Wireless Technologies: Diversity and Opportunities

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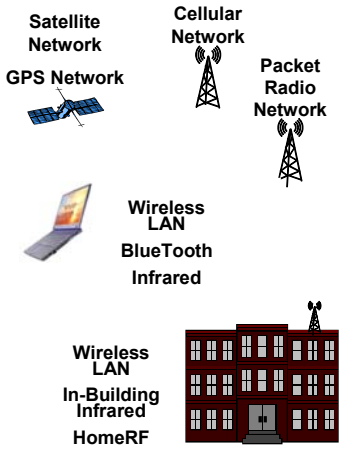
Wireless Communication in the Information Age

- Users
  - Have
    - Many devices
  - Want
    - Anytime/anywhere connectivity
    - From all devices
- Devices
  - Have
    - Multiple interfaces

Wireless Technologies

- Multiple choices
  - No one perfect technology
- Communication characteristics
  - Rate
    - Defines the communication speeds
  - Frequency
    - Defines the behavior in the physical environment
  - Range
    - Defines the physical communication area
  - Power
    - Defines the cost in terms of energy



Current Wireless Technologies

- IEEE 802.11
  - Wireless LAN (WLAN)
  - MAC layer based on Ethernet
    - Originally called “wireless Ethernet”

	Max Rate	Frequency	Range	Energy
IEEE 802.11b	11 Mbps	2.4 GHz	50 m	100 mW
IEEE 802.11g	54 Mbps	2.4 GHz	50 m	100 mW
IEEE 802.11a	54 Mbps	5 GHz	10 – 25 m	100 mW

IEEE 802.11 - Physical Layer

- IEEE 802.11 b
  - Direct Sequence Spread Spectrum
    - Uses 83 MHz in 2.4 GHz band
    - Spread the signal over a wider frequency band than required
    - Originally designed to prevent jamming
  - 3 orthogonal channels
- IEEE 802.11 g
  - Frequency-Hopped Spread Spectrum
    - Uses 80 1MHz sub-bands in 2.4 GHz band
    - Transmit over a random sequence of frequencies
      - Hop 10 times a second
    - Originally designed to avoid snooping
  - 3 orthogonal channels
- IEEE 802.11 a
  - Orthogonal Frequency Division Multiplexing (OFDM)
  - 13 orthogonal channels

IEEE 802.11 - Physical Layer

- Channel Rate vs. Signal strength
  - All versions of IEEE 802.11 can reduce the rate to increase the signal strength
    - IEEE 802.11 b — 1, 2, 5.5, 11 Mbps
    - IEEE 802.11 a, g — 6, 9, 12, 18, 24, 36, 48, or 54 Mbps
  - Increased range → lower signal → lower rate

IEEE 802.11 – MAC Layer

- CS – Carrier Sense
  - Nodes can distinguish between an idle and a busy link
- MA - Multiple Access
  - A set of nodes send and receive frames over a shared link
- CA – Collision Avoidance
  - Nodes use protocol to prevent collisions from occurring
    - RTS (request to send)
    - CTS (clear to send)

IEEE 802.11 Extensions

- IEEE 802.11e
  - Enhancements: QoS, including packet bursting
- IEEE 802.11i
  - Enhanced security
- IEEE 802.11n
  - Higher throughput improvements using MIMO (multiple input, multiple output antennas)
- IEEE 802.11p
  - WAVE - Wireless Access for the Vehicular Environment (such as ambulances and passenger cars)
- IEEE 802.11s
  - ESS Mesh Networking
- IEEE 802.11u
  - Interworking with non-802 networks (for example, cellular)

Current Wireless Technologies

- BlueTooth – IEEE 802.15.1
  - Originally designed as a cable replacement technology
  - Master/Slave configuration
  - Piconets

	Max Rate	Frequency	Range	Energy
BlueTooth	3 Mbps	2.4 GHz	100 m	100 mW
			10 m	2.5 mW
			1 m	1 mW

BlueTooth

- Physical Layer
  - Frequency-Hopped Spread Spectrum
    - Uses 79 1MHz sub-bands in 2.4 GHz band
    - Transmit over a random sequence of frequencies
      - Hop 1600 times a second
    - 5 orthogonal sub-hopping sets
- MAC Layer
  - Slotted
    - Managed by the master
    - Single slot packet
      - Max data rate of 172Kbps
    - Multislot frames
      - Support higher rates of 721Kbps

Current Wireless Technologies

- ZigBee – IEEE 802.15.4
  - Low power, short range
    - Sensor networks
    - Personal area networks

	Max Rate	Frequency	Range	Energy
ZigBee (IEEE 802.15.4)	250 kbps	2.4 GHz	10 - 100 m	1 mW
	40 Kbps	915 MHz	10 - 100 m	1 mW
	20 Kbps	868 MHz	10 - 100 m	1 mW

ZigBee

- Physical Layer
  - Direct Sequence Spread Spectrum
    - 2.4 GHz – 16 orthogonal channels
    - 915 MHz – 10 orthogonal channels
    - 868 MHz – 1 channel
- MAC Layer
  - CSMA/CA
  - Battery Life Extension (BLE) mode
    - Limit the back-off exponent to max 2

Current Wireless Technologies

- Ultra Wide Band – IEEE 802.15.4a
  - Low power
  - Short range
  - Improved use of spectrum

	Max Rate	Frequency	Range	Energy
UWB (IEEE 802.15.4a)	500 Mbps	3.1-10.6 GHz	2m	0.5 mW
	110 Mbps	3.1-10.6 GHz	10m	0.5 mW

UWB

- Two optional physical layers
  - UWB Impulse Radio
  - Chirp Spread Spectrum (operating in 2.4GHz)
- Benefits
  - Limited or no multipath fading

Current Wireless Technologies

- InfraRed
  - Directional

	Max Rate	Frequency	Range	Energy
InfraRed – IrDA	9600 bps – 16 Mbps		< 1 m	Low

Current Wireless Technologies

- RFID
  - Passive technology
  - Used for inventory control

	Max Rate	Frequency	Range	Energy
RFID – Near Field			< 10 cm	Self-powered
RFID – Far Field			< 3 m	Self-powered

RFID

- RFID Basics
  - Reader powers the “tag”
  - Antenna “captures” the energy for a response
  - Simple MAC
    - All tags respond
  - Contention-based MAC
    - Use ALOHA or Tree-splitting algorithm to avoid collisions
- Near field
  - Magnetic induction
    - Range < 10 cm
- Far field
  - Electromagnetic wave capture
    - Range < 3 m

Current Wireless Technologies

- WiMAX – IEEE 802.16
  - Wireless Metropolitan Area Networks (WMAN)
  - May require line-of sight (LOS)

	Max Rate	Frequency	Range	Energy
WiMAX –LOS	70 Mbps	10-66 GHz	50 km	Very high
WiMAX Non-LOS		2-11 GHz		Very high

Communication Characteristics

- Rate
  - Defines the communication speeds
- Frequency
  - Defines the behavior in the physical environment
- Range
  - Defines the physical communication area
- Power
  - Defines the cost in terms of energy

Communication Characteristics

- Rate
  - Defines the communication speeds
  - Channel Bandwidth
    - Defined by the specifications of the technology
  - Available Bandwidth
    - Defined by the current use of the communication channel
      - Channel competition – MAC layer
      - Bandwidth competition – Transport layer
- Which is better?
  - IEEE 802.11a or IEEE 802.11b

Communication Characteristics

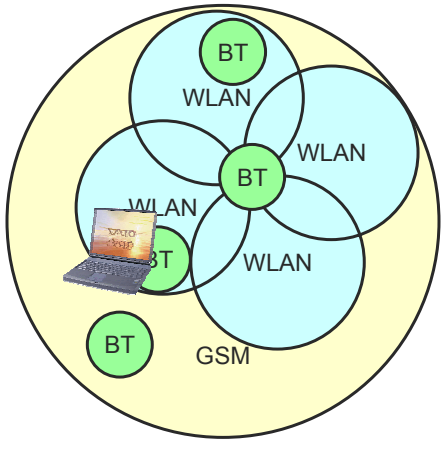
- Frequency/signal characteristics
  - Defines the behavior in the physical environment
    - Does the signal go through walls?
    - Is the signal susceptible to multipath fading?
  - Challenge
    - Many technologies use the same frequency
- Which is better?
  - Environment: a home with WiFi and cordless phones
  - Bluetooth or UWB?

Communication Characteristics

- Range
  - Defines the physical communication area
  - May be affected by buildings, walls, people
  - May be affected by distance
- Which is better?
  - InfraRed or ZigBee?

Communication Characteristics

- Power
  - Defines the cost in terms of energy
  - Power can be adapted to save energy
    - Inversely affects range
- Which is better?
  - IEEE 802.11g or ZigBee?

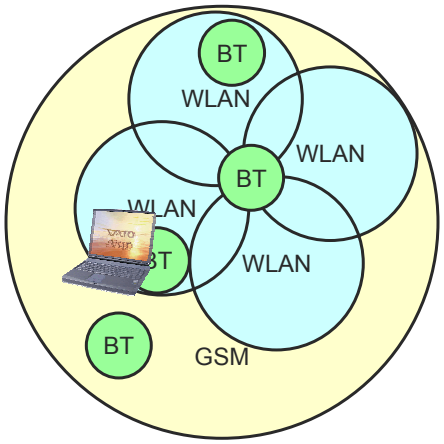


Diversity

- Mobile hosts may have multiple network interfaces
- Coverage areas of different technologies may overlap

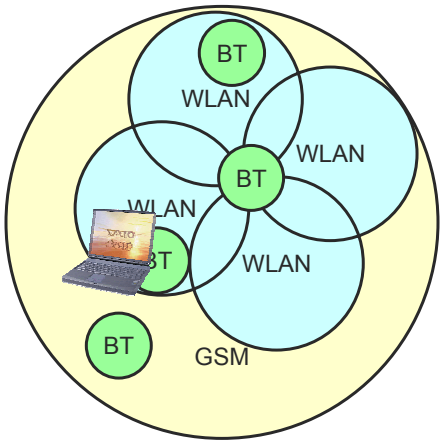
Benefiting from Diversity

- Opportunity
  - Mobile hosts may be able to access multiple technologies
- Goal
  - Intelligent use of the resources from multiple interfaces



A Multitude of Resources

- End-to-end communication
  - Multiple paths may exist between a sender and a receiver
- Find each path
  - Find your neighbors
- Determine the “quality” of each path

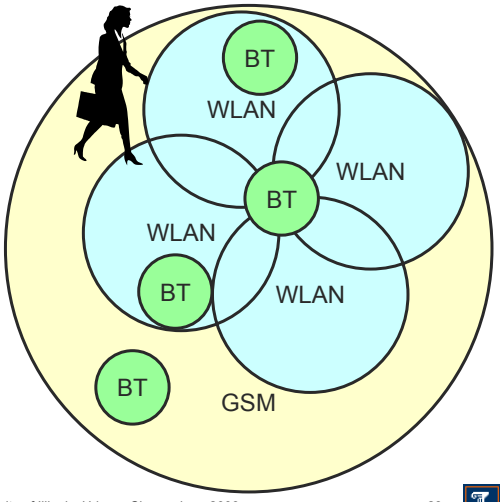


Finding Your Neighbors

- Detection
  - Determine which physical interfaces are currently available
- Challenge
  - Most interfaces can operate on multiple channels
    - Search space = number of interfaces x number of channels
  - Connectivity may change over time
    - Search frequency depends on the expectation of new technologies in the area

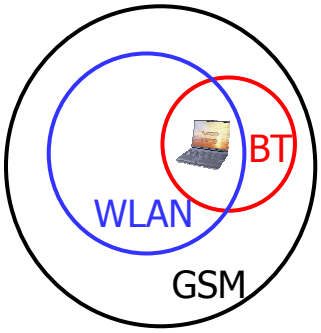
Detection

- Availability
  - What physical interfaces/ channels are currently available?
  - Need to check all channels on all interfaces



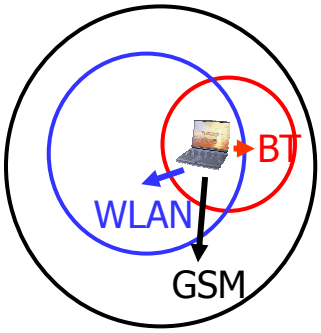
Detection

- Passive listening
  - Periodically listen to on-going communication
  - Cost
    - Listening may not be cheap
  - Limitation
    - Cannot listen all the time
    - Cannot detect idle media
    - Not possible for some technologies



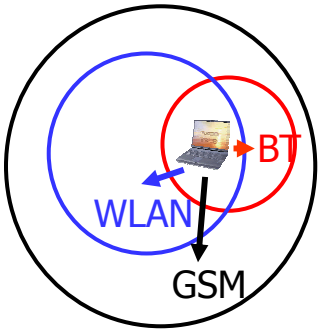
Detection

- Active probing
  - Periodically send a probe on each potential channel to advertise presence
  - Cost
    - Advertising is not cheap
  - Limitation
    - Coordination – someone better be listening to your probe!



Detection

- Tradeoffs
  - More accurate
    - Increased energy costs
  - Less accurate
    - Increased communication delay
- Bottom line
  - The more available interfaces/ channels, the more expensive, complex and inaccurate detection becomes



Choosing the Right Technology

- "I found 3 available channels. Which one should I use?"
  - Channel quality
  - Application requirements
  - Communication cost

Channel Quality

- Quality parameters
  - How much bandwidth?
  - How much congestion?
  - How long is the delay?
  - Is the channel error-prone?

Determining Channel Quality

- Specifications
  - Effectiveness
    - Provides maximums
  - Does not consider
    - Interference
    - Cross traffic
  - Cost
    - No energy
    - No bandwidth

Determining Channel Quality

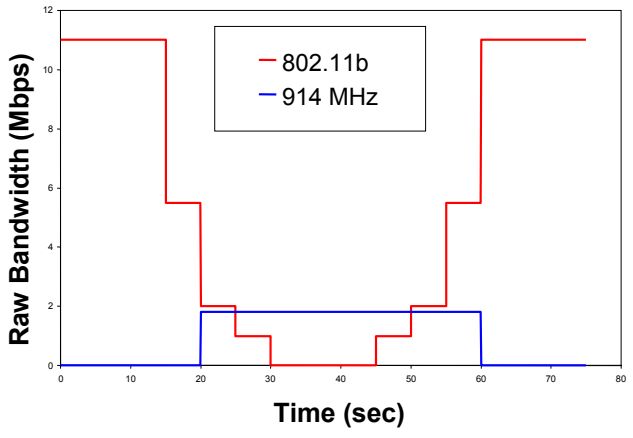
- Passive listening
  - Effectiveness
    - Provides estimates in the presences of current traffic
  - Does not consider
    - Effect of competition for the channel or the bandwidth
  - Cost
    - Low energy
    - No bandwidth

Determining Channel Quality

- Active probing
  - Effectiveness
    - Provides real estimates
  - May not consider
    - Application traffic patterns/demands
  - Cost
    - High energy
    - Low – high bandwidth

Choosing the Right Technology

- "I found 3 available channels. Should I use more than one?"
  - One channel per application stream
    - When to hand off between channels?
  - Multiple channels per application stream
    - Which and how many channels to use?



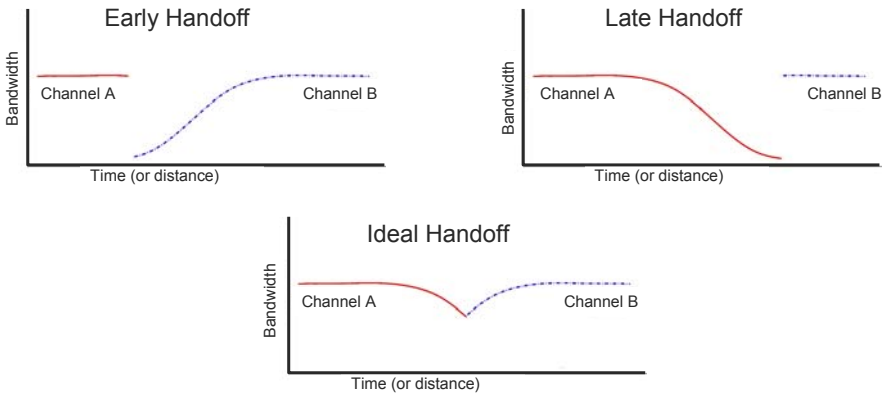
Available Channels

Handoff

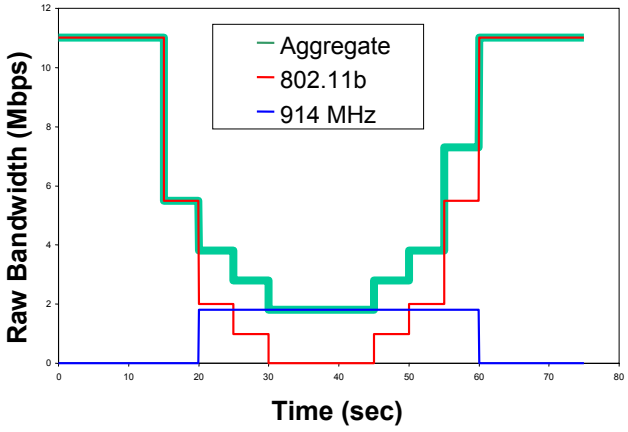
- One channel per application stream
  - Use the best until it deteriorates, then find the next best

Handoff

- When to hand off?

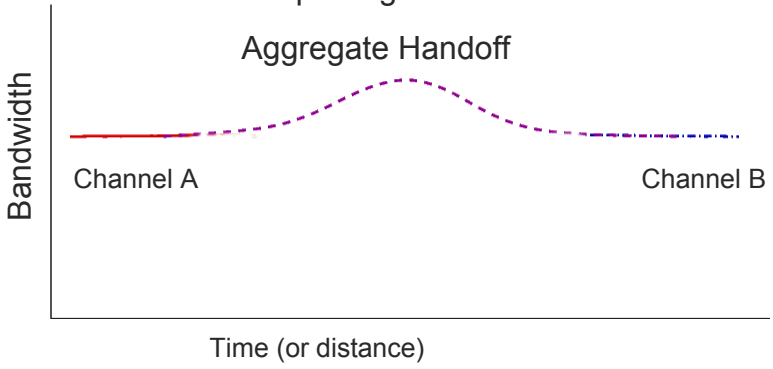


Available Channels



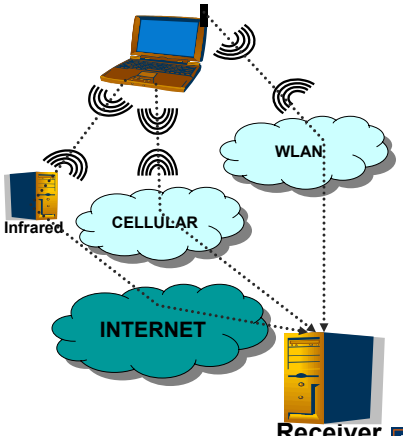
Multiplexing

- Use multiple channels per stream
  - Inverse multiplexing



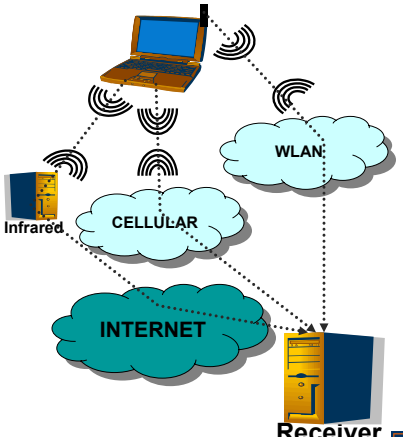
Multiplexing

- Approach
  - Combine the capabilities of all channels
- Benefits
  - Enables bandwidth aggregation
  - Avoids choosing a single channel
  - Can smooth handoffs



Multiplexing

- Inverse Multiplexing
  - Simultaneous use of multiple interfaces
- Approach
  - Per-channel congestion control
  - Per-flow reliability and flow control



Multiple Interfaces in Practice

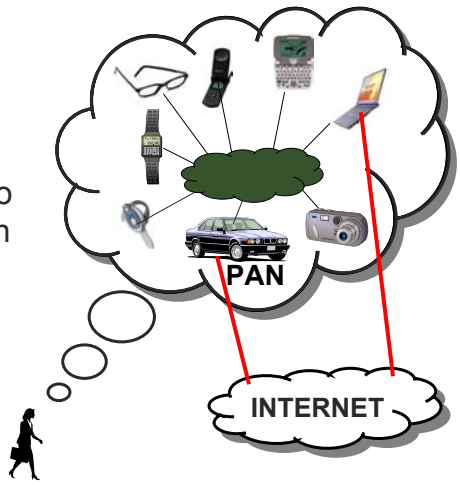
- Scenario: Personal Area Network
  - A group of devices that communicate and cooperate to support an individual

Personal Area Network

- Internal Connectivity
  - The devices form a small local network connected via wireless technologies
  - Each device has the potential to send, receive or route data through the PAN

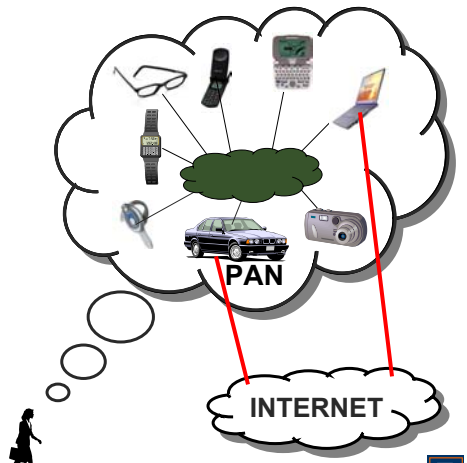
Personal Area Network

- External Connectivity
  - Each device may have connectivity to the Internet through some external communication service provider



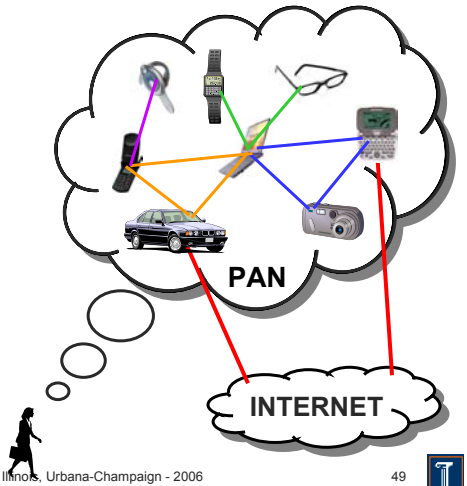
Personal Area Network

- Benefits
  - Combine the capabilities of all devices
    - More bandwidth
    - Better connectivity
    - Diversity
- Challenge
  - Which devices to use and when!



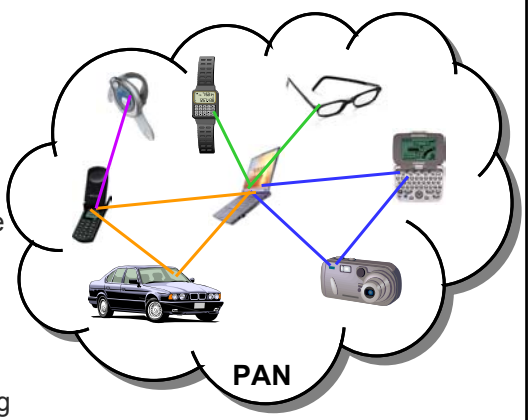
Personal Communications

- Goal
  - Manage the devices and interfaces available in the PAN
  - Maintain effective and efficient communication in the face of dynamically changing
    - Availability
    - Connectivity
    - Capacity
    - Cost



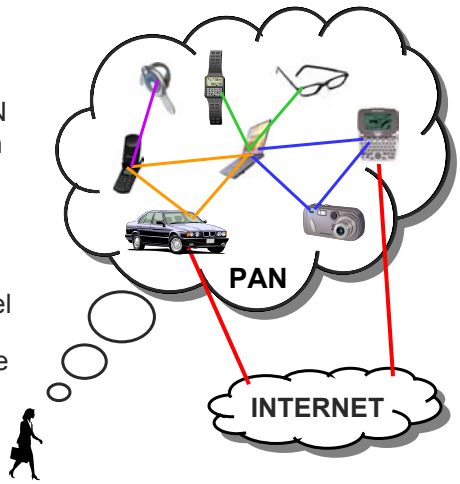
Internal Routing

- Routes - Internal destinations
  - Only need local addressing
  - Simple routing algorithms
  - Routes may include multiple technologies
- Challenge
  - All nodes must participate in routing



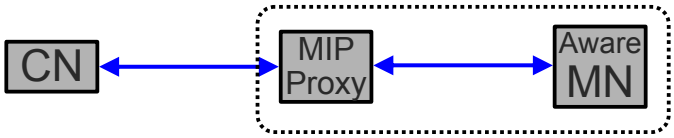
End-to-End Communication

- Environment
  - Multiple points of connectivity to the PAN
  - Multiple routes through the PAN
- Goal
  - Provide a stable communication channel through the PAN
  - Make us of all available resource
  - Manage limited resources



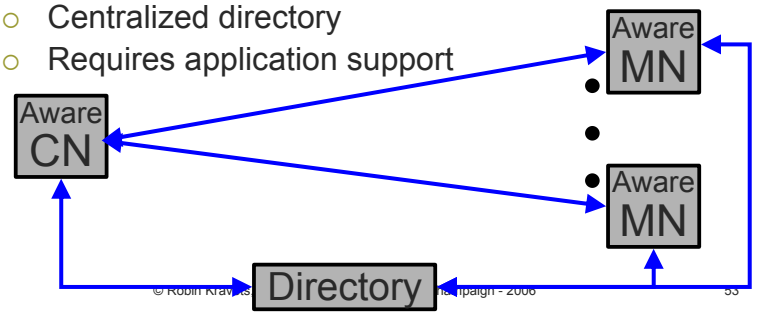
Genealogy: MobileIP

- Problem
  - Users with a single mobile device
- Solution: MobileIP
  - Location transparency
  - User is an IP address
  - Unaltered applications



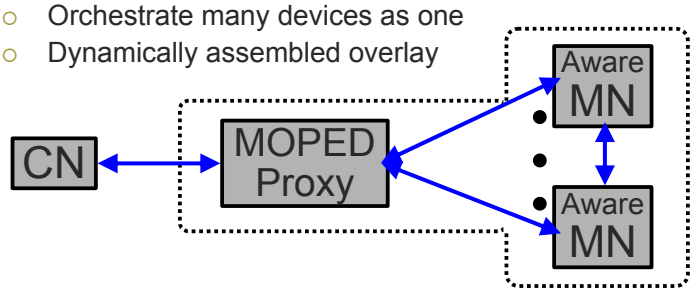
Genealogy: Mobile People

- Problem
  - Users with multiple means of access
- Solution: Mobile People
  - User is set of application-specific addresses
  - Centralized directory
  - Requires application support



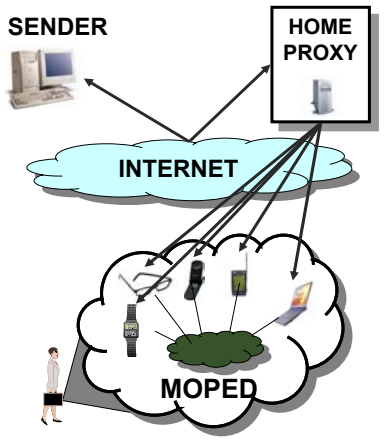
Genealogy: MOPED

- Problem
  - Users with multiple, under-utilised devices
  - N x M communication complexity
- Solution: MOPED
  - Orchestrate many devices as one
  - Dynamically assembled overlay



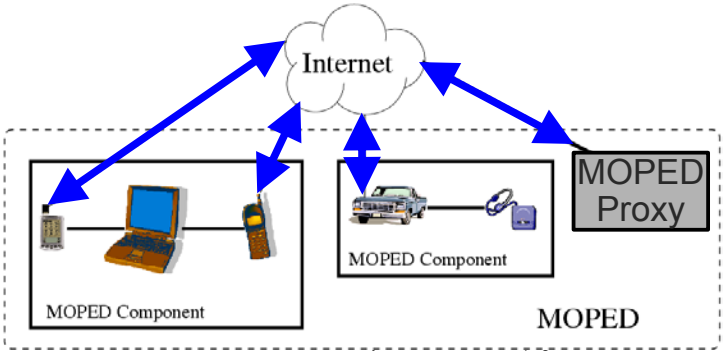
End-to-End Communication

- MOPED - MObile grouPEd Device
  - The group appears as a single entity to the rest of the Internet, providing a point of presence on the Internet for the user



End-to-End Communication

- MOPED Approach
  - Orchestrate many devices as one
  - Dynamically assembled overlay



Realizing Multi-interface Communications

- Increasing end-host diversity
  - Multiple interfaces
  - Cognitive radios
- Increasing environmental diversity
  - Personal area networks combine
    - Point-to-point networks
    - Ad hoc networks
    - Sensor networks
    - Delay tolerant networks
  - Islands of connectivity

Why aren't we there yet?

- No common control channel
- Unit of communication in IP is an Interface
  - IP address ≠ Device
  - IP address ≠ Person
- Routing is left to the routers!
  - Don't always need Internet communication

Wireless Technologies: Diversity and Opportunities

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