Radio Resource Management in Heterogeneous Wireless Networks

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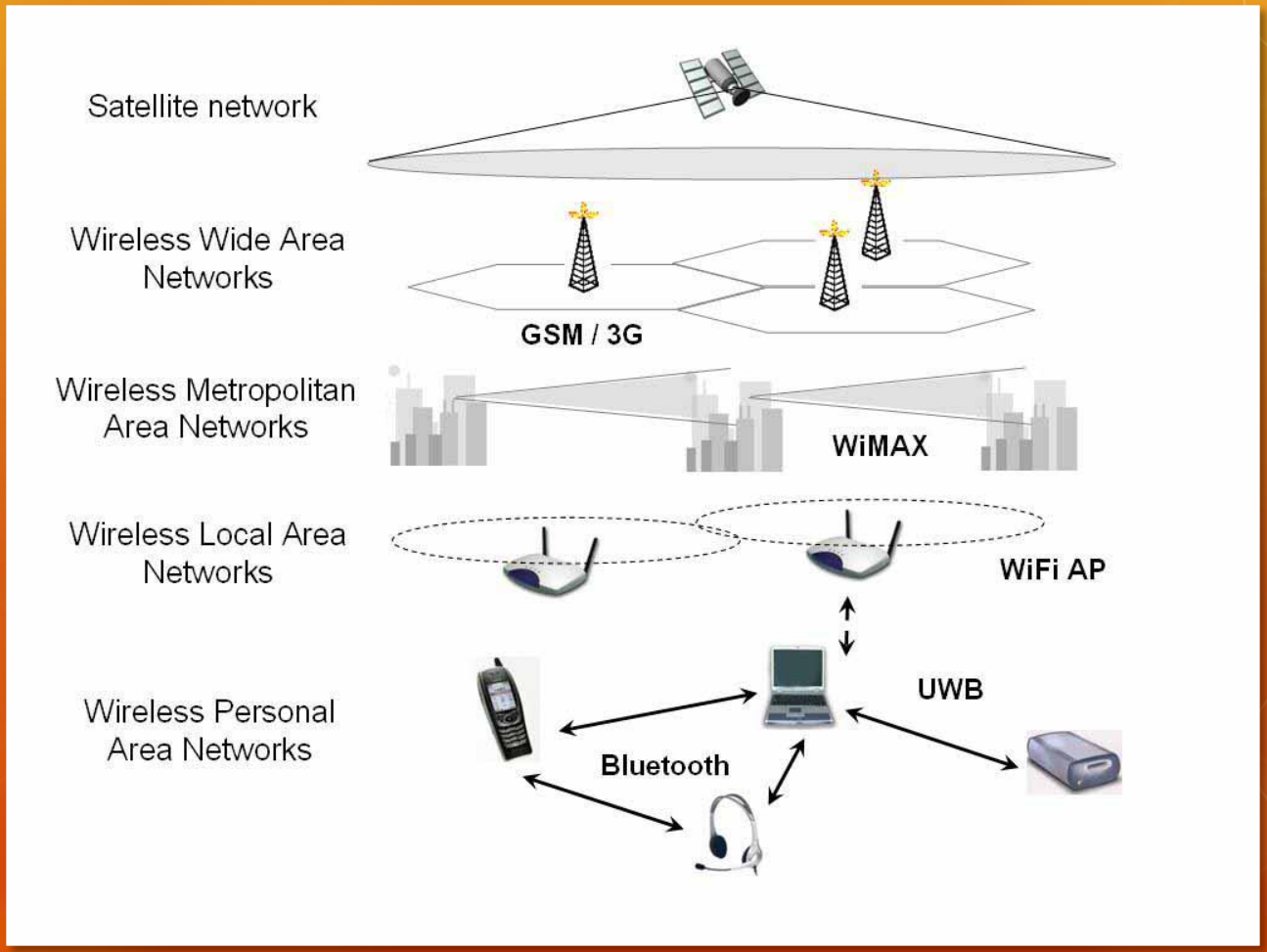
Outline

- **Introduction**
- Motivation
- Architectures for HWNs
- Applications and Deployments of HWNs
- Classification of Solutions
- Limitations, Open Research Problems
- Conclusions & Future Work

Introduction

- Heterogeneous Wireless Networks (HWNs)
  - Composed of component (homogeneous) networks or technologies
    - 802.11 (Wifi), 802.15 (Bluetooth, Zigbee), 802.16 (WiMAX), Cellular and Mobile Technologies
  - Called “Radio Access Technologies” or RATs
  - Many modern devices contain several different radios: ex) Bluetooth, Wifi, GPS, CDMA

Introduction



Source: http://www.comp.nus.edu.sg/~chenbinb/

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Motivation

- Cellular / Mobile & WiMAX technologies provide widespread coverage
  - Limited bandwidth, high cost
- Wifi, Bluetooth, Zigbee provide high bandwidth, low cost
  - Limited coverage
- Existing technologies do not work well together
- Users manually select technology / radio for use in many cases

Motivation

Start on wifi, want to
Seamlessly continue
transmitting via Skype
On my way to my car

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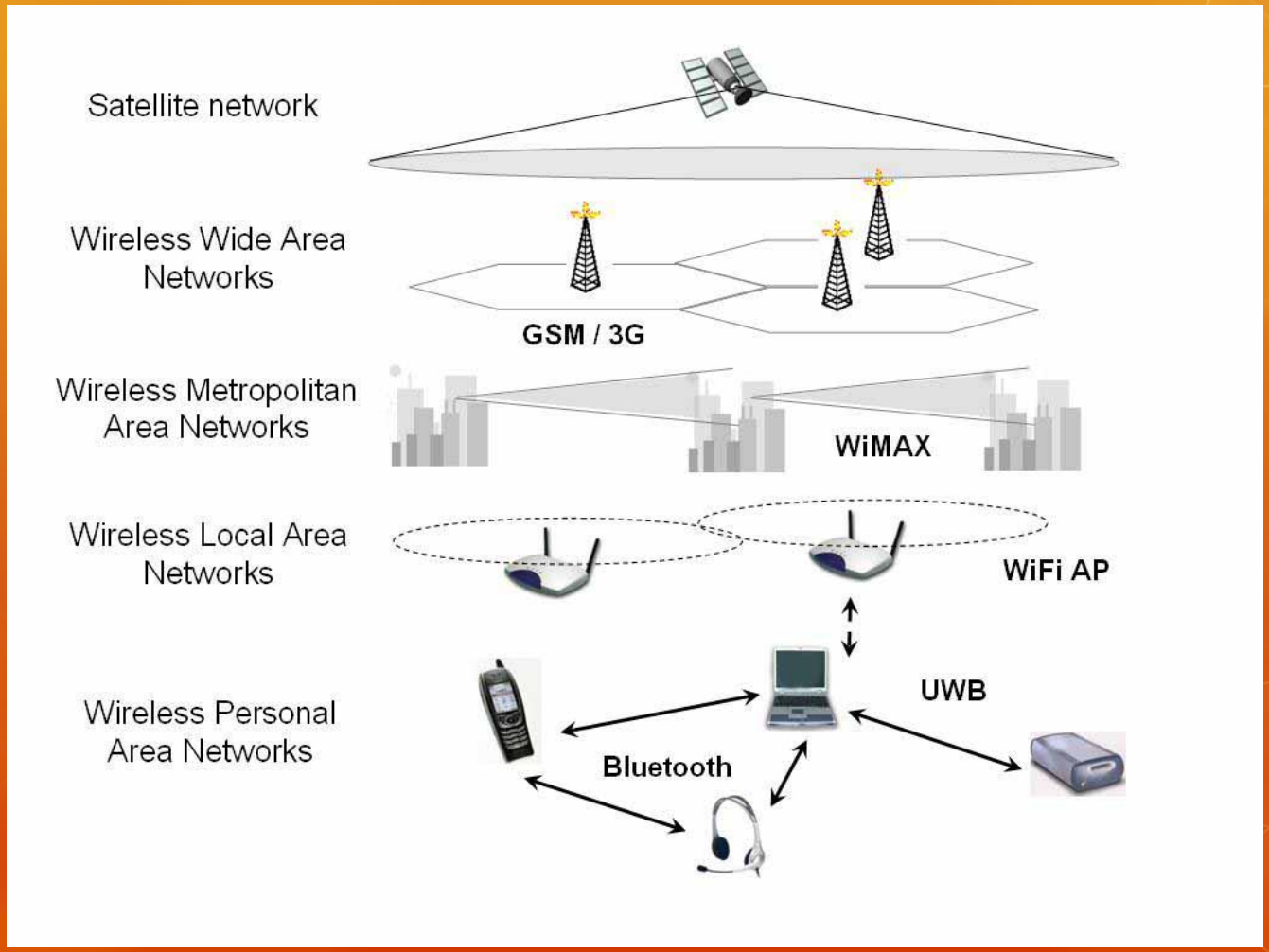
Dense Architectures

- Multiple RATs available in many places within the network
- User device or networks able to decide on best access
- Best used in:
  - urban environments
  - Environments with extensive infrastructure
  - Where more capacity is required in the network

Dense Architecture



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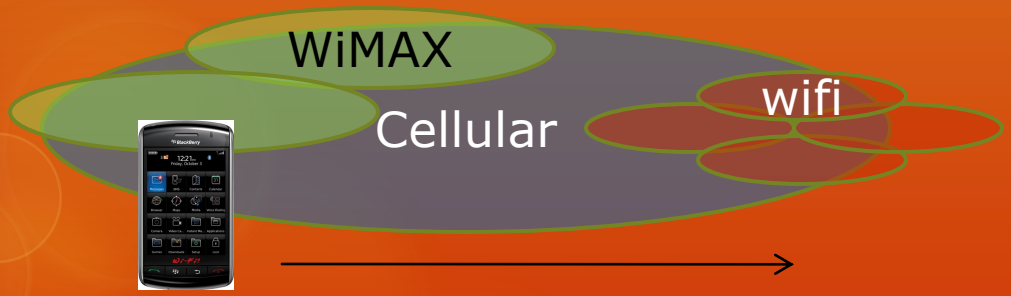
Dense Architecture

At a given position, a device may have multiple technologies it is able to connect to

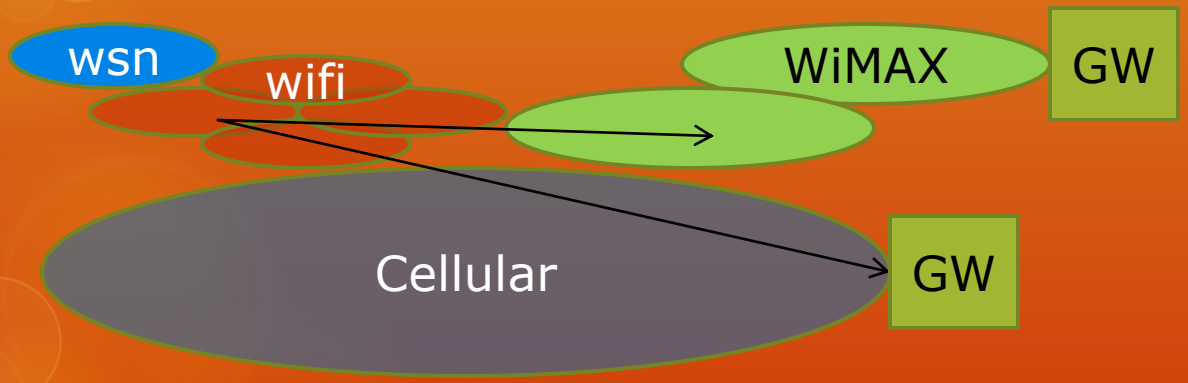


Sparse Architectures

- Network stitched together with different technologies
- Often only one possible choice for access
- Route traffic through several technologies to Internet gateway
- Best used in:
  - rural environments
  - developing countries

Sparse Architecture

- Traffic originating in a network without an Internet gateway (GW)
- Which network to route through?
  - Consider: cost, capacity, congestion, power levels etc.
- Also consider networks which are opportunistic
  - Portions of the network may be unavailable at a given time



Variations on Architectures

- Variations of HWN Architectures
  - Repeater / Relay Nodes [15]
    - Used to add capacity, reduce distance of long links, aggregate data, reduce power consumption
  - Caching / Prefetching Solutions [13,14]
    - One of more layers cache data to reduce requests to Internet
  - Clustering [12]

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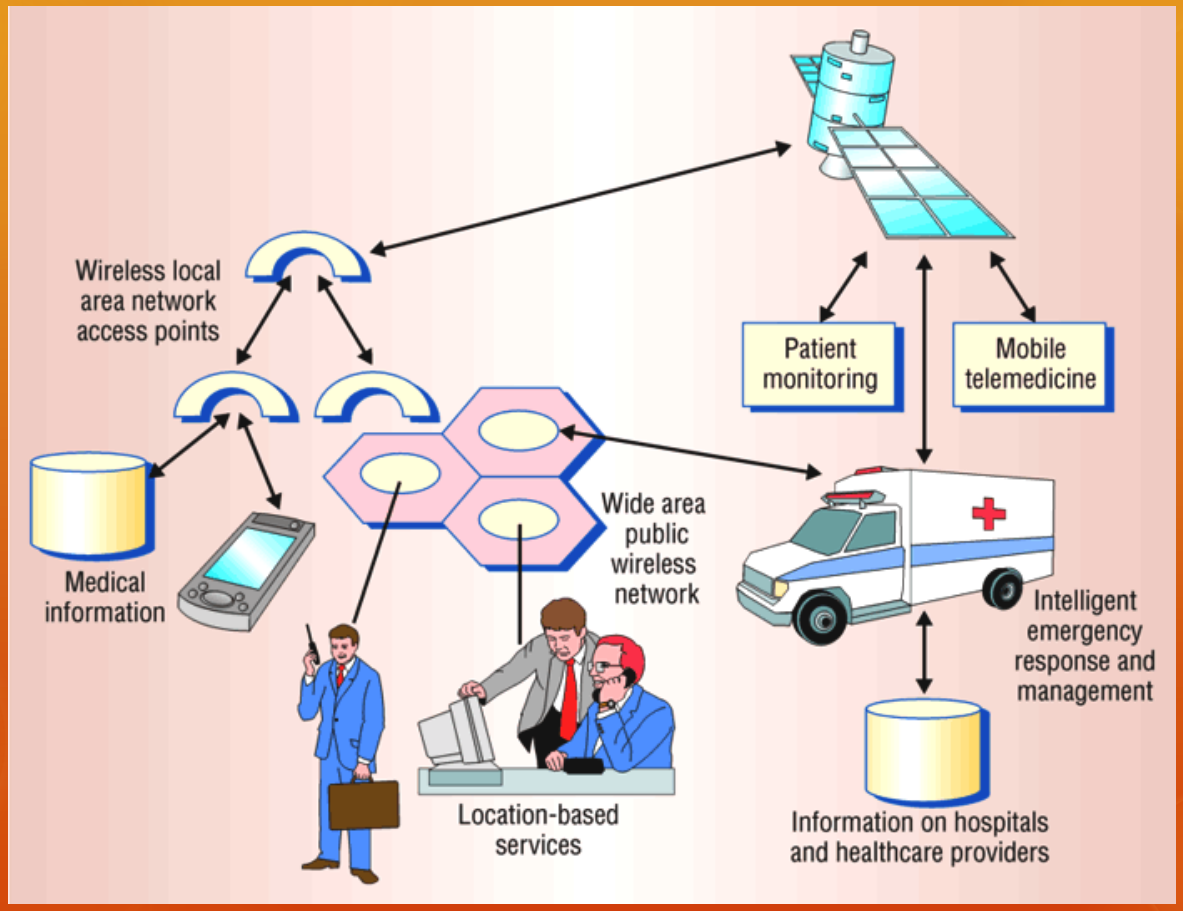
Applications

- Improved network access and capacity [1,2,9]
- Rural and Broadband access, Community Access Networks, Pervasive Network Coverage [5,6]
- Increased choices for consumers
  - (ability to pay more for increased service using multiple RATs)
- Multimedia Applications [4,7,8]
  - Unique challenge – high QoS requirement
- Health care, Military, Emergency Response
  - Unique challenge – high QoS and security requirement
- Interplanetary Networks [17]
  - Unique challenges – delay tolerance

Applications

Source: Rolta & Thales (rolta.com accessed August 2010)

Applications

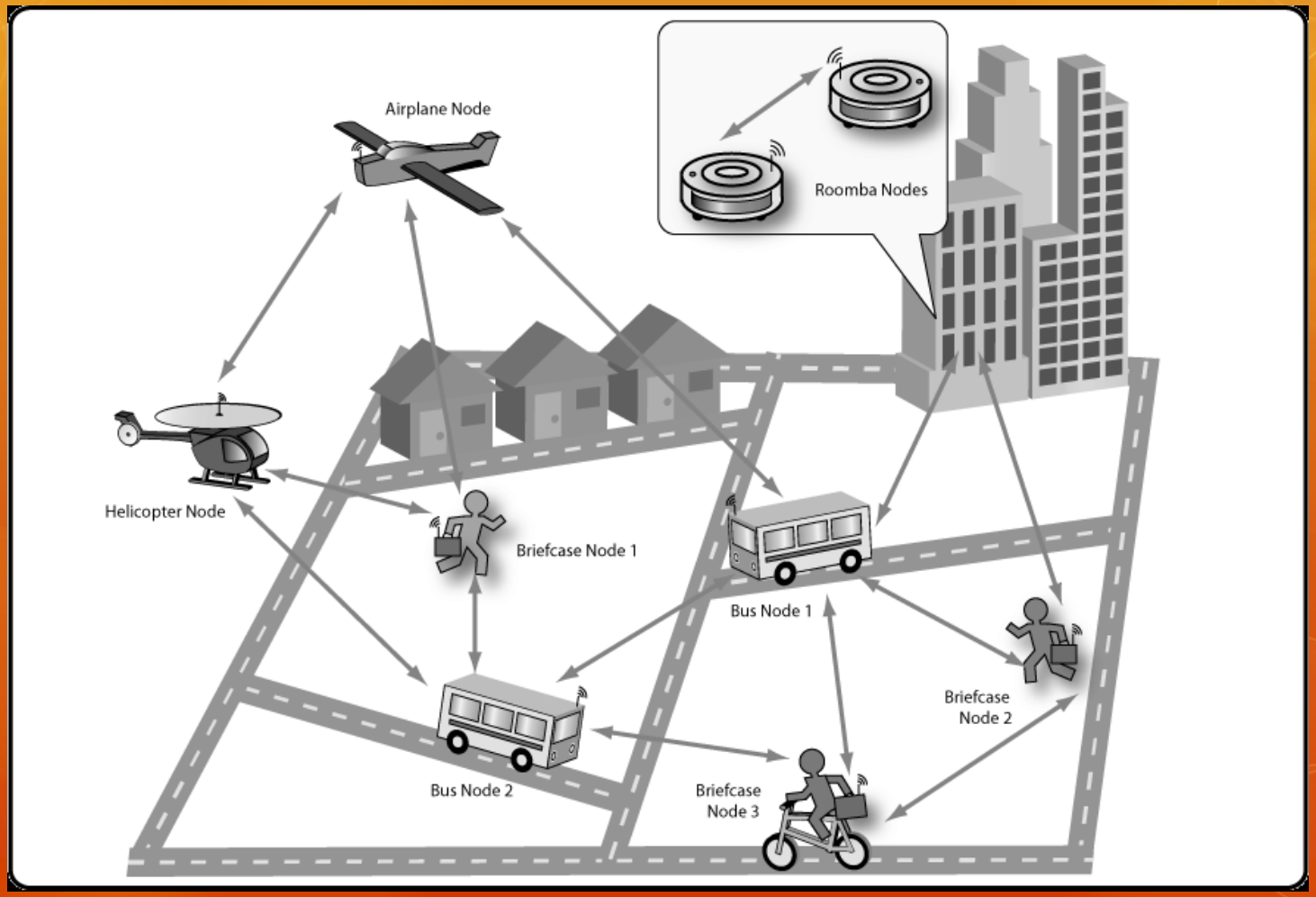


Source: Pervasive Healthcare: IEEE Computer Society

Deployments

- Testbeds:
  - HAWK – Heterogeneous Advanced Wireless networK (Hong Kong Polytechnic University) (2009) [5]
  - SCORPION – Santa Cruz mObile Radio Platform for Indoor and Outdoor Networks (University of California at Santa Cruz) (2009) [6]
- Some LTE or 4g mobile networks
  - Smooth handover / handoff between heterogeneous networks is a requirement of these networks
  - Many LTE and 4g Networks are still in early stages of deployment
  - "Heterogeneous" usually does not include technology such as wifi (only other existing mobile technologies)

Deployments – SCORPION [6]



Source: Bromage et al. [6]

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Classifications by Research Area

- Radio Resource Management
  - Resource Scheduling [16]
  - Power Control, Rate Control, Access Control [7,8,9]
  - Prefetching, Caching [13,14]
  - Cognitive / Software Defined Radio
- Quality of Service (QoS)
  - Service classes, Access Control / Access Selection [8,9]
  - Topology Control, Routing, Relay Placement [11,12,13]
  - Delay Tolerance [17]
- Handover / Handoff
  - Optimal Network Selection [4]
  - Mobility Management [1,2]
- Other popular research areas that will not be covered in this talk
  - Security, Multichannel / Multi radio, non-QoS routing …

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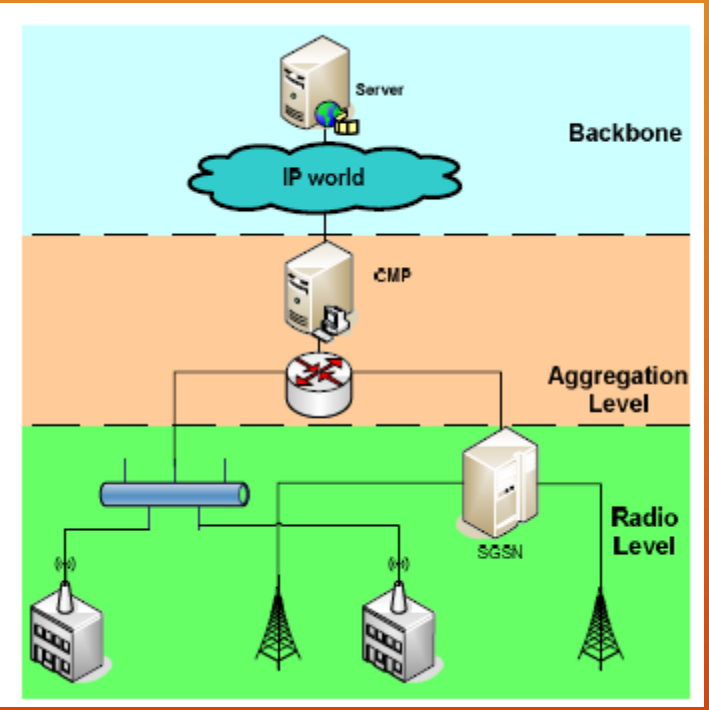
Open Research Problem: Radio Resource Management

- Limited bandwidth in wireless networks
- Broadcast medium creates problems such as hidden and exposed terminal
  - Contribute to poor multi-hop wireless performance
- Mobile devices extremely limited in resources (power, cpu, memory)
- Manage the Resources in the network while keeping in mind QoS
  - In HWN, the major unique problem is vertical handover
  - In other networks, Resource Management & QOS studied extensively (WLAN, WMN, adhoc etc)

Open Research Problems: Radio Resource Management

- Resource Scheduling [16]
  - Managing Time, Space in Queues, Frequency etc.
- Power Control, Rate Control [7], Access Control [8,9]
  - Avoid interference, minimize power consumption
  - Prevent buffer overflows, avoid bottlenecks
  - Avoid admitting more users than can be supported
- Prefetching, Caching [13,14]
  - Avoid requests from the original source on the Internet by temporarily storing at some level in the hetero network
- Cognitive / Software Defined Radio

Open Research Problems: Radio Resource Management



Source: Goebbels [14], ex) of caching archtiecture

Open Research Problems: Quality of Service (QoS)

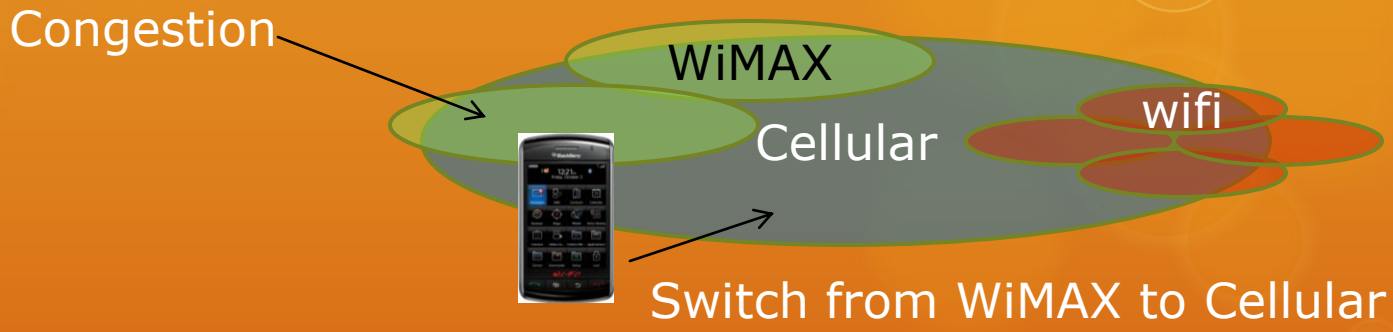
- Provide some guarantee of service level, support for particular applications (multimedia, voice, web, email etc)
- Service classes, Access Control / Access Selection [8,9]
  - Each service class has different priority
  - Access is controlled by whether there is capacity to admit based on priority classes
- Topology Control [11,12], Routing, Relay Placement [13]
  - QoS aware routing
  - Some research suggests relays increase capacity, thus increase QoS by adding more relays in strategic points
  - GW placement for optimal QoS
- Delay Tolerance [17]
  - Some applications have delay tolerance (email, download etc)
  - Some network types this becomes more important (long distance, or opportunistic networking)

Open Research Problems: Handover

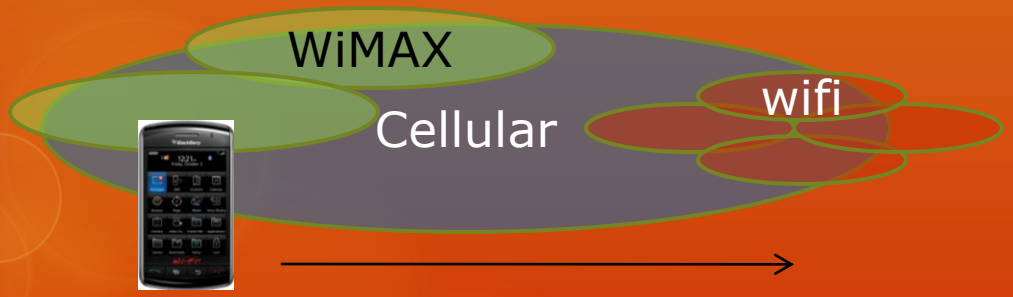
- Decide when to switch between technologies or between stations
- Optimal Network Selection [4]
  - Decide when to change networks while stationary (because of changing conditions)
  - Dense HWN, select the best network based on some criteria, ex):
    - Cost, Capacity, "user fairness", …
  - Sparse HWN, which network to forward through
- Mobility Management [1,2]
  - Deciding when to change networks while moving
  - Vertical Handover (between technologies or component networks) [9,1,2]
  - Horizontal Handover (within a technology or component network) (many existing works in cellular/mobile ,WMN etc

Handover

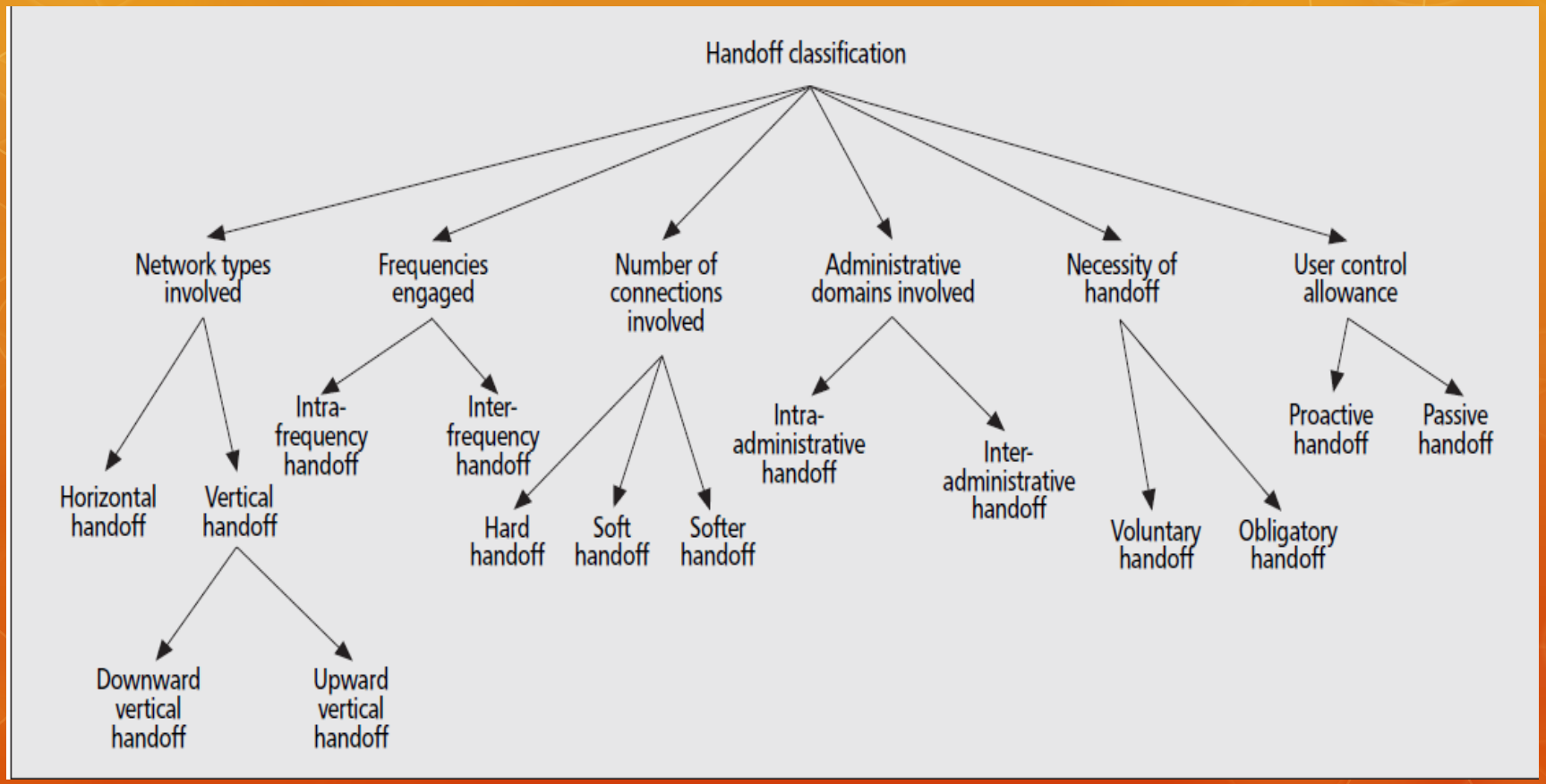
Optimal Network Selection



Mobility Management



Handover Types



Source: Nasser et al [2]

Handover

- Often formulated as an optimization problem
  - Cost / Reward function which determines whether a handoff should occur [3,4]
- Many solutions are adaptive and make use of "cognitive/software radio" techniques
  - (applying AI, certain types of optimization)
  - Traditionally used to determine if radios can venture into licensed bands when not in use

Limitations & Assumptions

- Some experiments make use of small networks, more research required to ensure the networks are scalable
  - [8] uses only three WLANs and two 3g networks
- Some proposals do not account for future technology, designed specifically to a set of existing technology
  - Not "future-proof"
  - Ex) assumption of ipv4
  - Ex) assume only 2 or 3 network types: 802.11, 802.16 etc.
    - [9] Assumes only 802.11 + 3G
- Many proposals for interoperability, little work in standardization [9]
- Existing work uses mostly simulation, it is recognized that experiments must be evaluated in test-beds and on real equipment when possible

Limitations & Assumptions

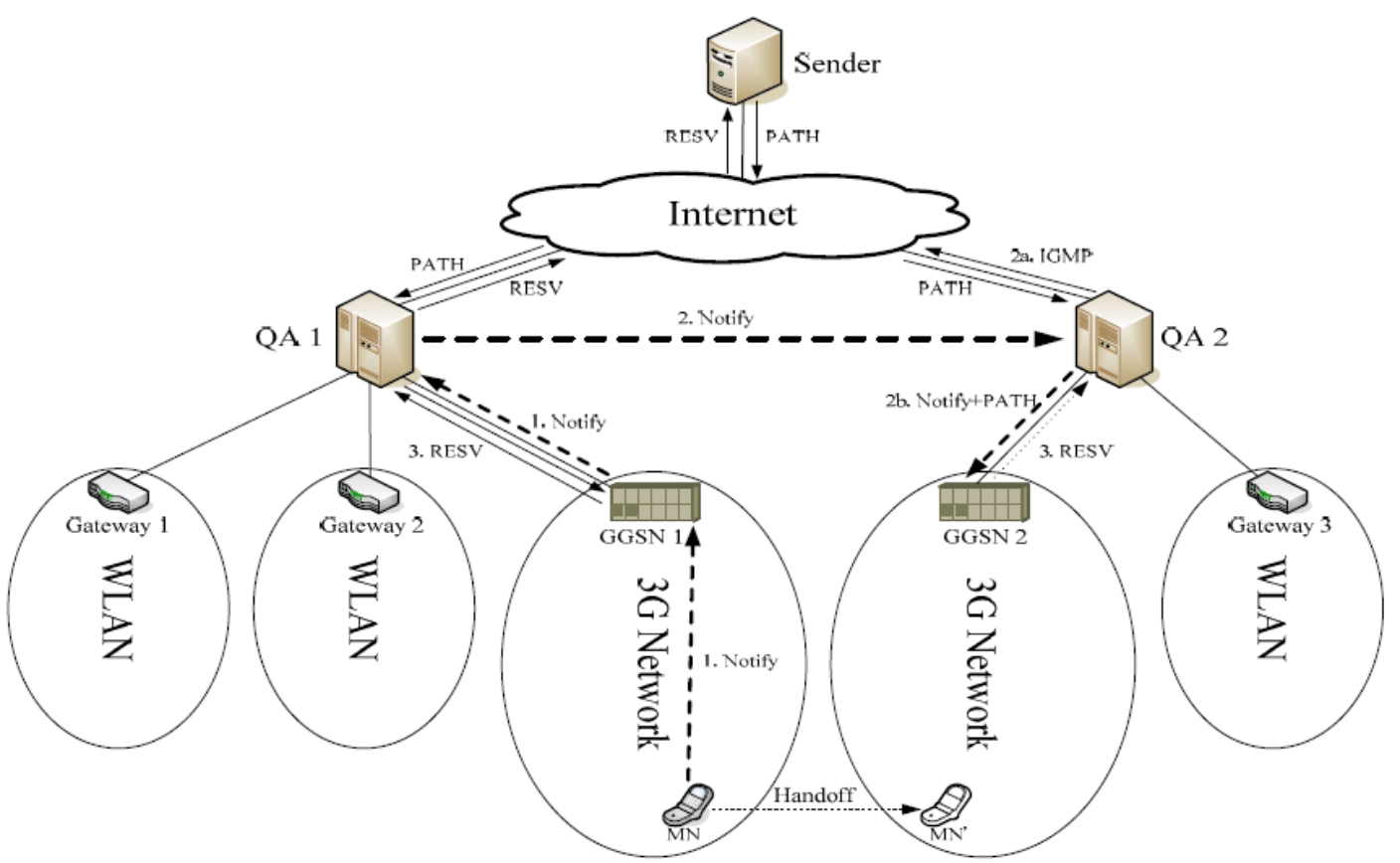


Fig. 5. Inter-site reservation setup procedure.

Source: Wang et al [8]

Future Work

- Investigate cross-layering [10] to help solve wireless problems since OSI model is not suited to wireless
  - ex) TRAMCAR cross layer architecture for HWN[1]
- Ensure any framework which is designed or used will be scalable, extensible and flexible to support future technologies
- Develop a business model or incentive program which motivates service providers to swap traffic in a manner similar to the Internet
- Many existing experimental work performed in simulation
  - extend to test-bed with equipment in PERWIN lab

Conclusions

- Broad overview of state of research in HWNs
  - Emphasis on Resource Management, QoS and Handover
- Two architectures discussed
- Existing approaches classified according to solution type
- Open Research Problems, Limitations

- Exciting active field with many applications

- Much to be done to fully realize potential of the technology

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Questions?

Thanks for listening

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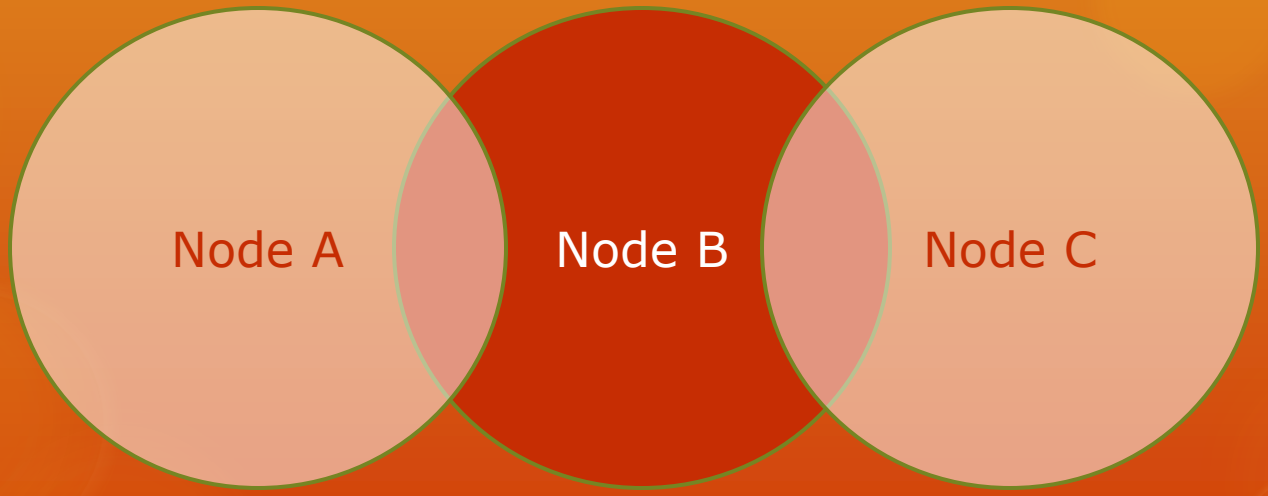
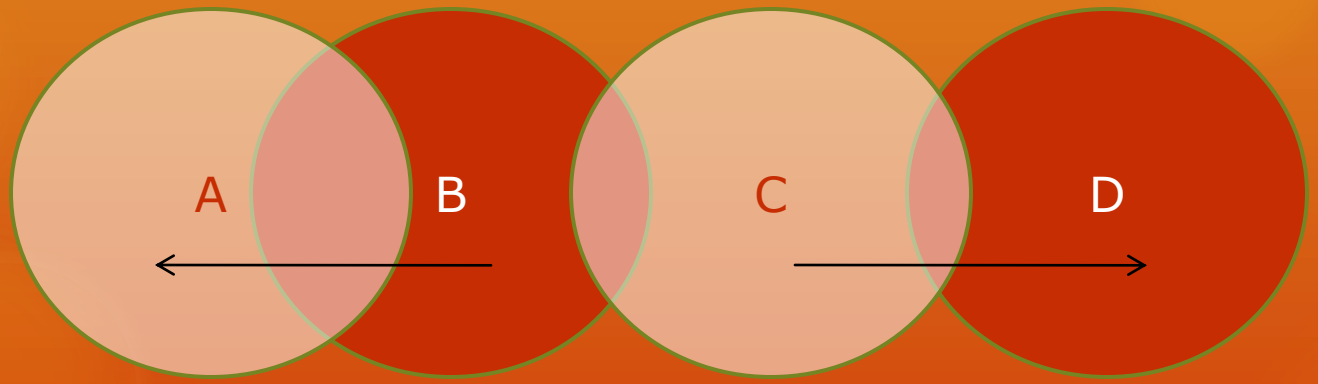
Hidden Terminal Problem



Both A and C can communicate with B but cannot detect each other leading to collisions at B, solved with RTS/CTS but introduces ET problem

Exposed Terminal Problem



B and C detect each other and fail to transmit even though A is out of range of C and D is out of range of A

Classification by Network Type

- Number and type of technologies involved
  - Ex) 802.11, 3g [9]
- Number of layers / tiers involved (the highest number of overlapping coverage technologies)
  - 2 Layer [9]
  - 3 Layer
  - 4 Layer …
- Sparse or dense (whether overlap is supported or not)
  - Majority of current work is in dense HWN

Classification by Objective

- Increasing performance (packet delivery ratio, throughput, delay etc.)
- Increasing profit, or conversely decreasing cost (take into consideration cost of using particular networks within the hetero network)
- Increasing coverage or capacity (solutions which use multiple access technologies to increase service)