Dynamic Power Management Strategies within the 802.11 Standard

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Outline (1/3)

- Introduction to 802.11b wireless LANs
  - Network architecture
  - Mobility support
  - Power issues
- 802.11b MAC layer
  - Frame composition
  - Management frames
  - Power related information

Outline (2/3)

- DPM in 802.11b networks
  - DPM support (Doze mode and radio-gating)
  - DPM support for infrastructured WLAN
  - DPM support for ad-hoc networks
- DPM strategies
  - How to efficiently exploit doze mode?
  - Application-level radio-gating

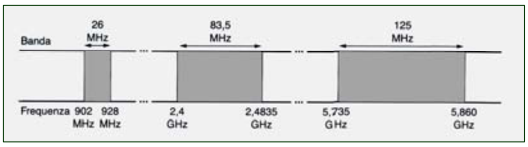
Outline (3/3)

- Wireless network interface model
  - Model characterization
  - Active mode
  - Doze mode
- Energy/QoS trade-off analysis
  - Markovian model
  - Exponential and deterministic model
  - Model validation

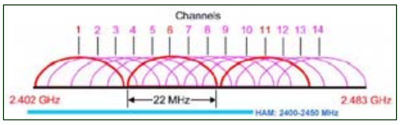
Introduction to 802.11b Networks

Wireless LAN 802.11

- ISM frequencies (Industry, Scientific, Medical)



- 14 channels
  - ch1, ch6 and ch11 not overlapped
- Spread spectrum over a single channel (802.11b/g)



Glossary of 802.11 (1/2)

- Station (STA): A computer or device with a wireless network interface.
- Access Point (AP): Device used to bridge the wireless-wired boundary, or to increase distance as a wireless packet repeater.
- Ad Hoc Network: A temporary one made up of stations in mutual range.
- Infrastructure Network: One with one or more Access Points.
- Channel: A radio frequency band, or Infrared, used for shared communication.
- Basic Service Set (BSS): A set of stations communicating wirelessly on the same channel in the same area, Ad Hoc or Infrastructure.
- Extended Service Set (ESS): A set BSSs and wired LANs with Access Points that appear as a single logical BSS.

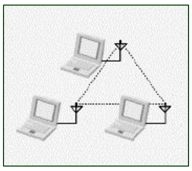
Glossary of 802.11 (2/2)

- BSSID & ESSID: Data fields identifying a stations BSS & ESS.
- Association: A function that maps a station to an Access Point.
- MAC Service Data Unit (MSDU): Data Frame passed between user & MAC.
- MAC Protocol Data Unit (MPDU): Data Frame passed between MAC & PHY.
- PLCP Packet (PLCP_PDU): Data Packet passed from PHY to PHY over the Wireless Medium.

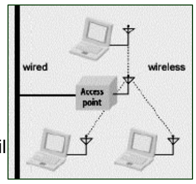
802.11 Architecture (1/2)

- Network architectures (BSS = basic service set)

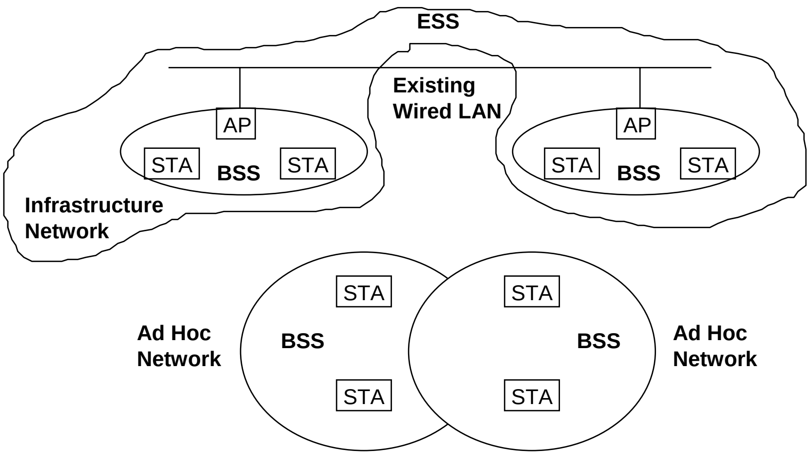
  - **Ad-hoc o Independent BSS (IBSS)**
    - Peer to peer communication among stations
    - Not infrastructured environments



  - **Infrastructural BSS (BSS)**
    - Need association to base station (*Access Point*)
    - Stations communicate through the AP



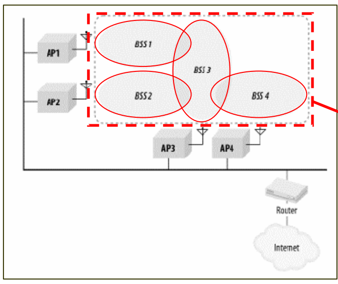
802.11 Architecture (2/2)



Wireless LAN 802.11

BSS = limited coverage area
(10-20m with walls ÷ 100m w/o walls)

- ESS (Extended Service Set)



ESA (Extended Service Area)

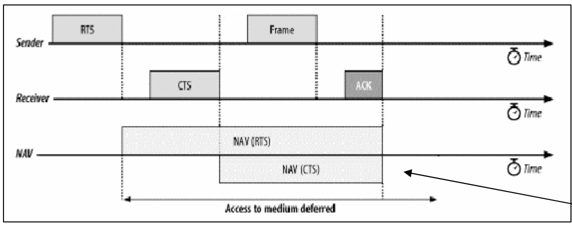
Wired vs. Wireless LANs

- 802.3 (Ethernet) uses CSMA/CD, Carrier Sense Multiple Access with 100% Collision Detect for reliable data transfer
- 802.11 has CSMA/CA (Collision Avoidance)
  - Large differences in signal strengths
  - Collisions can only be inferred afterward
    - Transmitters fail to get a response
    - Receivers see corrupted data through a CRC error

Standard 802.11 (MAC)

IBSS: channel access is coordinated by DCF
(Distributed Coordination Function)

- *CSMA/CA* protocol (Carrier Sense Multiple Access with Collision Avoidance)
- STA senses the channel, if it is free, the STA transmits the whole frame. In presence of interferences, it retries the transmission after a random backoff period
- NAV (Network Allocation Vector): period of time in which the medium is reserved (carried in the header of the frame)



RTS: Request To Send

CTS: Clear To Send

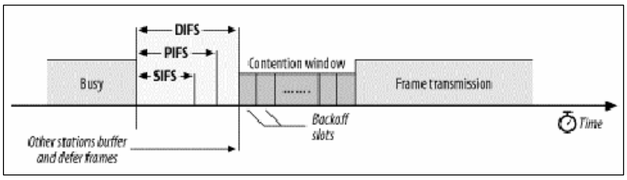
NAV: Network Allocation Vector

This is required because other Stations may not hear the NAV

Standard 802.11 (MAC)

BSS: channel access is coordinated by
PCF (Point Coordination Funcion)

- Centralized control: no collisions
- Periodic broadcast transmission of signaling frame (beacon) wich contains synchronization information
- Each STA receives a fraction of the total bandwidth



SIFS: Short InterFrame Spacing
DIFS: DCF InterFrame Spacing

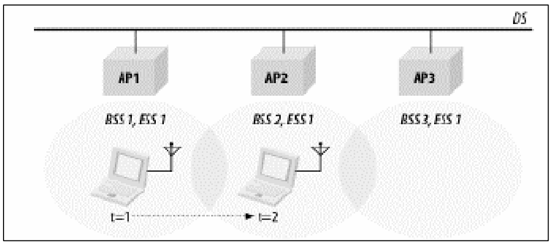
802.11 Services

Service	Station or distribution service?	Description
Distribution	Distribution	Service used in frame delivery to determine destination address in infrastructure networks
Integration	Distribution	Frame delivery to an IEEE 802 LAN outside the wireless network
Association	Distribution	Used to establish the AP which serves as the gateway to a particular mobile station
Reassociation	Distribution	Used to change the AP which serves as the gateway to a particular mobile station
Disassociation	Distribution	Removes the wireless station from the network
Authentication	Station	Establishes identity prior to establishing association
Deauthentication	Station	Used to terminate authentication, and by extension, association
Privacy	Station	Provides protection against eavesdropping
MSDU delivery	Station	Delivers data to the recipient

Mobility Support (1/2)

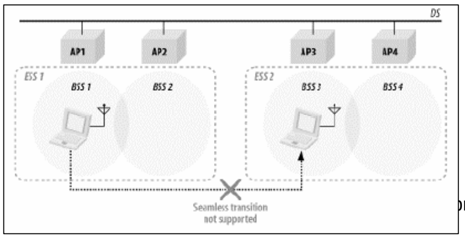
Handoff: a STA moves from a coverage area to another

- **BSS transition**
  - STA: monitoring of signal strength of each AP in the ESS
  - AP: exploits IAPP to inform other APs about STA movements



Mobility Support (2/2)

- **ESS transition**
  - From one ESS to another
  - 802.11 supports this type of handoff in two cases:
    - Communication with current ESS falls down
    - ESSs are close enough to allow “fast” transition
  - Must be supported by higher layers of the network
    - Ex: for TCP/IP is required *Mobile IP*



Handoff (1/3)

Handoff phases:

- **Scanning**
  - **Scan:** search for a network
    - **Active scanning:** “On each channel, <u>*Probe Request*</u> frames are used to solicit responses from a network with a given name. <u>*Probe Response*</u> frames are generated by networks, when they hear a Probe Request”
    - **Passive scanning:** “A station moves to each channel on the channel list and waits for <u>*Beacon*</u> frames. Any Beacons received are buffered to extract information about the BSS”
  - **Scan Report:** list of available BSS
  - **Joining:** select a BSS

Handoff (2/3)

- **Authentication (o Preauthentication):**
  - Define the identity of a STA
  - Standard authentication approaches:
    - **Open system authentication**: “the access point accepts the mobile station without verifying its identity”
    - **Shared-key authentication**: “Shared-key authentication makes use of WEP (Wired Equivalent Security) and therefore can be used only on products that implement WEP”
  - May happen during scanning phase with each base station found

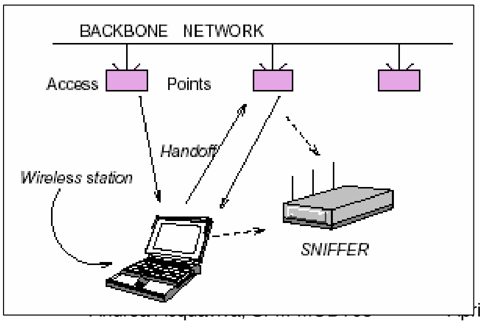
Handoff (3/3)

- **Association**
  - After authentication phase
  - It is mandatory in BSS for STA to associate to the AP to gain access to the network
  - Allows to the distribution system to keep track of STA location
- **Reassociation**
  - The association is moved from an AP (current) to another (new)
  - Involved APs may interacts using an Inter Access Point Protocol (IAPP) through the backbone network

Handoff Latency

“We divide the entire handoff latency into three delays”:

- **Probe Delay** (due to messaging during active scan phase)
- **Authentication Delay**
- **Reassociation Delay**

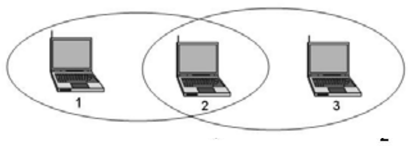


Power Issues

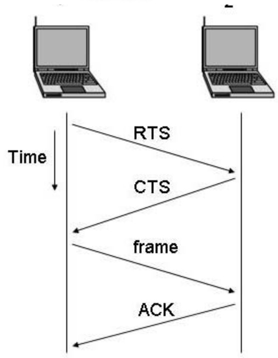
- 802.11 WNIC consume a considerable amount of power
  - Large impact on mobile devices
  - Battery lifetime
  - Size and weight of mobile devices

802.11b MAC Layer

802.11 MAC (1/3)



- **Carrier Sense**
  - Listen before talking
  - Random back-off after collision is determined
- **Handshaking** to infer collisions
  - DATA-ACK packets
- **Collision Avoidance**
  - RTS-CTS-DATA-ACK to request the medium to prevent collisions from hidden nodes
  - RTS silences any stations that hear it
  - The target station responds with a CTS. Hidden nodes beyond the sender station are silenced by the CTS from the receiver
  - Net Allocation Vector (NAV) to reserve bandwidth
  - After frame transmission a positive acknowledge is sent by the target STA



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802.11 MAC (2/3)

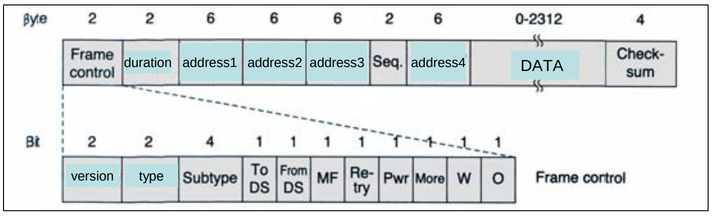
- Fragmentation
  - Bit Error Rate (BER) goes up with distance and decreases the probability of successfully transmitting long frames
  - MSDUs given to MAC can be broken up into smaller MPDUs given to PHY, each with a sequence number for reassembly
    - A RTS/CTS threshold can be set. RTS/CTS messages are used only for data frames larger than the threshold
    - Can increase range by allowing operation at higher BER
    - Lessens the impact of collisions
    - **Trade overhead for overhead of RTS-CTS**
    - **Less impact from Hidden Nodes**

802.11 MAC (3/3)

- **Beacons** used convey network parameters and synchronization info
- **Probe Requests** and **Responses** used to join a network
- **Power Savings Mode**
  - Frames stored at AP or STA for sleeping STAs
  - STAs wake-up periodically (listen period) to listen for beacons
  - Traffic Indication Map (TIM) in frames alerts awaking STAs about buffered packets

Standard 802.11 (MAC)

802.11 frame:



- **Address are of 802 type**
  - 48-bit addresses
    - 1° bit = 0 => single STA address (unicast)
    - 1° bit = 1 => group of STAs (multicast)
    - all 1 => to all the STAs (broadcast)
- **Frame types: data, control and management**

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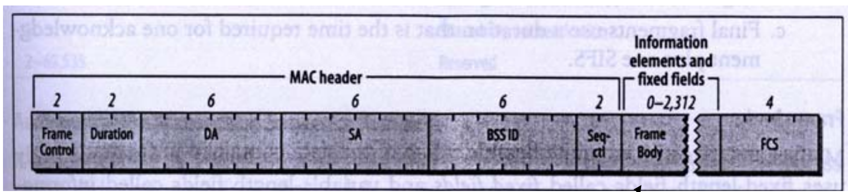
Management Frames



- header: similar to data frames
- frame body:
  - fixed fields: 10 types, fixed length
  - information elements: variable length, can be defined by newer version of 802.11, appear in specific order
- These fields are building blocks of management frames

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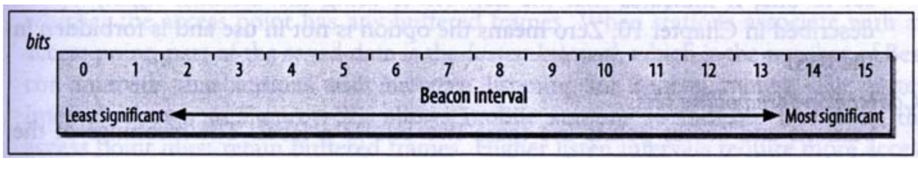
Types of Management Frames

- Fixed fields and information elements will be used in the body of management frames to convey information
- Frame types:
  - Beacon, Probe Request, Probe Response, ATIM, Disassociation, Deauthentication, Asso. Request, Reasso. Request, Asso. Response, Reasso. Response, Authentication

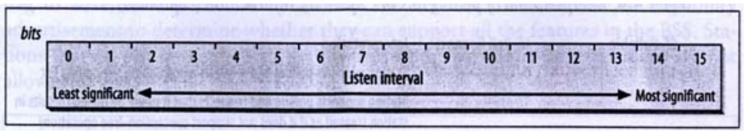
Fixed Field: Beacon Interval

- to indicate how frequent beacons sent
- time unit (TU) = 1,024 us (about 1 ms)
- beacon interval is commonly set to 100 TU (about 100 ms = 0.1 sec)



Fixed Field: Listen Interval

- To indicate under PS mode, how often a STA will wake up to check buffered frames
  - unit = one beacon interval
- From this, AP can determine can estimate the resource required for buffering
- Set during the association



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Information Element: TIM

	Element ID	Length	DTIM Count	DTIM Period	Bitmap Control	Partial Virtual Bitmap
Octets:	1	1	1	1	1	1–251

- Transmitted in beacon frames
- Indicates which low-power STAs have buffered traffic waiting to be picked up
  - partial virtual bitmap
    - each bit for one association ID (AID)
    - 1 = traffic buffered
  - Multicast and broadcast frames are linked to an AID=0

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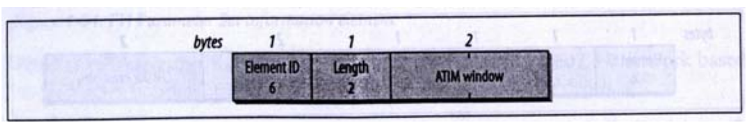
Deliverying TIM

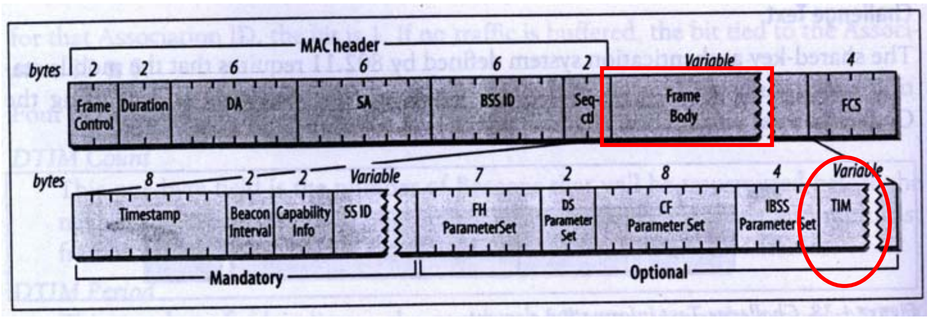
- Used with frames with group address (cannot use a polling algorithm – see later)
- DTIM count:
  - when will the next DTIM frame arrives
  - DTIM is for buffered broadcast/multicast
  - unit = beacon interval
- DTIM period:
  - period of DTIMs (unit = beacon interval)
  - Multicast and broadcast buffered frames are transmitted after a DTIM beacon
- The card can be configured to not wake-up to listen for DTIM beacons

Information Element: IBSS Parameter Set

- to indicate the period of IBSS Beacons in an ad hoc network
  - unit = TU
  - the period is contained in ATIM (ATIM = Announcement TIM)



Beacon Frame



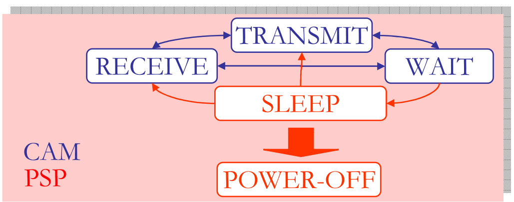
- FH and DS Parameter Sets are mutually exclusive (depending on the physical layer)
- It contains a TIM (Traffic Indication Map)

DPM in 802.11b

DPM

- We focus on in infrastructured networks
  - Greatest power savings
  - All traffic for mobile clients goes through APs
  - Ideal location to place buffers, no need to distributed buffer system on every station
  - APs are always active
- APs are aware of STAs
  - STAs communicate power management state
  - Determines whether a frame should be forwarded to a STA
  - Announcement of buffered traffic

WNIC DPM Support



- DPM support efficiency depends on:
  - Device energy states
  - Transition energy and time
- MAC vs application layer support
  - MAC-level DPM: PSP mode
  - Radio-off: needs software support (API)

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WNIC 802.11b DPM

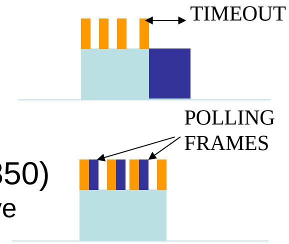
Power Save Protocol (PSP)

- WNIC switches between CAM (Continuos Access Mode) to PSP upon user command
- WNIC goes into sleep state and wakes-up periodically (listen period) to synchronize with the access point (AP)
- The AP sends to WNIC buffered traffic
- WNIC may use timeout or polling frames to retrieve backlog from AP

MAC-Level DPM

- The card goes into low-power idle state
- Each beacon period it wakes-up to synchronize to the AP and downloads accumulated (in the AP buffer) packets
- After downloading, the card goes back to sleep after a timeout or after the reception of the last packet (depending on the implementation)

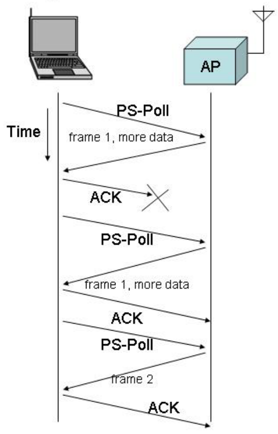
WNIC 802.11b DPM



- Timeout based (LUCENT)
  - Timeout after last packet retrieved from AP
  - Timeout delay/energy
- Polling frames based (CISCO Aironet 350)
  - Uses a packet to poll access point to retrieve each packet
  - No timeout delay/energy BUT additional packets overhead
- CISCO PSPCAM
  - Automatically switches between PSP and CAM depending on traffic
  - Try to compensate for performance loss in PSP

DPM in Infrastructured WLAN

- TIM & PS-Poll mechanism
- A PS-poll frame is used to retrieve one buffered frame
- A more-data bit is used to determine if there are more frames to retrieve



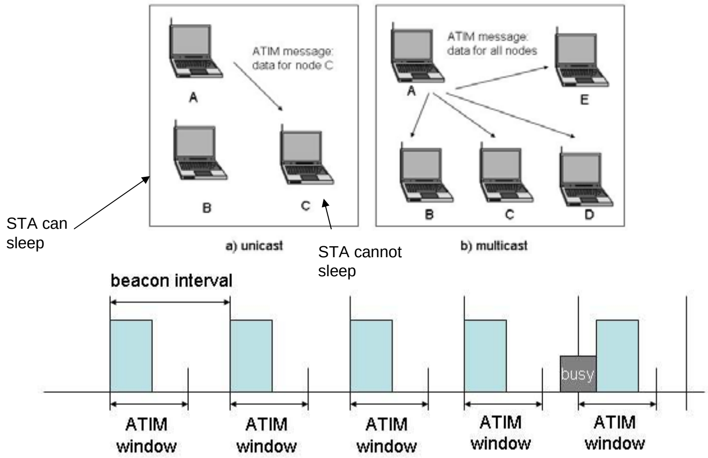
ATIM (for IBSS)

- Announcement TIM or ad-hoc TIM
  - Keeps the transceiver on because there are pending data
- When a STA has buffered frames for a sleeping receiver, it sends ATIM frame during the delivery period to notify the sleeping STA

ATIM Window

- It is a time window following the beacon transmission
- Is the period during which nodes must remain active
- It ends after a period specified when the IBSS is created (if 0 power management is disabled)
- Stations transmitting ATIMs cannot sleep
  - It means that STA wants to transmit buffered traffic
  - Target STAs remain active until the conclusion of next ATIM window

DPM in Ad-Hoc Networks



- ATIM and ATIM window

App/OS-Level Radio Gating

- WNICs radio can be shut-off via software (API)
- Wake-up time state is large (300ms for re-association, channel search), BUT:
  - Power close to zero
  - No periodic wake-up as in 802.11b DPM
  - No sensitivity to traffic towards other clients
  - Transition is controlled by OS/applications, that can exploit high level information to perform preemptive wake-up

DPM Characterization

Device	State	Power [mW]	Timeout [ms]	WU-time [ms]	WU-power [mW]
NIC_{CISCO}	Receive	755			
	Transmit	1136			
	Wait	525			
	Doze(PSP/PSPCAM)	113	0/850	14/14	400
	Power-Off	0	any	370	451
NIC_{LUCENT}	Receive	548			
	Transmit	798			
	Wait	407			
	Doze	38	100	1	800
	Power-Off	0	any	270	357

PSP w polling frames

PSP w/o polling frames

large wake-up delay but OS controlled

DPM Strategies

Legacy DPM

- Network-driven
  - Exploiting doze mode in not-standard way [Chiasserini03]
    - Within channel access
  - Exploiting network conditions (expected delay) to decide when to enable PSP mode [Banginwar05]
  - Adjusting listen interval through a Markov decision process model [Chen04]
- Application-driven
  - Sleep between voice frames exploiting management frame info [Chen04]
  - Averaging past WNIC sleep intervals [Anand03], packet arrival rates in streaming applications [Chandra02],
  - App driver: idle period length adaptation for mobile agent-based retrieval information applications [Jiao05]
- Low-power modification to the standard have been proposed

WNIC Model

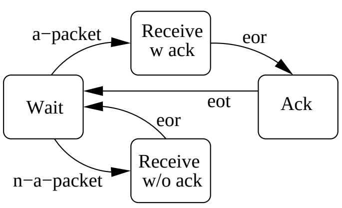
Modeling the WNIC

- Target: study energy/QoS trade-off
- Use of state diagram based on protocol specification and observation of power profiles
- Each state is associated to a power consumption level
- Definition of two macro-states
  - ON mode (always active)
  - PSP mode (power save protocol)
- Focus on UDP traffic
  - Do not model TCP behavior
  - Allows to concentrate on MAC-level analysis

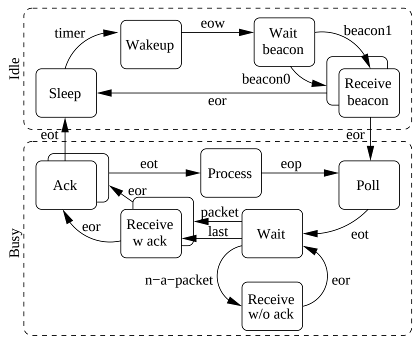
Model Features

- Network simulators (e.g. NS2)
  - No detailed model for the WNIC
  - No detailed power models for the WNIC
  - Focus on scalable network simulation
  - Model collision management
  - Model PHY level (propagation model)
- Our model
  - Focus on infrastructured BSS
  - Detailed model of WNIC power states
  - Modelling of power management support
  - Formal analysis VS simulation
  - Validation against hardware measurements

WNIC State Diagram



ON MODE



PSP MODE

- PSP mode with polling packets

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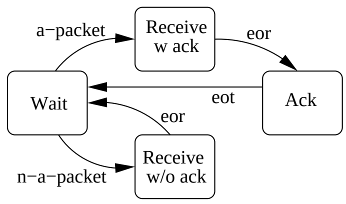
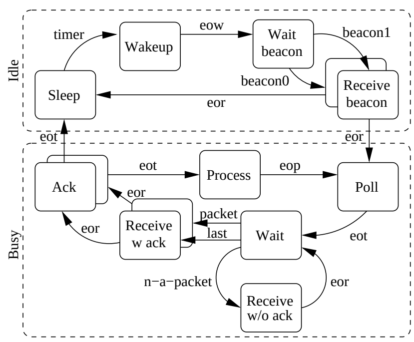
ON Mode

- The card waits for incoming packets
- May send an acknoledgement frame
  - Depending on the correctness of the frame (no negative acknowledge)
  - Not sent for multicast and broadcast packets
- Receive with ack and receive without ack states have the same energy consumption



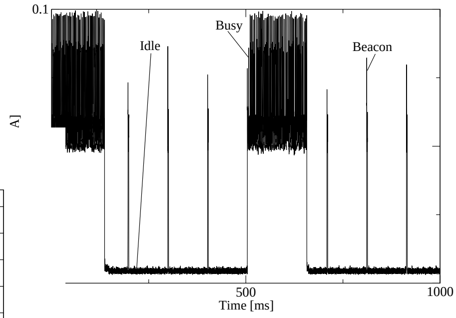
PSP Mode

- WNIC goes to sleep for a fixed period of time as soon as no traffic is detected
- Incoming packets are buffered within the AP
- After the expiration of the sleeping period, the card wakes-up to listen for AP beacon
  - Read info about buffered packets (TIM)
  - Depending on whether there are buffered frames the card sends a PS-poll frame
  - When the last frame is received (more_data =0), the card goes back to the sleep state

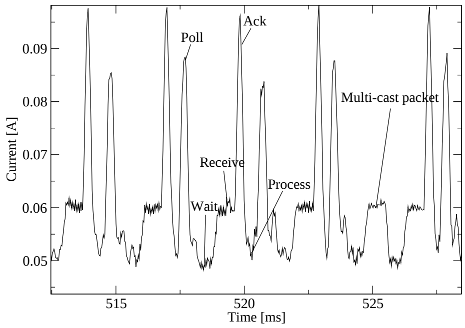


WNIC Characterization

- Power waveforms



doze mode

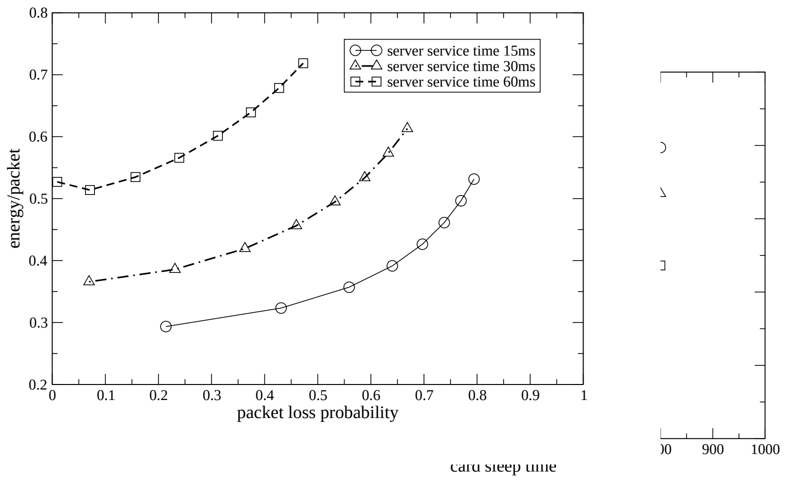


active mode

Analysis and Simulation

Case Study

- The WNIC model has been inserted in a large system
  - Application server sends UDP packets to a wireless client
  - Server is connected through a wired link to the AP
- We tune
  - inter-arrival time among packets
  - Card sleeping (listen) period
  - We considered a packet loss probability on the channel of 0.2% (i.e. there are retransmissions)
- Analysis
  - Pareto curve reliability/energy trade-off (packet lost at the AP buffer)
  - Packet loss probability (at the AP buffer) as a function of the WNIC sleep time

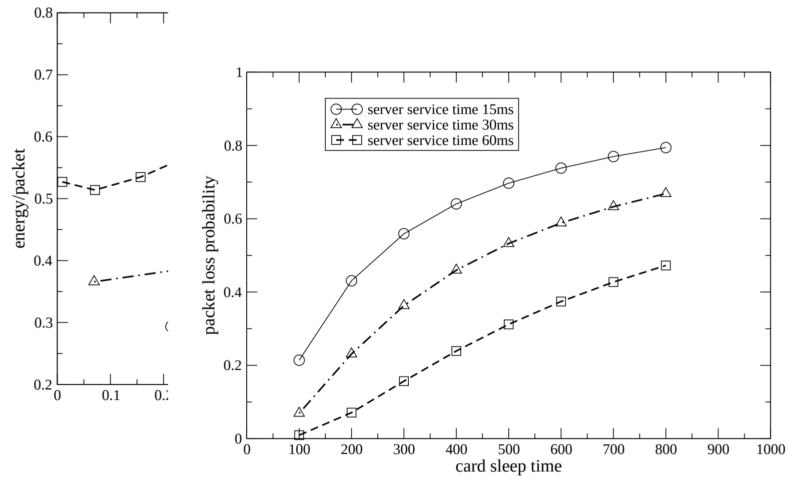


- Markoviar

Comments

- Energy per packet is lower if service time is lower (for a given packet loss prob)
  – Additional power cost spent by the card in waiting state when the server service time is larger
  – The cost is larger when the card sleep time increases (more power is spent by the card in sleep state). The per-packet contribution on energy consumption increases as sleeping time increases

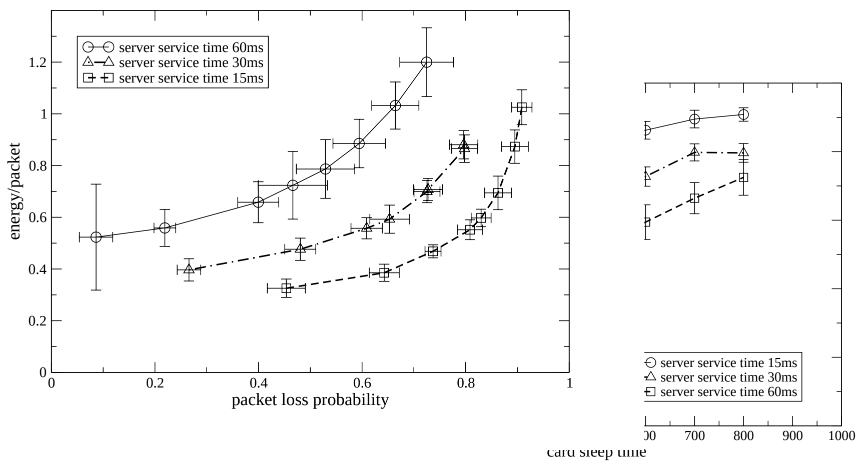
Energy/QoS (1/3)



- Markoviar

Comments

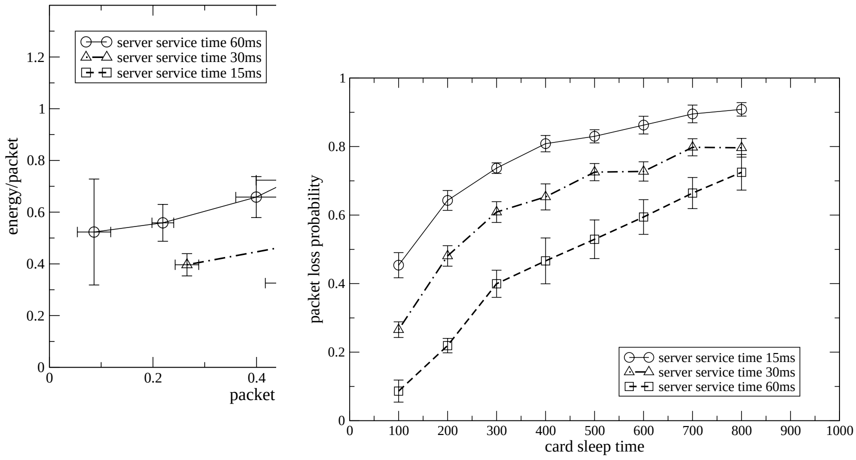
- For a given server service time, packet loss probability increases as a function of the sleep time
  - AP buffer saturation
  - AP buffer is 10 in our study



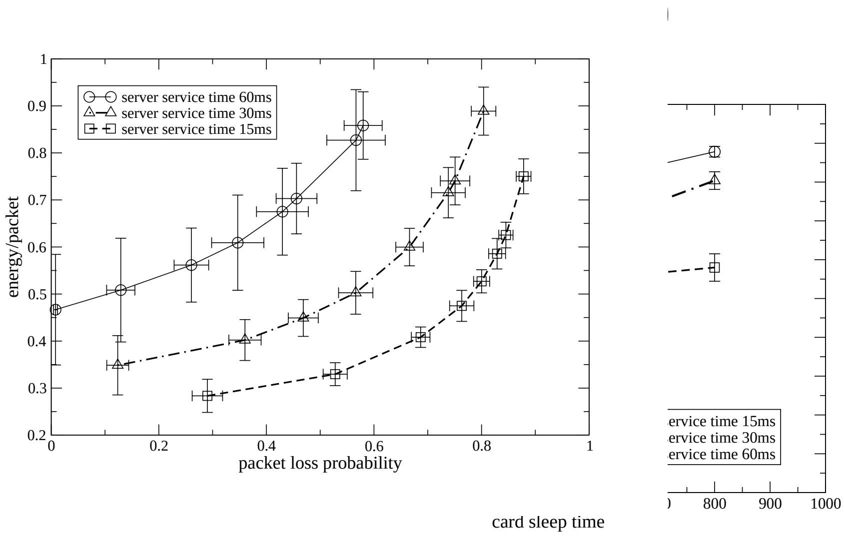
- Exponential model (use of exponential rates)

Andrea Acquaviva, SFM-MOBY05 April 29th, 2005

Energy/QoS (2/3)

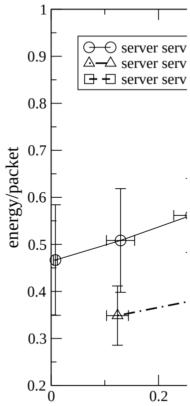


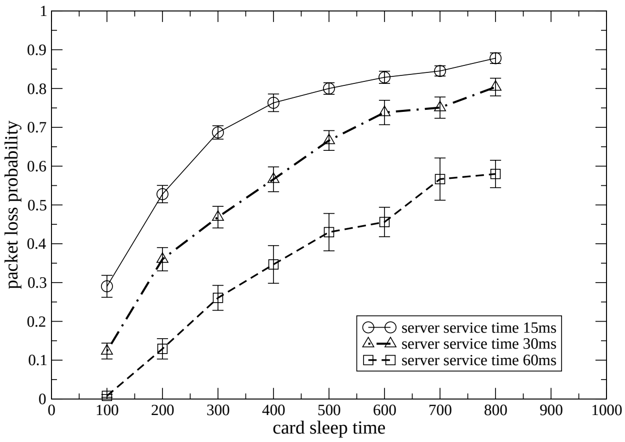
- Exponential model



- Determ

Energy/QoS (3/3)



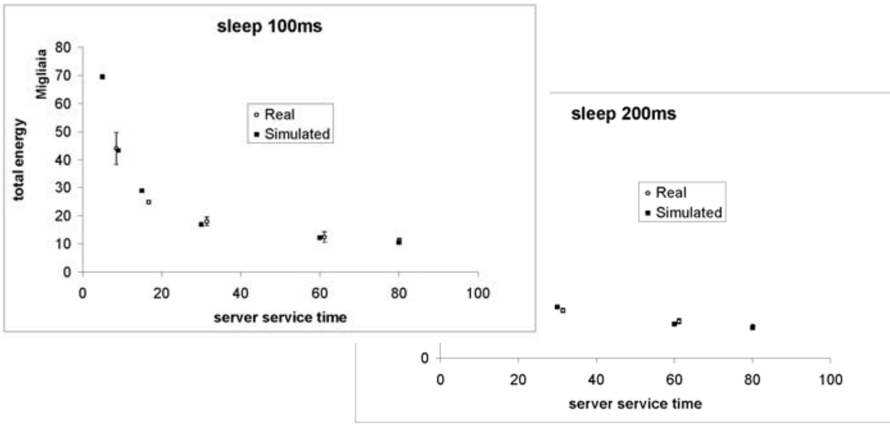


- Determ

Model Validation (1/2)

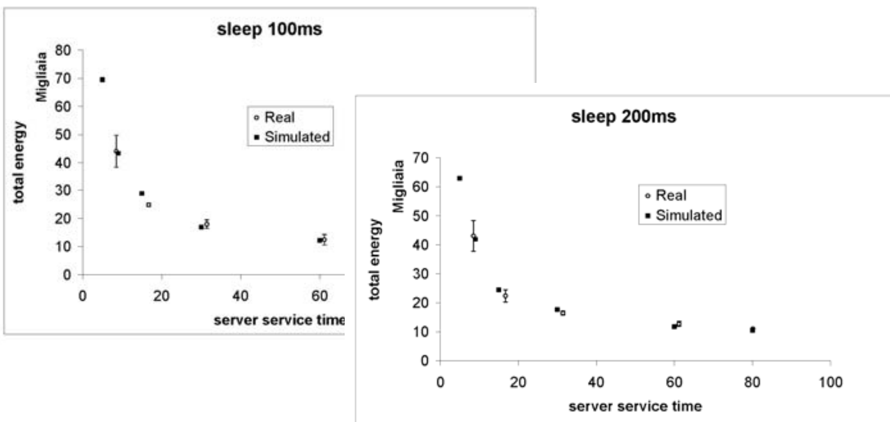
- Comparison between simulation (deterministic model) and real hardware measurements
- Set-up
  - Real WNIC installed on a laptop
  - Use a current monitor
  - Data acquisition board (DAQ) to digitize current data
  - Instrumentation control software (Labview) to collect current values over time

Model Validation (2/2)



- Model validation

Model Validation (2/2)



- Model validation

Comments

- 100ms and 200ms are sleeping time allowed by most of commercial cards
- 10 second experiments
- Total energy consumption decreases when service time increases, because the card receives less packets (service rate and total duration of the benchmark are constant)
- Negligible difference between the model and the measured power consumption

Thank you.