Exploring the Role of Multiple Radios in Short hop Wireless Systems

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Are any of these problems familiar?

"I don't keep my PDA connected to the wireless LAN because it kills my battery very quickly"

"Oh No! That cordless phone killed my WLAN connection"

"Hey, can I call you back? I can hardly hear you, your voice is clipped"

"How come I lose parts of the phone conversation whenever I walk around talking into my WiFi phone?"

"The network is really slow; the system load must be heavy"

General Issues in Wireless Networking

Signal propagation is unpredictable
- Attenuation depends on environment (multi-path, absorption,…)

Unlicensed spectrum is not pristine
- Current spectrum etiquette rules allow anarchy

Battery technology is not following Moore's Law
- Limits usage, battery power doubles every 35 years!

User mobility is difficult to handle
- Handoff between APs is flawed, harder with port-based security

Available spectrum is limited ⇒ Capacity is limited
- Shannon's Law: can pack only n bits / m Hz

Question: How can we build robust wireless systems?

Talk Outline

- Current state of wireless systems
- Our thesis
- Revisiting classical problems
  - Energy consumption
  - Mobility management
  - Last hop quality of service
  - Data link robustness
  - Capacity improvements
- Conclusions

RF Transceivers

An ideal radio:

- Consumes very little power
- Supports very high data rates
- Is robust to communication errors and mobility

However, current radios have either:

- High data rate, but poor energy consumption, mobility management and communication robustness, e.g. IEEE 802.11 {a,b and g}

or

- Low energy consumption, but low data rate and inefficient with respect to mobility, robustness, and capacity, e.g. IEEE 802.15{.1,.4}

Observations on Current Practice

What do designers do today?

- Design wireless cards to operate over a single radio
- When systems have more than one radio: applications / systems use them independently

Optimize individual components not the system

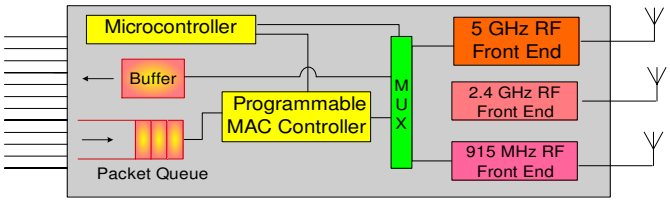
Our Thesis

Wireless systems can be improved by employing multiple radios as part of the same network

- Optimize complete system: hardware and software
- Radios with different properties cooperate with each other to accomplish the same task

Multi-Radio Concept

A single wireless NIC that contains IEEE 802.11{a,b,g} radio + a 802.15.4 Zigbee Radio



- Has major implications on hardware and software design
- Design is agnostic to particular radio models

Revisit "classical problems" in wireless networking

- Reduction of energy consumption
- Tolerance to device mobility
- Last hop quality of service
- Resiliency to interference
- Improvement in capacity

Making the Case for Multi-Radio Wireless Systems

Example 1: The Energy Consumption Problem

An obstacle to deployment of handheld WLAN-connected devices is battery lifetime

Problem: Energy Consumption

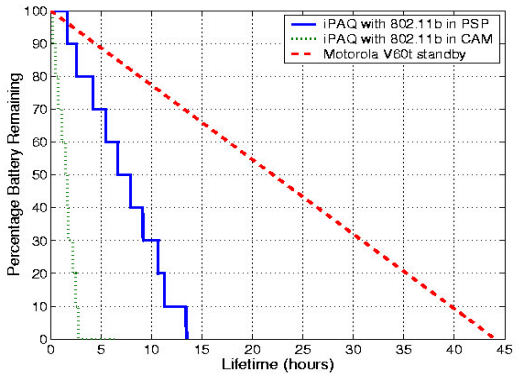
Mobile devices have limited energy supply

- Battery improvement not as rapid as one would hope

- Current approaches used by system designers
  - Design efficient circuits, improve radios
  - Use dynamic power management
  - Redesign protocols

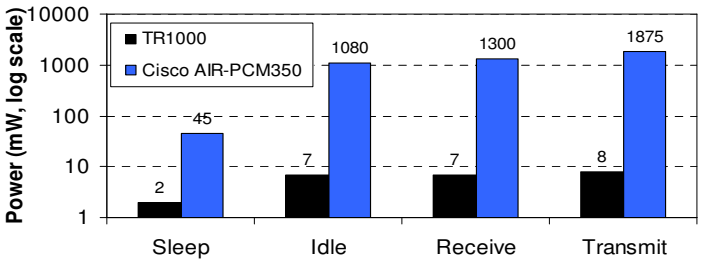
  … have limited effectiveness

State of the Art - Standby Lifetime



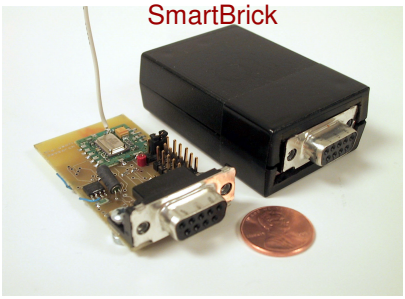
Typically, a significant fraction of NIC time is spent in idle mode

Wireless NIC Power Consumption



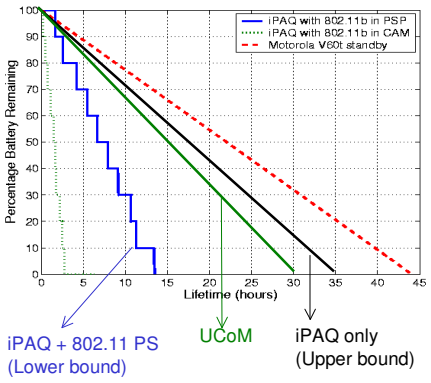
Multi-Radio Approach: Reduce idle energy consumption by using a second low-power radio

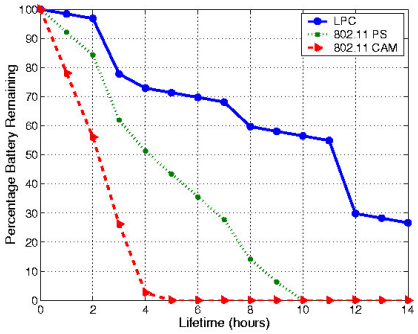
The Universal Communicator Device



- SmartBrick is attached to the UCoM proxy
- Power is derived from serial port

Power Savings Performance





Standby Time: 115% improvement in battery lifetime over Power-Save mode

For usage based on user profile:
Gain over 802.11b PS > 40%
Gain over 802.11b CAM > 180%
i.e., recharge once a day only

WoW Summary

Started with

- iPAQ H3650 (no wireless connectivity): 35 hours lifetime
- iPAQ H3650 with 802.11b (Power-Save mode): 14.5 hours lifetime

Accomplished

- Standby lifetime of UCoM device is **over 30 hours – improvement of 115%**
- For a typical user with 82 min/day use – **improvement of over 40%** or a battery lifetime of **over 20 hours**

See paper for more details

Wake on Wireless: An Event Driven Energy Saving Strategy for Battery Operated Devices: In MobiCoM, Atlanta, GA, Sept 2002

- Compares UCoM with Cell Phone
- Compares UCoM with iPAQ + 802.11b + Bluetooth

Energy Management Summary

Today, there is no single radio that gives you very low power and very data rates but …

Multi-radio wireless LANs can get you there …

- WoW: Eliminate wastage when no communications
- CoW: Eliminate wastage during active communications
- DoW: Trade-off data rate for power savings

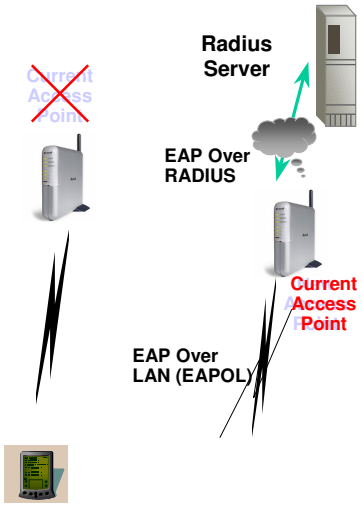
Making the Case for Multi-Radio Wireless Systems

Example 2: Managing Mobility

An obstacle in deploying WLAN-based VoIP devices is poor mobility management

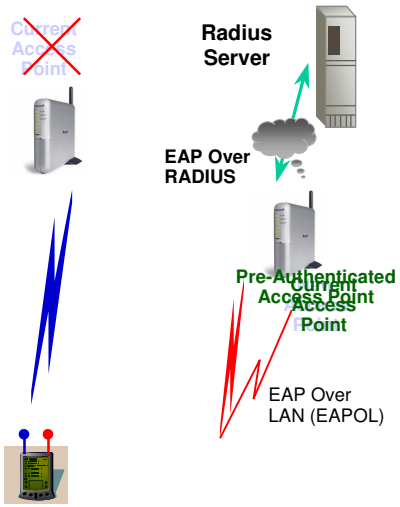
(Hard) Handoff in WLANs

- Client initiates handoff when SNR goes below threshold
- Handoff (with security) includes:
  Break – Locate – Authenticate – Associate
- Handoff delay can be a few seconds due to Radius server
  - Can be devastating for a WiFi phone

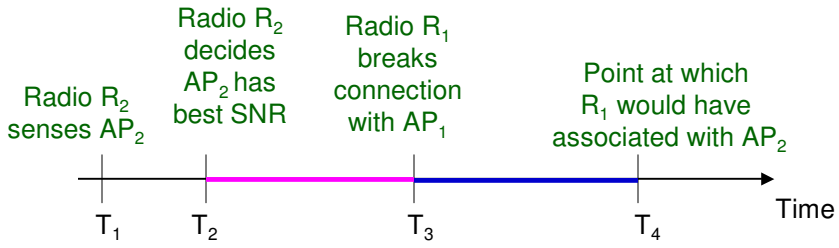


Soft Handoff with Multiple Radios

- Pre-authenticate with next AP in advance
- Converted a "break-before-make" to a "make-before-break"
- Reduces handoff latency and packet loss



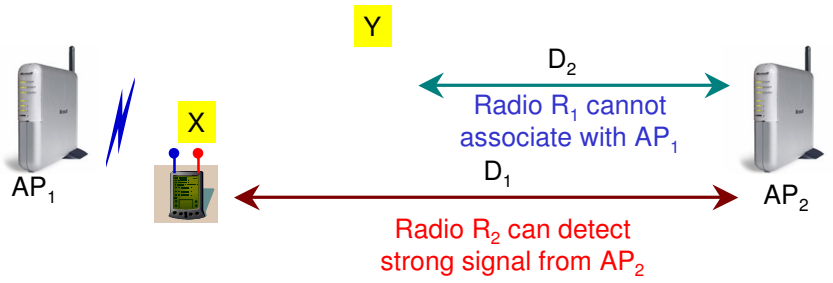
Conditions for No Packet Loss



Time taken between R_2 choosing AP_2 and R_1 breaking from AP_1 $\geq$ Time to pre-authenticate + pre-associate

Helps system designers in determining upper bound on authentication protocol time

Conditions for No Packet Loss (Cont.)



Time taken to travel from X to Y $[(D_1 - D_2)/\text{Speed of node}]$ $\geq$ Time to pre-authenticate + pre-associate

Helps network administrators in determining the AP overlap needed for no packet loss

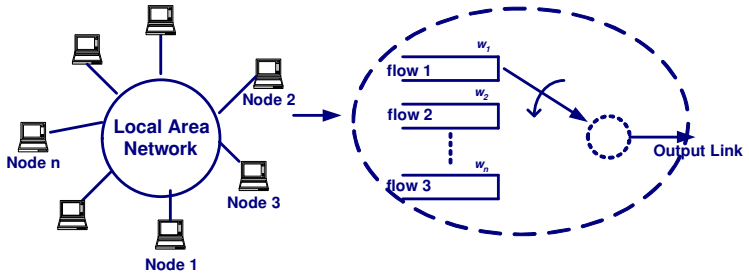
Making the Case for Multi-Radio Wireless Systems

Example 3: Differentiated Service

QoS has been identified as an important component for the success of WLANs

Classical Scheduling

Based on Generalized Processor Sharing (GPS)
(or Weighted Fair Queuing (WFQ))



Multi-radio approach:
Use one radio for data and other for scheduling traffic

Making the Case for Multi-Radio Wireless Systems

Example 4: Communication Robustness

Interference in the same frequency band can result in poor network performance

Frequency Diversity

Many disparate devices operating in the same frequency range

- Single frequency band problems:
  - Interference, e.g., cordless phones, microwave ovens
  - Signal absorption for that spectrum
- Multi-radio approach adds robustness:
  - Multiple radios on different channels in same frequency band
  - Multiple radios in different bands: can choose another frequency range, e.g., 915 MHz or 5 GHz

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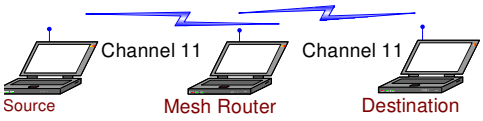
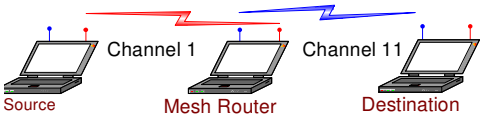
Example 5: Capacity Enhancements

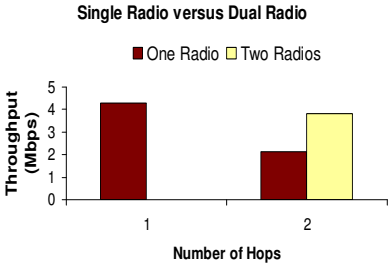
Capacity improvements are necessary for the scalability of multi-hop mesh networks

Enhancing Capacity with Multiple Radios



- Cannot transmit and receive at the same time ⇒ Bandwidth halved
- Other scenarios where even lower b/w





- **Use two radios for pipelining**
- Allows simultaneous send/receive on a router node

Conclusions

- Current wireless LANs, which contain a single radio, will be inadequate
- Proposed approach: use multiple radios in a WLAN
- Can help address issues such as power, mobility, capacity, robustness
- This design approach has the potential to significantly enhance the "wireless experience"