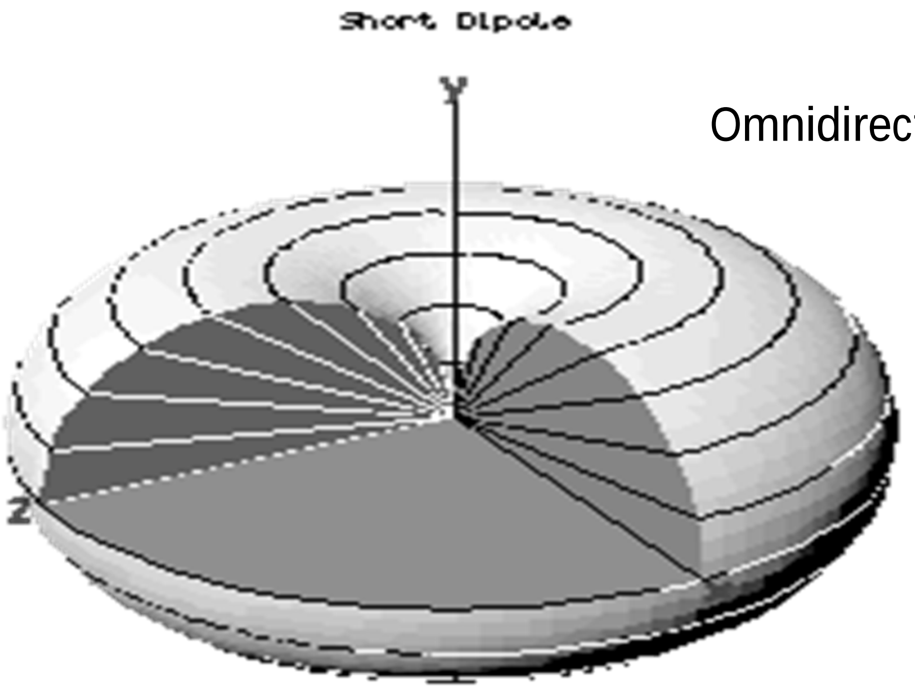
- Multi-channel single-transceiver MAC
  - One tranceiver available at network device
  - Only one channel active at a time in each device
- Multi-channel multi-transceiver MAC
  - Network device with multiple RF front-end chips & baseband processing modules to support several simultaneous channels
  - Single MAC layer

  controls & coordinates the access to multiple channels
- Multi-radio MAC
  - network device with multiple radios

    each with its own MAC & physical layer



Directional antenna
a small pyramidal horn
with boresight on the +z- axis
the figure shows the directive pattern



Omnidirectional pattern of a dipole antenna

Dipole:
the most common type of antenna
In its simplest case:
a **small length of conductor** carrying an alternating current

Beamforming

- Signal processing techniques for **directional** signal transmission or reception
- **Combining** elements in a phased array
- Signal at particular angles experience **constructive interference** while others experience **destructive interference**
- Used at both the transmitting & receiving ends to achieve spatial selectively
- Change the directionality: a **beamformer controls** the **phase and relative amplitude** of the signal at each transmitter

Beamforming

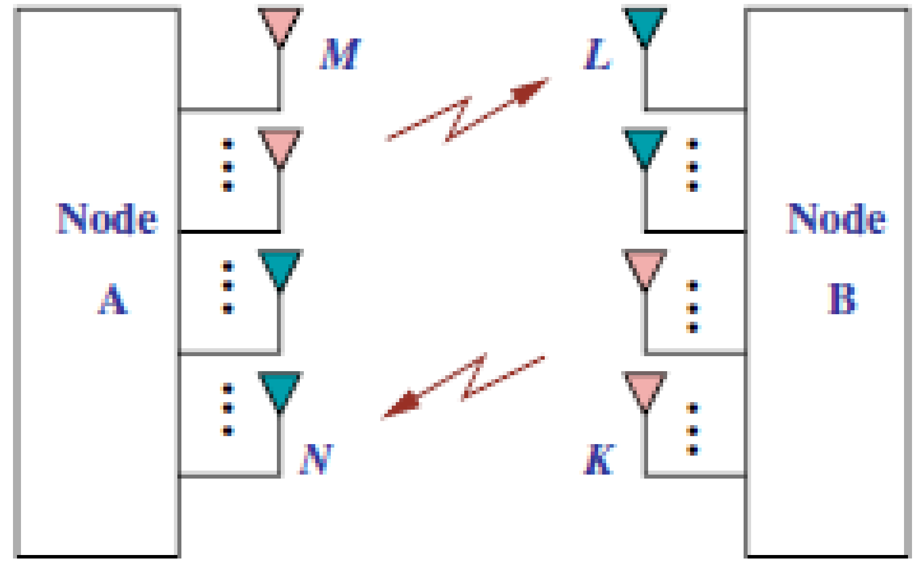


Fig. 12. Multiple-antenna systems.

Beamforming: method to create the **radiation pattern** of the **antenna array** by **<u>adding constructively</u>** the **phases of the signals** in the direction of the targets/mobiles desired,

and **<u>nulling the pattern of the targets/mobiles</u>** that are undesired/interring targets

Antenna diversity

- Based on the fact that signals received from **uncorrelated antennas** have **independent fading:**

high probability that at **least one good signal** can be received @ receiver

- The **antenna uncorrelation** is achieved through

(A) space, polarization, pattern diversity, and the

(B) processing technologies for diversity

include switch diversity, equal gain, and maximum ratio combining

Adaptive antenna array processing

- Shape the antenna beamform to enhance the desired signals while to nullify the interfering signals
- Algorithms that identify spatial signal signature (e.g., direction of arrival) and use it to calculate beamforming vectors

to track and locate the antenna beam on the mobile/target

Antenna diversity (con’td)

- Complexity & cost ⇨ such antennas are used in BS of cellular networks
- **Mechanically or electronically steerable** or switched directional antennas tuned to certain direction
- Using directional transmission, interference between nodes can be mitigated ⇨ improve network capacity

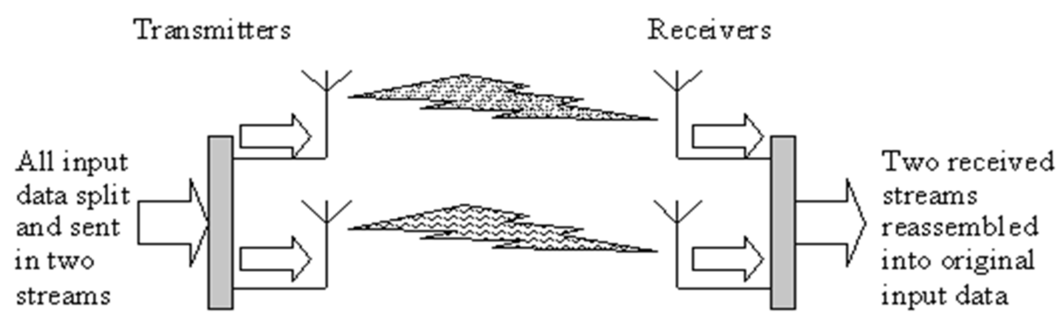
802.11n

- Addresses the need for higher data transfer rates (54M-600Mpbs):
- Couples MIMOs and wider bandwidth
  - Channel width of 40MHz (vs. 20MHz in 802.11b)
  - **Multiple antennas** to coherently resolve more information than possible using a single antenna

  e.g., using **Spatial division multiplexing**: multiplexes multiple independent data streams (i.e., **independent & separately** encoded data signals), transferred **simultaneously** within ***one spectral channel of bandwidth***

  Each spatial stream requires a **discrete antenna** at both the transmitter & receiver

in simple words: receivers "work together", each one is synchronized to its own signal, one receiver's reception can be used to counter phase or nullify its component of the signal for the opposite receiver and therefore improve the overall quality of the reception



Spectral Efficiency

- The number of bits per second and per Hz that can be transmitted over the wireless channel
- The practical multiplexing gain can be limited by spatial correlation, which means that some of the parallel streams may have very weak channel gains
- The performance of wireless communication systems can be improved by having multiple antennas at the transmitter and the receiver. The idea is that if the **propagation channels between each pair of transmit and receive antennas are statistically independent and identically distributed**, then multiple independent channels with identical characteristics can be created by precoding and be used for **either transmitting multiple data streams** or increasing the reliability (in terms of bit error rate).
- In practice, the channels between different antennas are often correlated and therefore the potential multi-antenna gains may not always be obtainable. This is called **spatial correlation** as it can be interpreted as a correlation between a signal's spatial direction and the average received signal gain

On IEEE802.11

- **One transceiver, use of multiple channels**
  - ***One channel*** for control & remaining for data
    - Dedicates a **channel for control packets**
    - Uses the **remaining channels for data packets**
  - All channels identical
- **When multiple transceivers available**
  - Multiple-transceivers with **one transceiver per channel**
  - Use of **common channel for all tranceivers**
  - Unlike the multi-transceiver case, a common transceiver operates on a single channel at any given point of time
- Manufacturers (eg, Engim, D-Link), have launched APs that use multipl channels simultaneously
    - claim to provide high-bandwidth wireless networks

Spectrum Division

Non-interfering disjoint channels using different techniques:

– ***Frequency division***

Spectrum is divided into disjoint frequency bands

– ***Time division***

channel usage is allocated into time slots

– ***Code division***

Different users are modulated by spreading codes

– ***Space division***

- Users can access the channel at
  - the same time
  - the same frequency

  by exploiting the spatial separation of the individual user

- ***Multibeam (directional) antennas***

used to separate radio signals by pointing them along different directions

Power Consumption

1. Energy consumption of a wireless network interface in an ad hoc networking environment
2. Energy Metering Framework for Android Smartphones using AppScope

Lucent IEEE 802.11 DSSS PC Card Characteristics

		documented	measured
2 Mbps (Bronze)	Sleep Mode	9 mA	14mA
	Receive Mode	280 mA	200 mA
	Transmit Mode	330 mA	280 mA
11 Mbps (Silver)	Sleep Mode	10 mA	10mA
	Receive Mode	180 mA	190 mA
	Transmit Mode	280 mA	284 mA
	Voltage	5 V	4.74 V

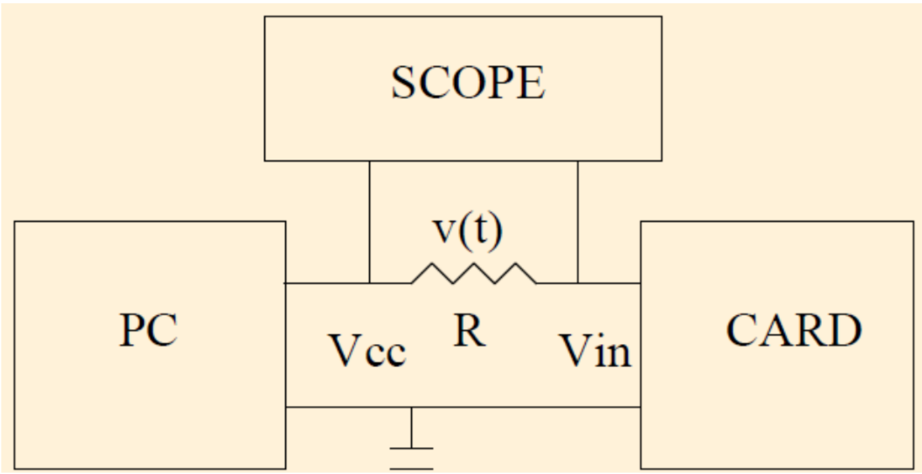
Approach

Make measurements and report *helpful* results.

- packet oriented
- network oriented

Use numeric results as input to network simulations.

Precise values are less important than developing insights that are useful for protocol development.



Linear Model

Fixed component: channel acquisition

Incremental component: packet size

$$Energy = m \times size + b$$

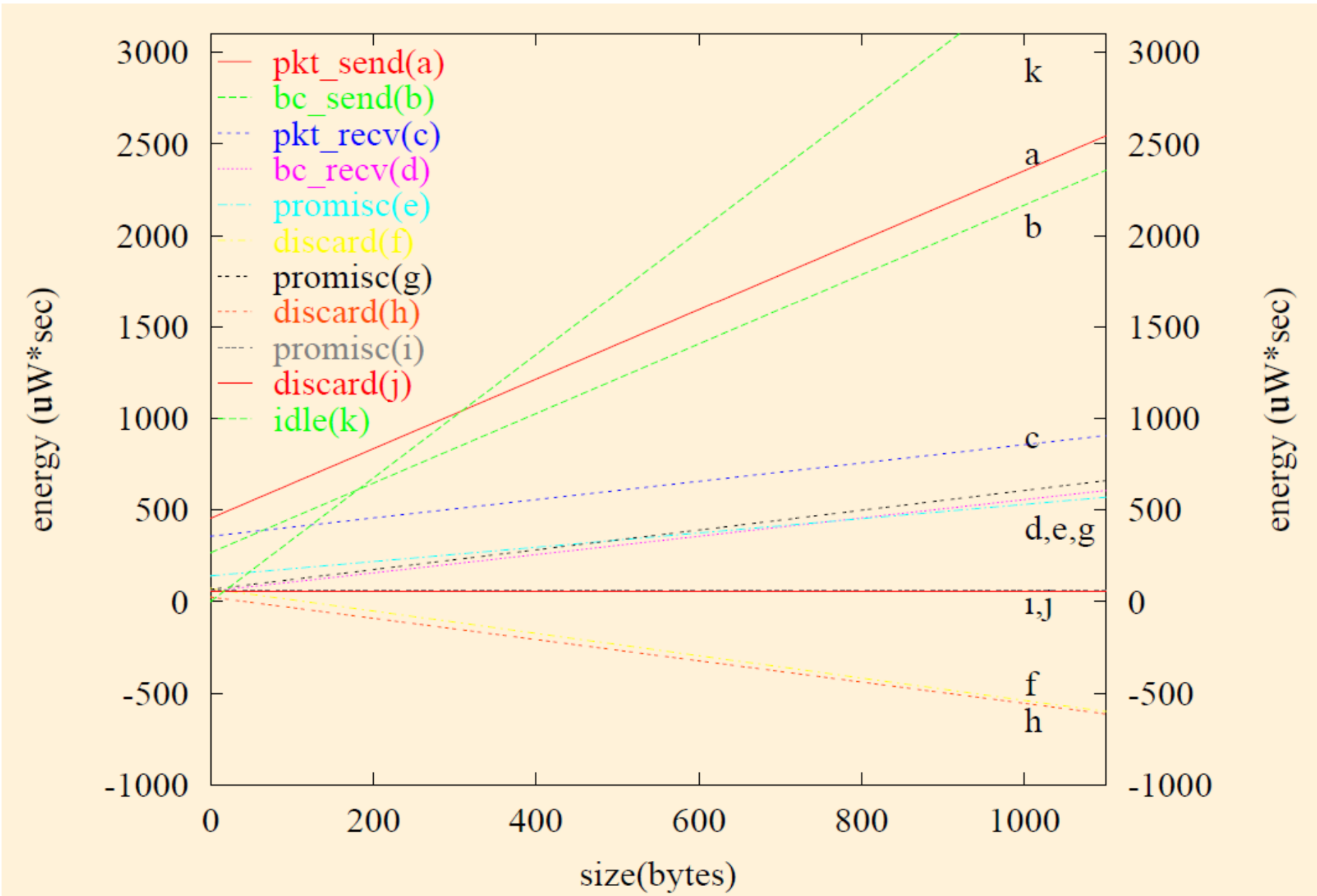
$$Energy = E_{tx} + \sum n \in RE_{rx} + \sum n \in DE_{discard}$$

- Linear regression is used to test the model and find values for *m* and *b*.
- Model ignores backoff and retransmissions, which are better analyzed using a traffic and mobility model.

Incremental Consumption: 2Mbps

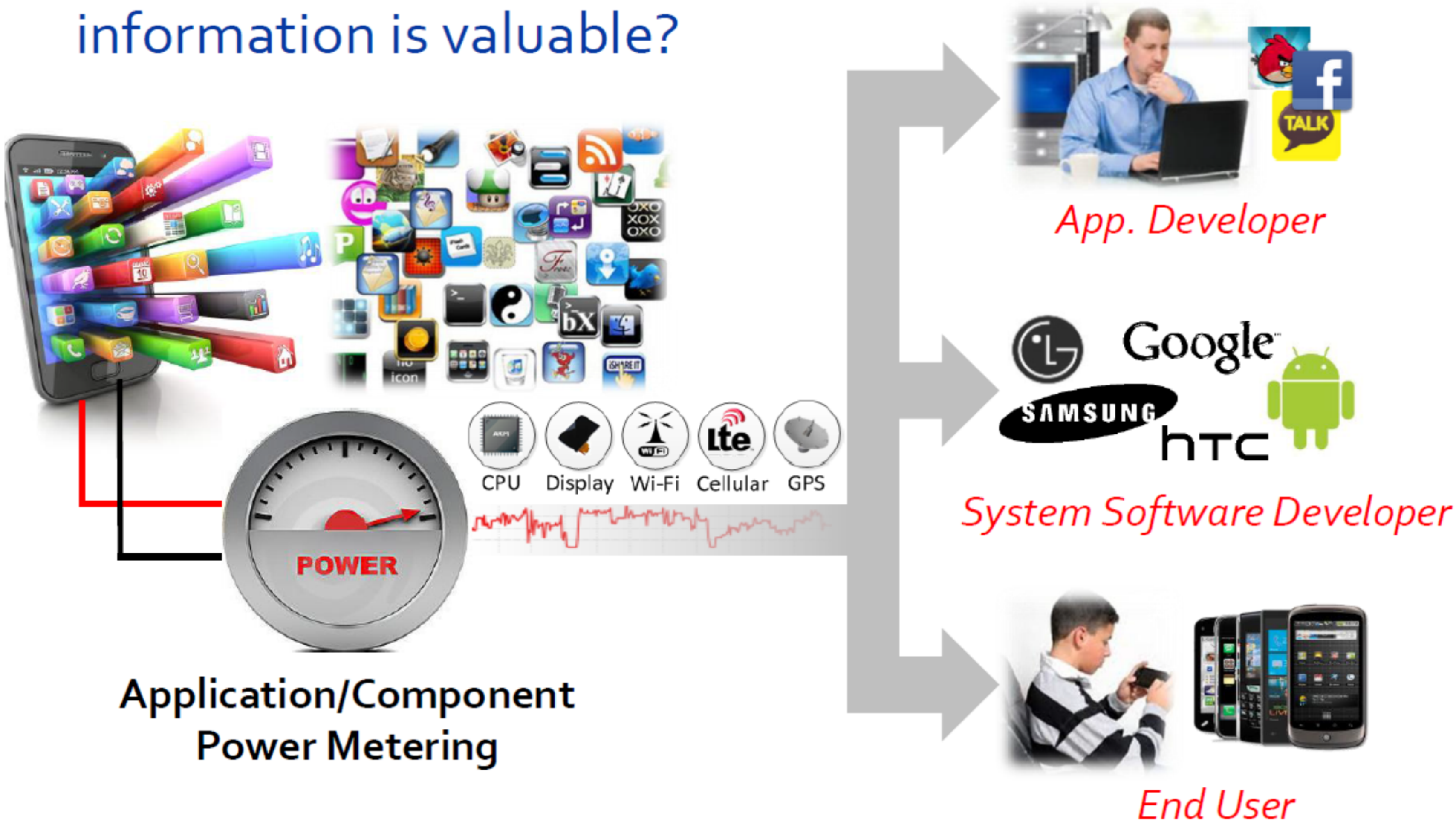
	$\mu W \cdot sec/byte$[a]		$\mu W \cdot sec$
point-to-point send (a)	1.9	$\times size$	+ 454
broadcast send (b)	1.9	$\times size$	+ 266
point-to-point recv (c)	0.50	$\times size$	+ 356
broadcast recv (d)	0.50	$\times size$	+ 56
	non-destination $n \in \mathcal{S}, D$		
promiscuous recv (e)	0.39	$\times size$	+ 140
discard (f)	-0.61	$\times size$	+ 70
	non-destination $n \in \mathcal{S}, n \notin \mathcal{D}$		
promiscuous recv (g)	0.54	$\times size$	+ 66
discard (h)	-0.58	$\times size$	+ 24
	non-destination $n \notin \mathcal{S}, n \in \mathcal{D}$		
promiscuous "recv" (i)	0.0	$\times size$	+ 63
discard (j)	0	$\times size$	+ 56
idle (ad hoc) (k)	843 mW		
idle (BSS)	66 mW		

Incremental Consumption: 2Mbps



AppScope: Application Energy Metering Framework for Android Smartphones using Kernel Activity Monitoring

- Why application/component energy information is valuable?



How can we estimate application energy?

Power Models

- Linear regression models
  a. MANTIS
  b. Lasso regression
  c. Others
- Non-linear regression models
  a. Exponential
  b. SVM
  c. Others
- Finite-state machine models
  - System call-based

Utilization-based Model

$$E^{App} = \sum_{i=0}^{\#ofComp} (\beta_i \times x_i^{App}) \times d_i^{App}$$

β_i → *Power coefficient value*

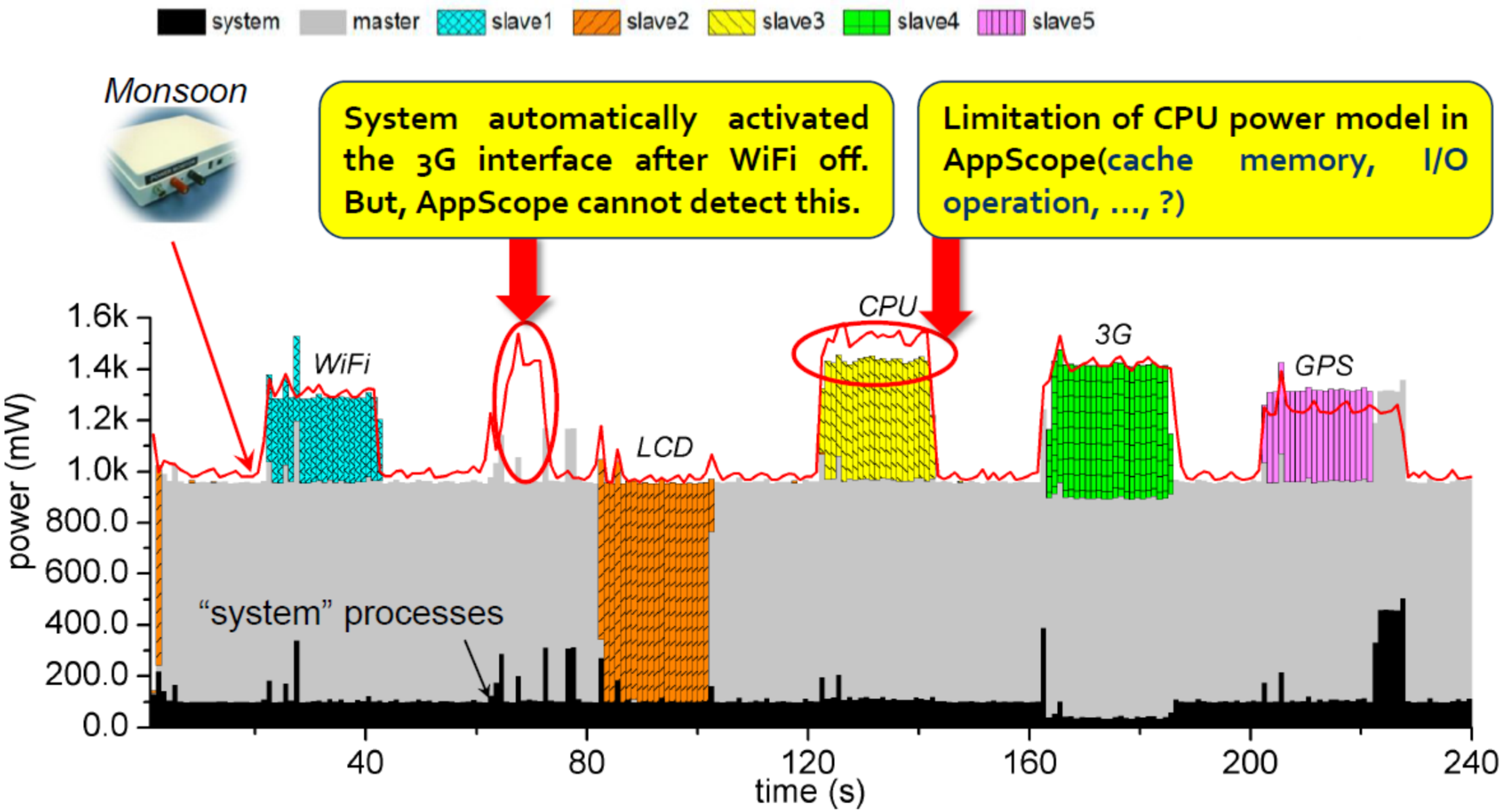
x_i^{App} → *Utilization*

d_i^{App} → *Activated duration*

Hardware Component Usage

Testbed

Measurements



References

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Τέλος Ενότητας

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