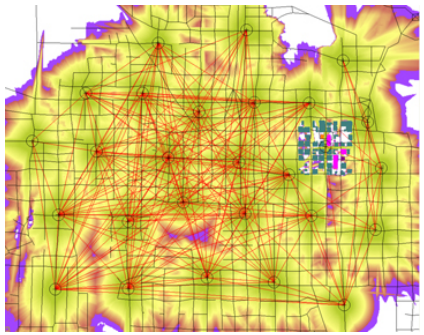

Introduction to Wireless Mesh Networks

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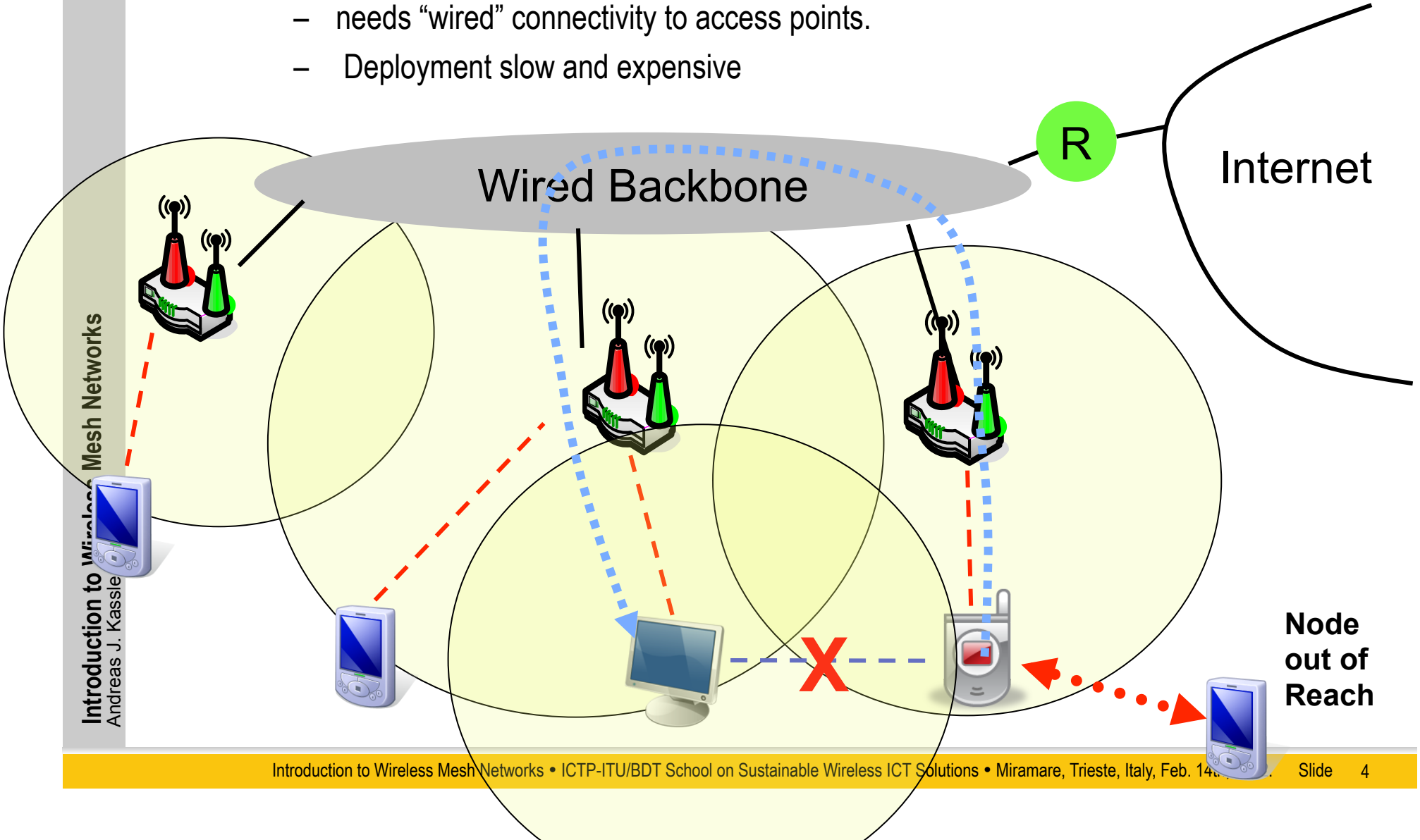
- Wireless Mesh Networks
  - Introduction
  - Routing
  - Channel Assignment Schemes
  - Testbeds
  - Conclusion

- Wireless Mesh Networks
  - Introduction
  - Routing
  - Channel Assignment Schemes
  - Testbeds
  - Conclusion

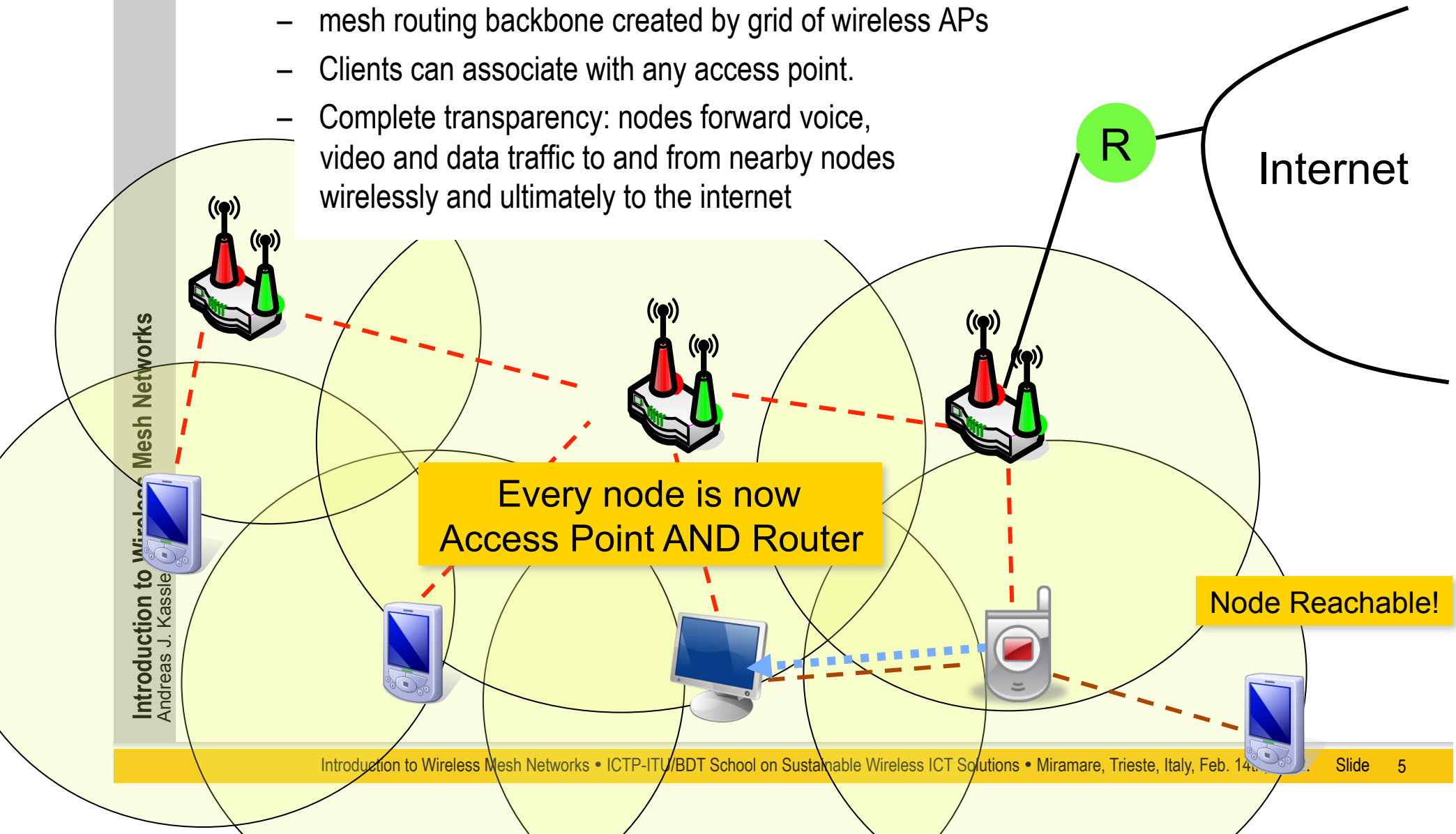
Principles of W-LAN meshes
Current Wireless Networks

- Infrastructure-based
  - needs “wired” connectivity to access points.
  - Deployment slow and expensive



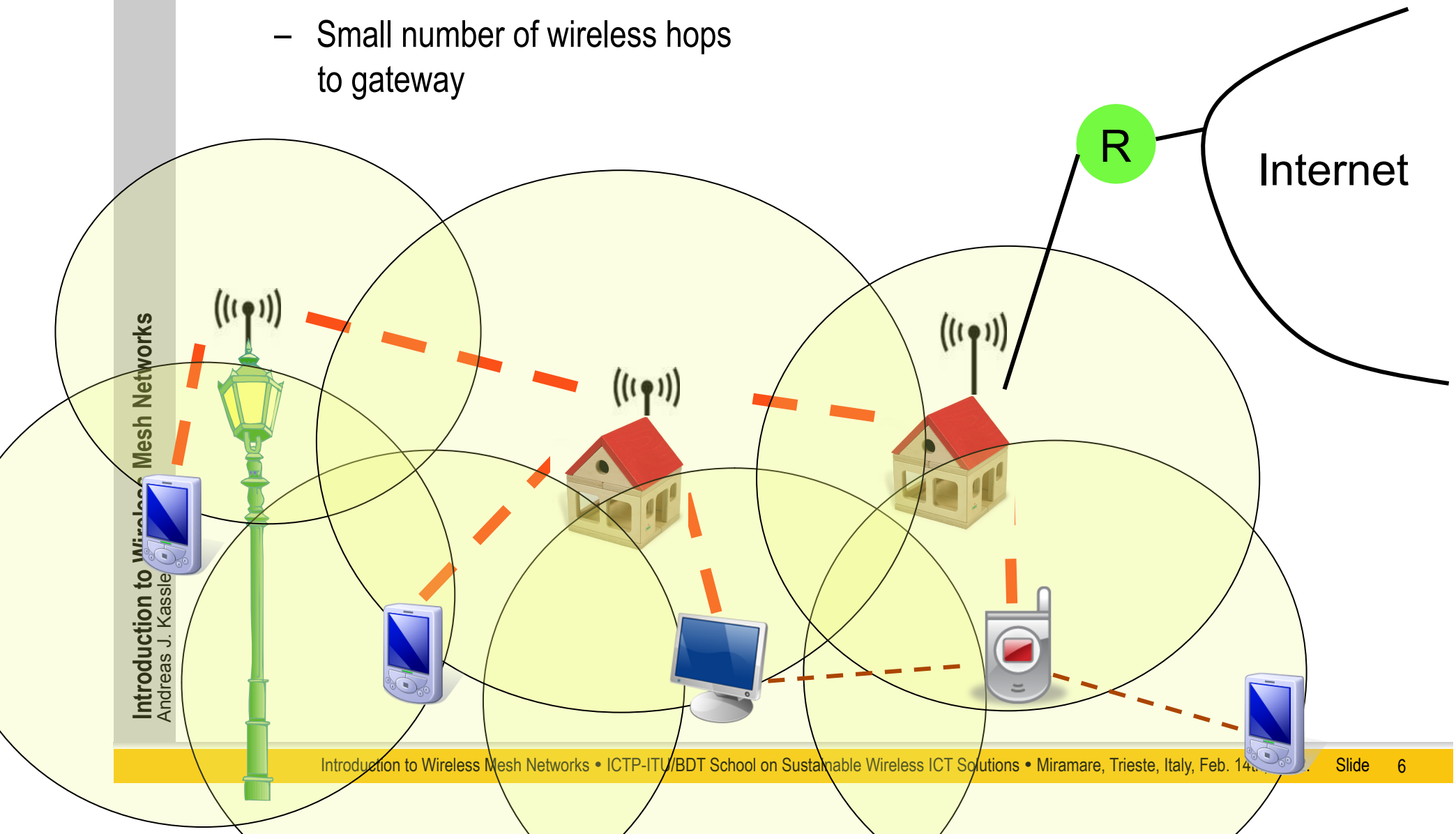
Principles of W-LAN meshes
Multi-Hop Wireless Networks

- Get rid of the wires!
  - mesh routing backbone created by grid of wireless APs
  - Clients can associate with any access point.
  - Complete transparency: nodes forward voice, video and data traffic to and from nearby nodes wirelessly and ultimately to the internet

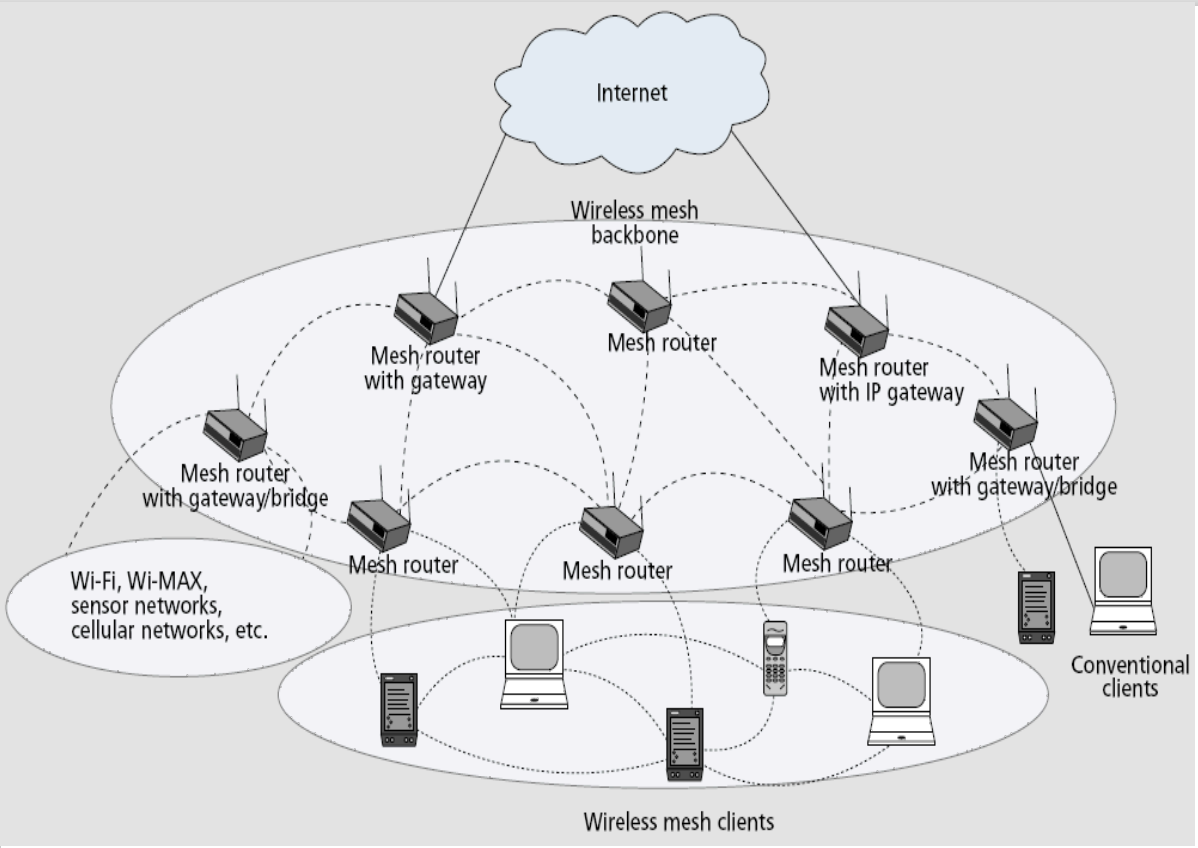


Principles of W-LAN meshes
Multi-Hop Wireless Networks

- Wireless mesh networks
  - Small number of wireless hops to gateway



Principles of W-LAN meshes
Multi-Hop Wireless Networks

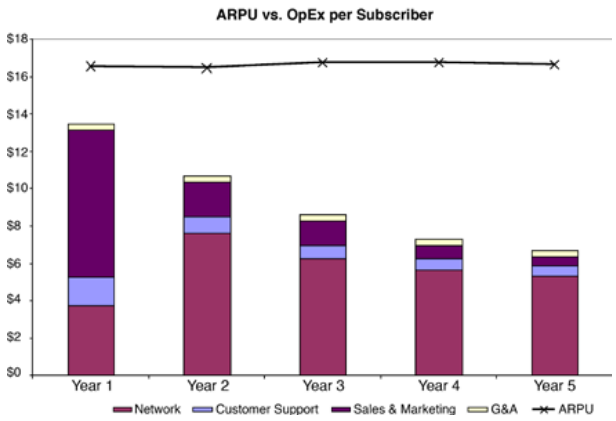


- Why interesting and study?
  - No Wires!
  - Properties:
    - Robust & Fault tolerant
    - Self-organising
    - Self-configuring
    - Self-healing
    - No centralized management

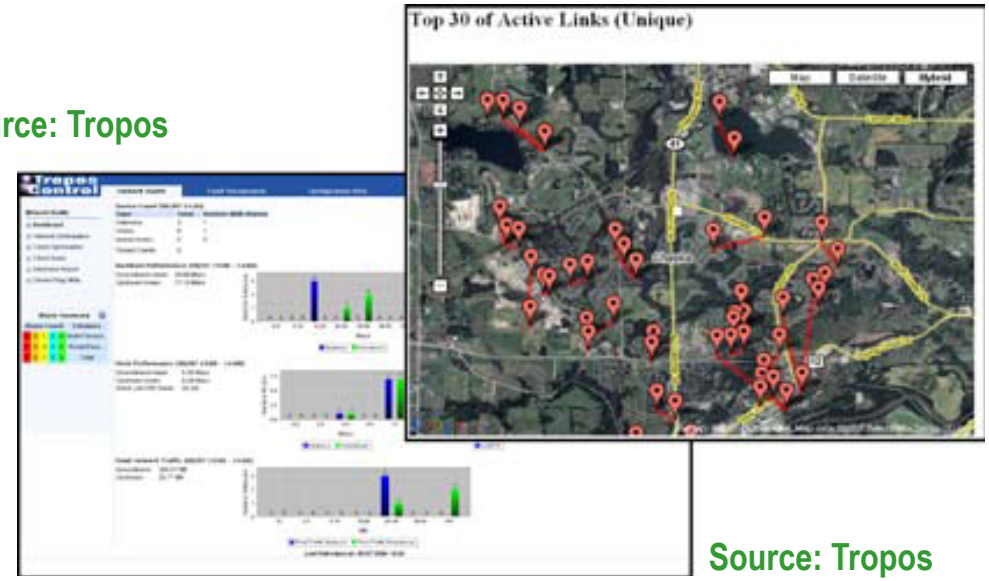
A WMN is dynamically self-organized and self-configured, with the nodes in the network automatically establishing and maintaining mesh connectivity among themselves

- Metropolitan scale mesh networks → chaska.net
  - City of Chaska (8000 homes, 23.000 residents)
    → 28% uptake after 2 years
  - Nomadic broadband service for $17.99 per month
  - Based on Tropos mesh products
    - $600,000 infrastructure plus 2 month deployment
    - 365 mesh routers → 95% coverage
    - 60 backhaul links

Source: Tropos



Source: Tropos



Source: Tropos

Introduction into Wireless Mesh Networks
WiFi Mesh for Developing Areas

- Extend Internet access into areas which do not have wired networking infrastructure.
- Reduced Infrastructure cost
- Typically semi-infrastructured backbone network (Mesh)
- Long distance links can be common
- Cheap, Off-the-shelf hardware
- Mission to support both social & economic development
- Useful for developing areas

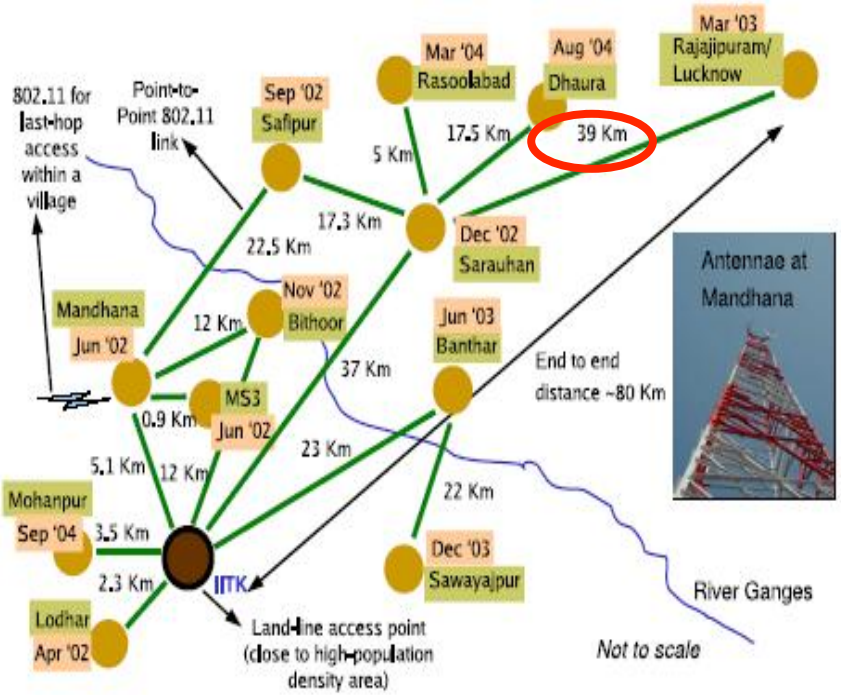
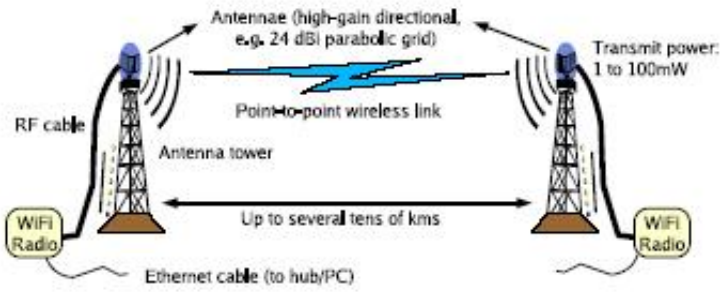


Figure 1. The Digital Gangetic Plains testbed



Challenges of W-LAN meshes
An Early Multi-Hop Wireless Network

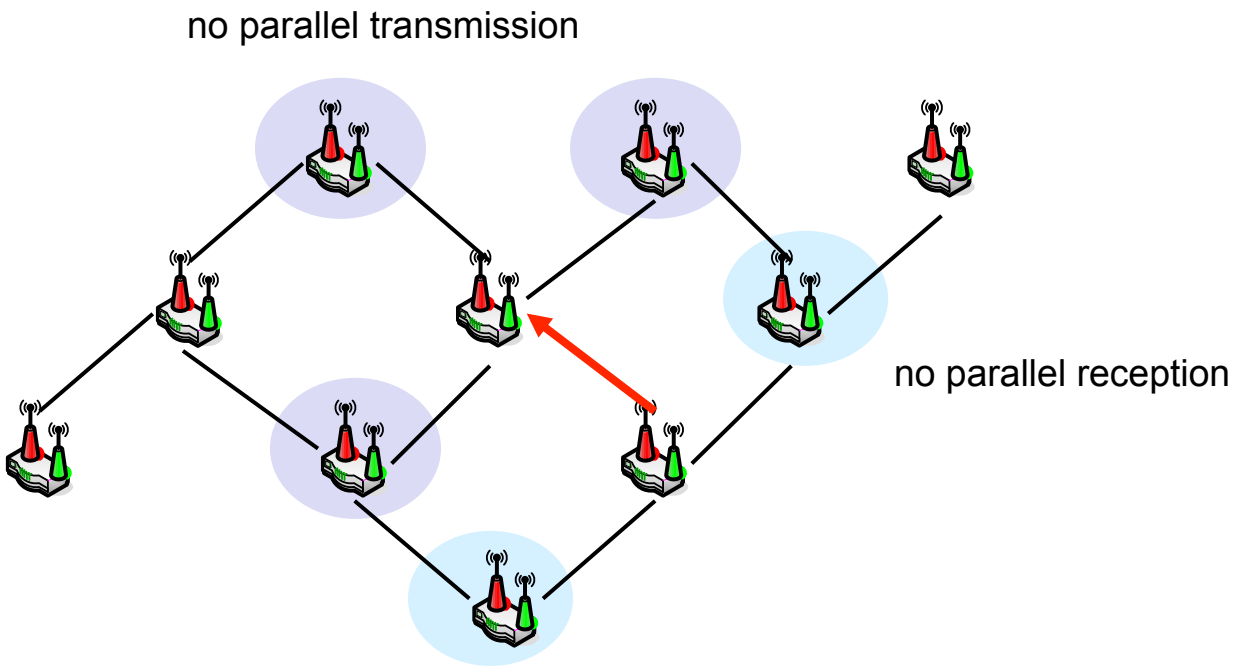
What Challenges can we identify?

Challenges of W-LAN meshes
Channel Access

- Wired networking protocols such as Ethernet perform poorly when used in wireless communication

Why? Because of media dependent differences

- You Should know:
  - Hidden terminal problem
  - Exposed terminal problem
  - Collision detection problem
  - Interference problem
  - MAC layer/Routing in MANET



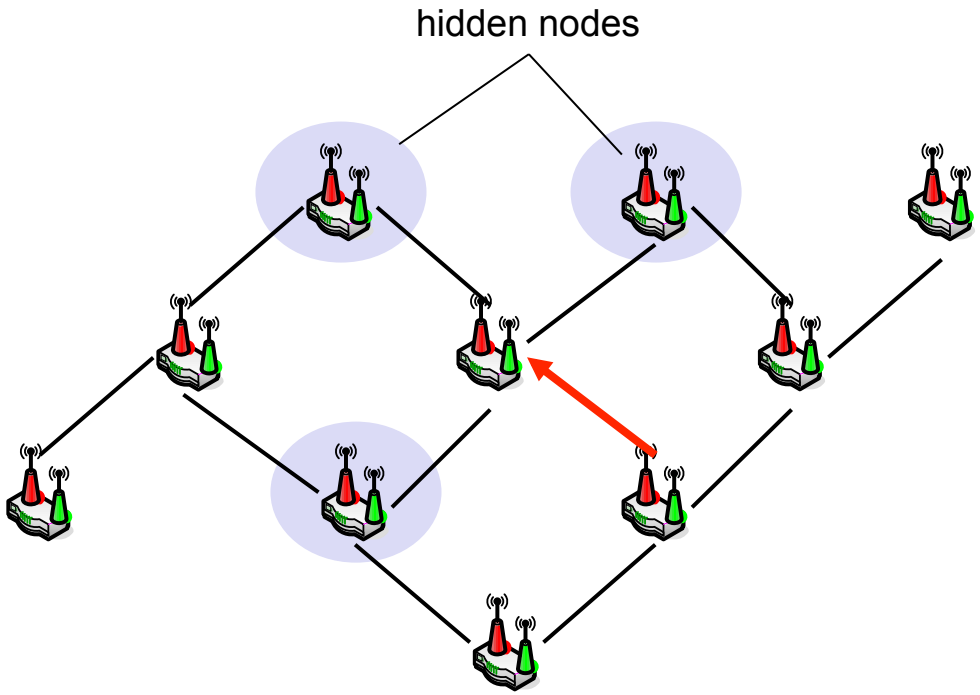
Goal for MAC layer design:

- avoid parallel interfering transmissions
- do not hinder parallel non-interfering transmissions

Hidden Node Problem

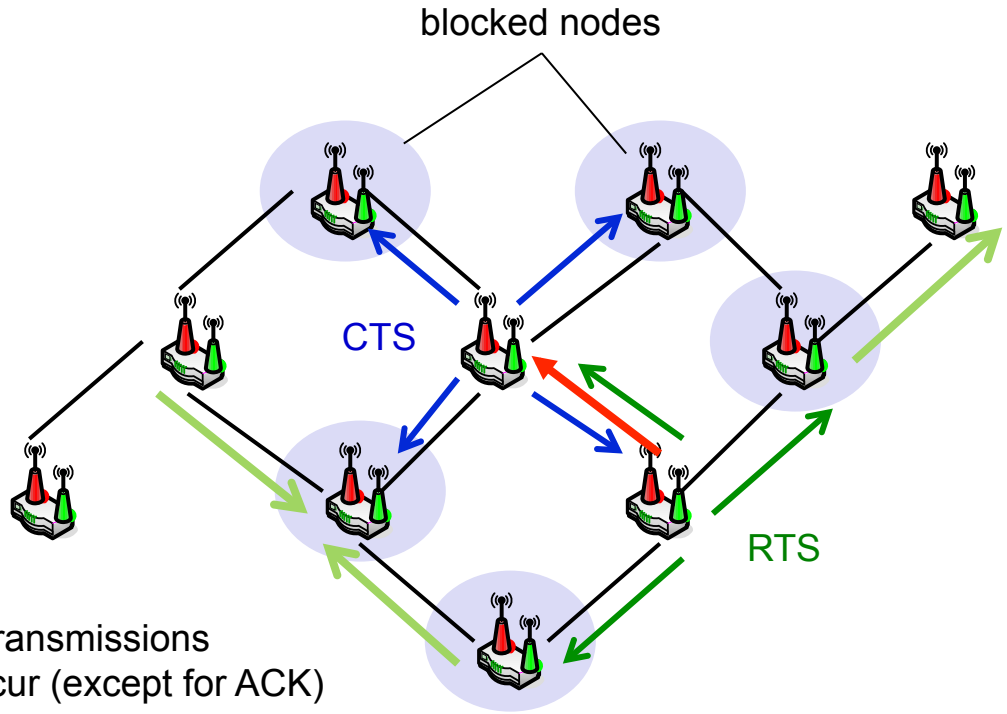
- Hidden Node Problem
  - A mesh node is hidden for an ongoing transmission if it is not able to sense the ongoing transmission but its transmission would disturb the reception.
  - A node not in the sensing range of the transmitter but within the interference range of the receiver

- HN-induced problems
  - Throughput degradation
  - Unfairness



MAC Layer
Exposed Node Problem

- disabling of possible non-interfering parallel transmissions
- nodes that only receive RTS can transmit
- nodes that only receive CTS can receive



Parallel transmissions
might occur (except for ACK)

Challenges of W-LAN meshes
How to detect Collisions?

- No collision detection in wireless communications
- In wireless can't listen while you send
  - Generally hardware is not flexible enough
  - All you hear is your own signal
    - Your own signal at your antenna is much stronger than anyone else's signal
    - The power law

$$P_r = P_t \left(\frac{d_o}{d_r} \right)^n$$

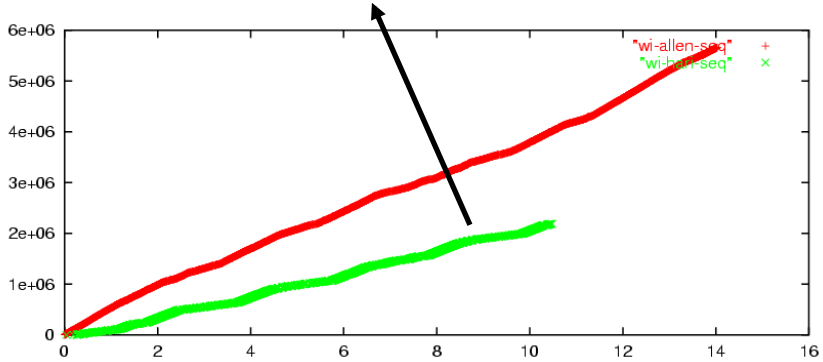
- Consequently,
  - wireless can't do collision detect like Ethernet

Challenges of W-LAN meshes
Spectrum Usage

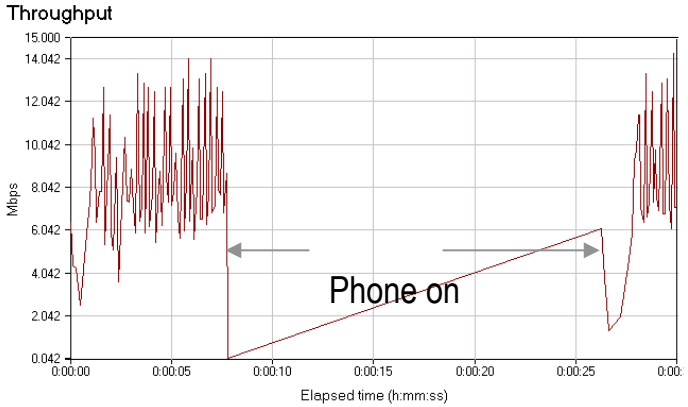
- WLANs operate in the following unlicensed bands (US)
  - 2400 – 2483.5 MHz (2.4 GHz),
  - 5150 – 5250 MHz (lower U-NII),
  - 5250 – 5350 MHz (mid U-NII), and
  - 5725 – 5825 MHz (upper U-NII)
- interference can happen based on, licensed services, other unlicensed devices, ISM equipment, and incidental radiators
- IEEE Standards operating in these bands include:
  - 802.11{b,g} in the 2.4 GHz band; 802.11a in the U-NII band
  - 802.15 WPAN (Bluetooth) in the 2.4 GHz band
  - 802.16 WirelessHUMAN in the mid and upper U-NII bands
- Other devices that also use these bands:
  - Field disturbance sensors, cordless telephones, low power devices, and microwave ovens
  - Non-802.11 Part 15 devices: cordless telephones, A/V repeaters, security cameras, baby monitors, & digital data links
- Licensed services that operate in these bands include:
  - Amateur radio in the 2.4 GHz and upper U-NII bands; fixed microwave in the 2.4 GHz band; and satellite in the lower U-NII band

Challenges of W-LAN meshes
Interference Problem

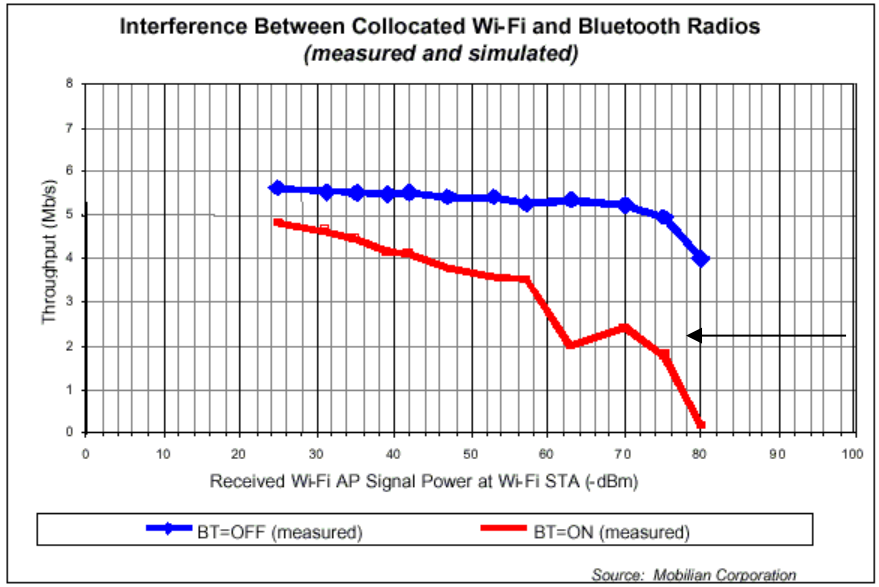
802.11 in presence of BT



TCP download from a 802.11 AP

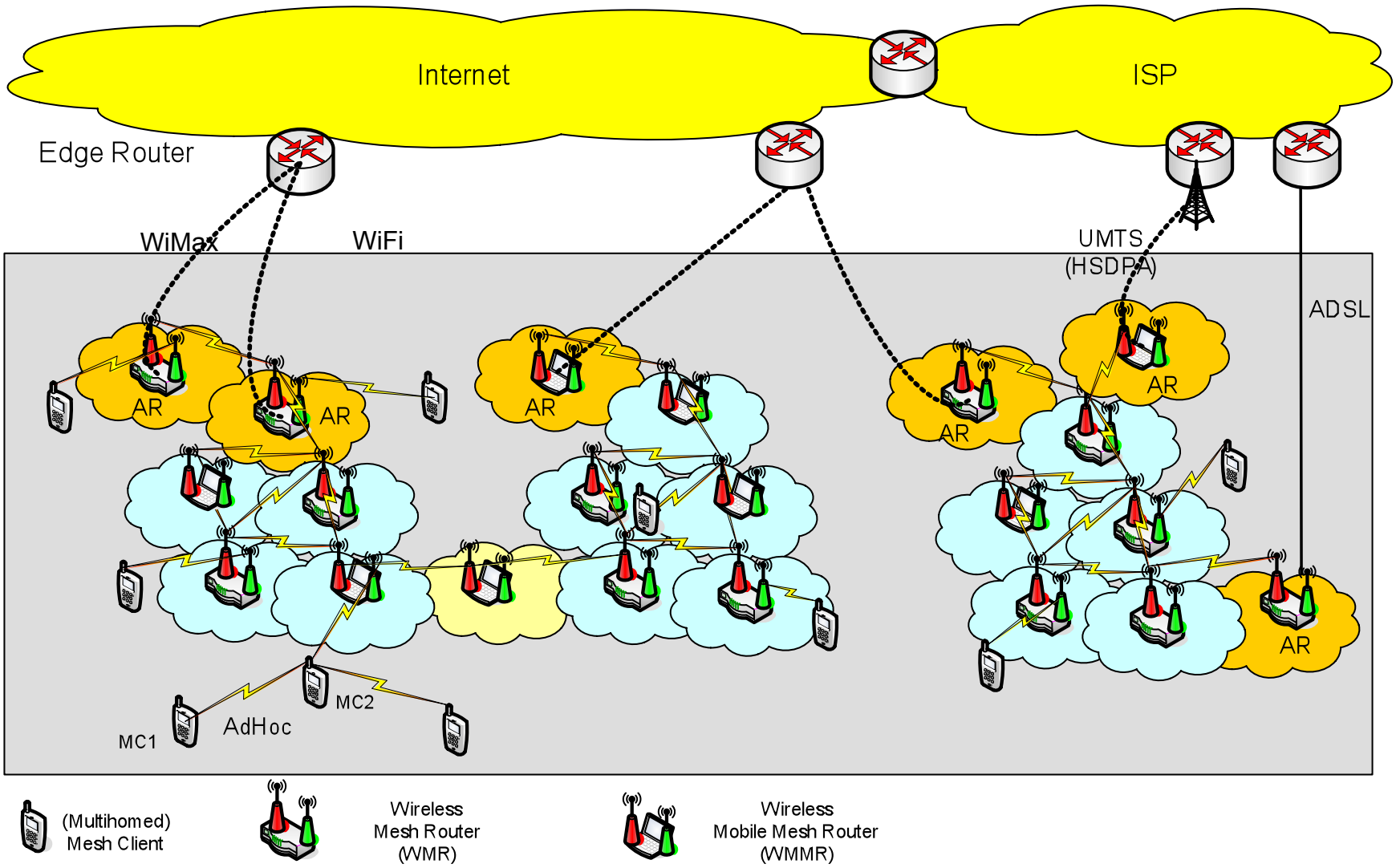


Panasonic 2.4GHz Spread Spectrum
Phone 5 m and 1 wall from receiver



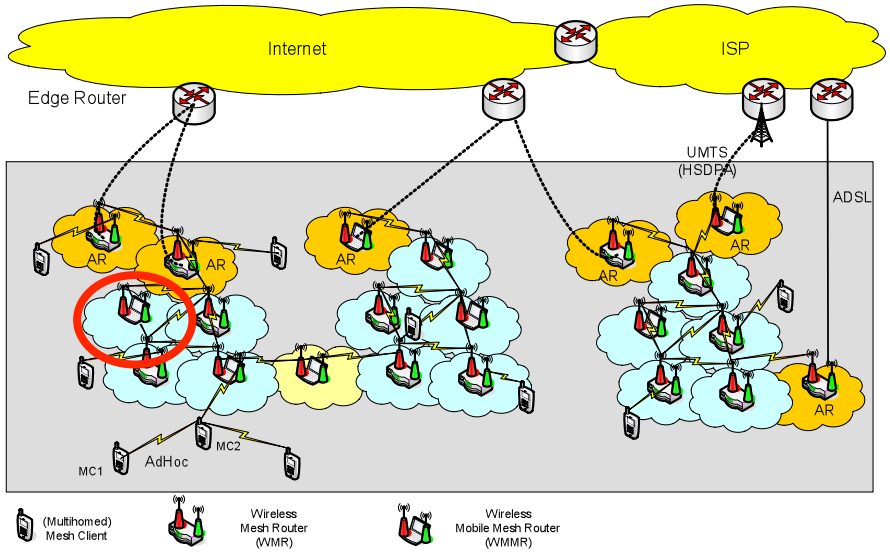
Performance worsens when there are large number of short-range radios in the vicinity

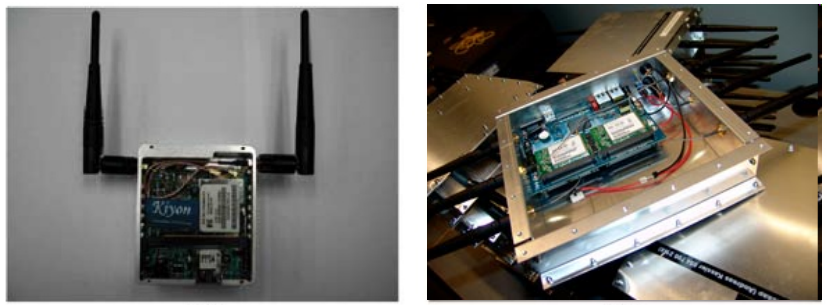
Terminology and Classification
Multi-Hop Wireless Networks



Terminology and Classification
Mesh Routers – Mesh Relay Nodes (MRN)

- At least one wireless interface.
  - Typically two
    - backbone mesh formation (Ad Hoc)
    - client access (Infrastructure)
  - Can have multiple (wireless) access technologies (e.g. WLAN and Cellular)
- Mobility
  - Stationary (e.g. rooftop)
  - Mobile (e.g., airplane, busses/subway).
- Provide coverage (acts as a mini-cell-tower) by establishing the mesh connectivity
- Contains routing logic for mesh connectivity
- Many needed for wide areas, hence, cost can be an issue.



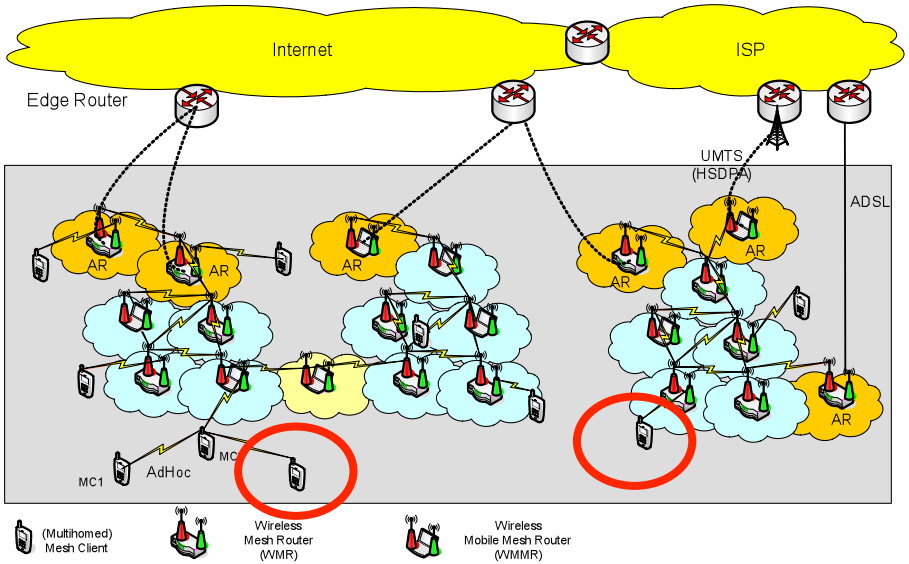


(a) (b)

(a) PowerPC and (b) Advanced Risc Machines (ARM)

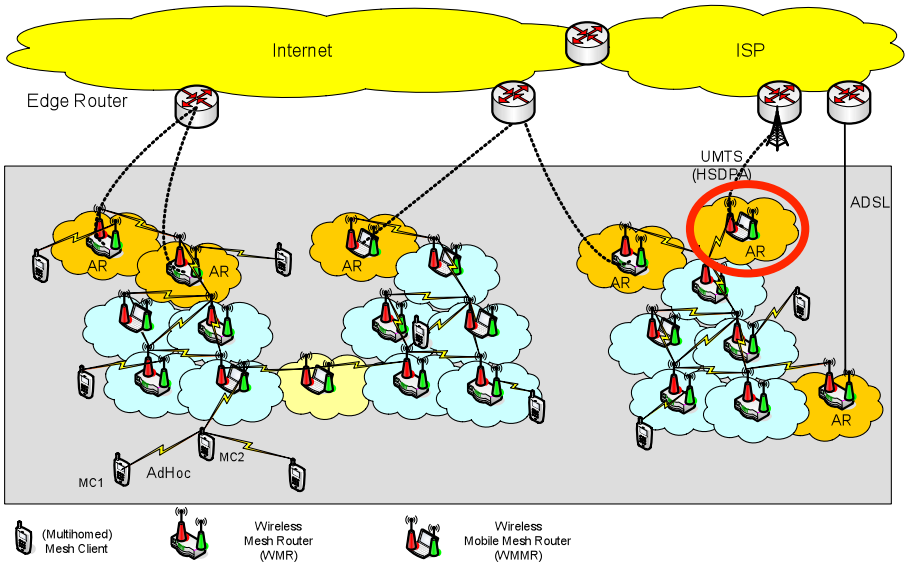
Terminology and Classification
Mesh Clients

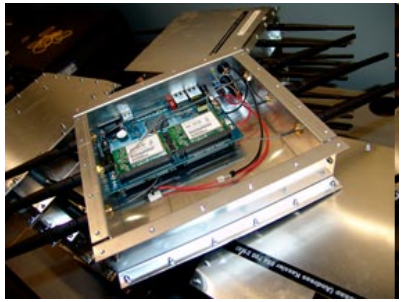
- Typically one interface.
  - Laptops
  - PDAs
  - MobilePhones
  - ...
- Mobility
  - Stationary
  - Mobile
- Can connect directly to the mesh network through mesh routers (or directly to gateways) through
  - Wireless (direct or via Ad-Hoc) or
  - Wired



Terminology and Classification
Access Routers (AR) and Gateways

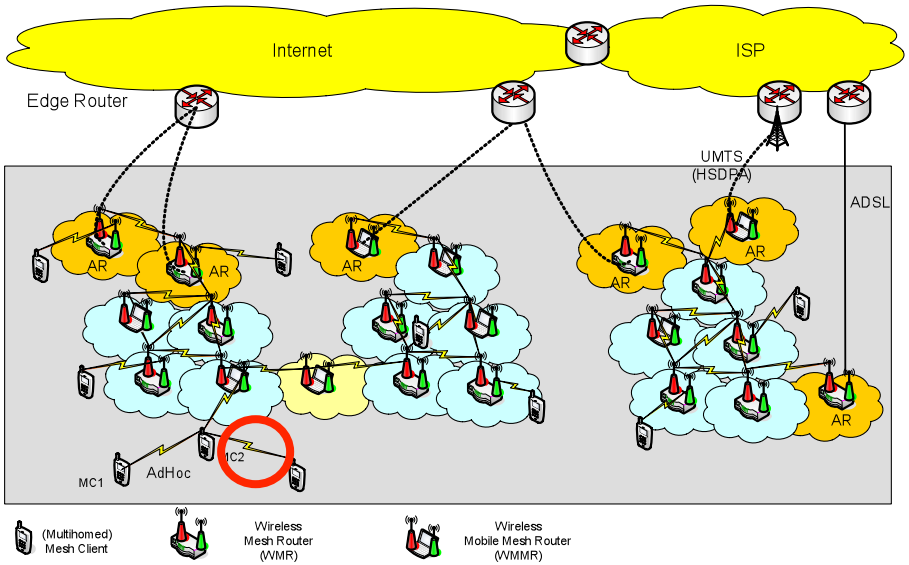
- Multiple interfaces (wired & wireless)
- Mobility
  - Stationary (e.g. rooftop) – most common case
  - Mobile (e.g., airplane, busses/ subway) → NEMO
- Serve as (multi-hop) "access points" to user nodes
- Relatively few are needed
- Integrate WMNs with various existing wireless networks such as
  - Cellular
  - Wireless sensor
  - WiMax





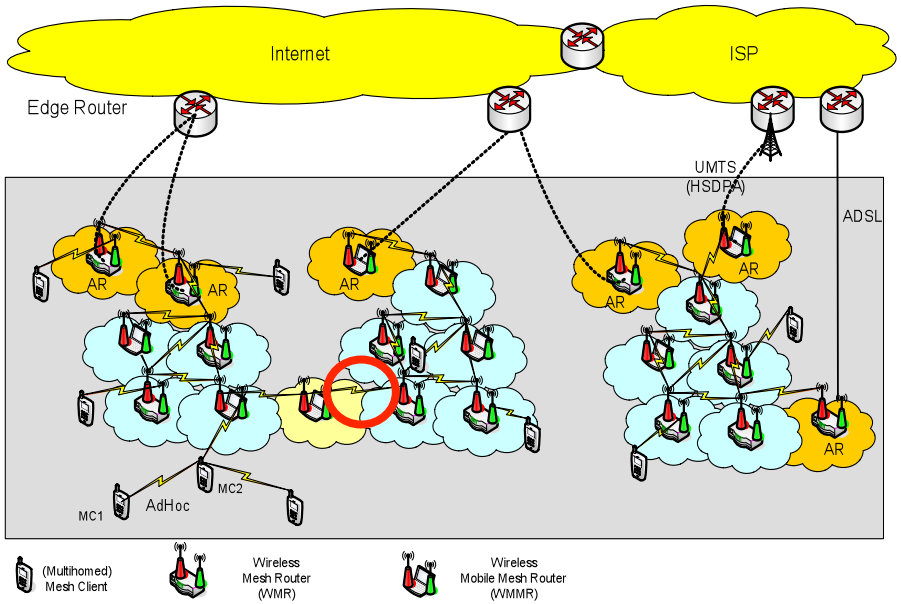
Terminology and Classification
User – Mesh Router Links

- Wired
  - Bus (PCI, PCMCIA, USB)
  - Ethernet, Firewire, etc.
- Wireless
  - 802.11x
  - 802.16
  - Bluetooth
  - Proprietary
- Point-to-Point or Point-to-Multipoint
- If properly designed is not a bottleneck.



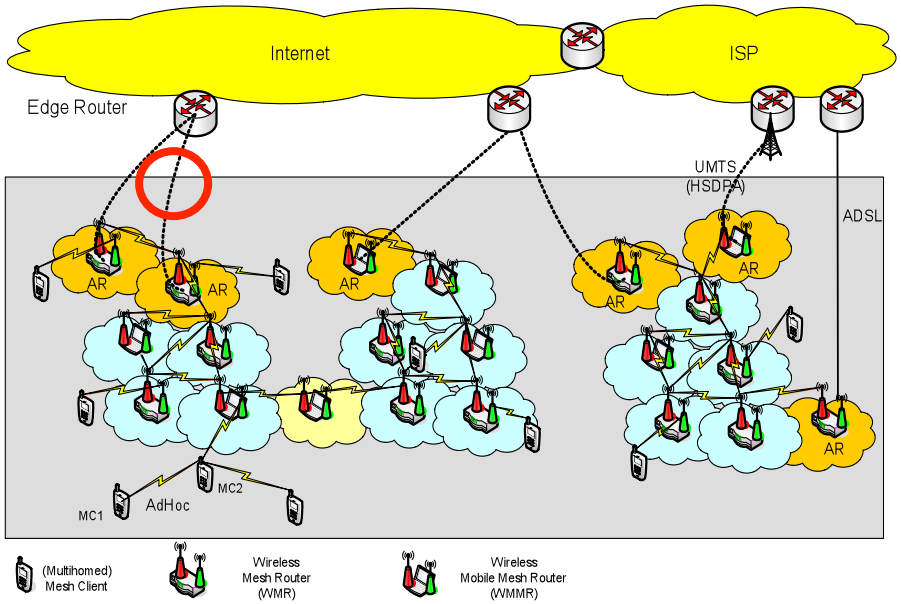
Terminology and Classification
Router to Router Links

- Wireless
  - 802.11x
  - 802.16
  - Proprietary
- Usually multipoint to multipoint
  - Sometimes a collection of point to point
- Often the bottleneck
- Also called backhaul links



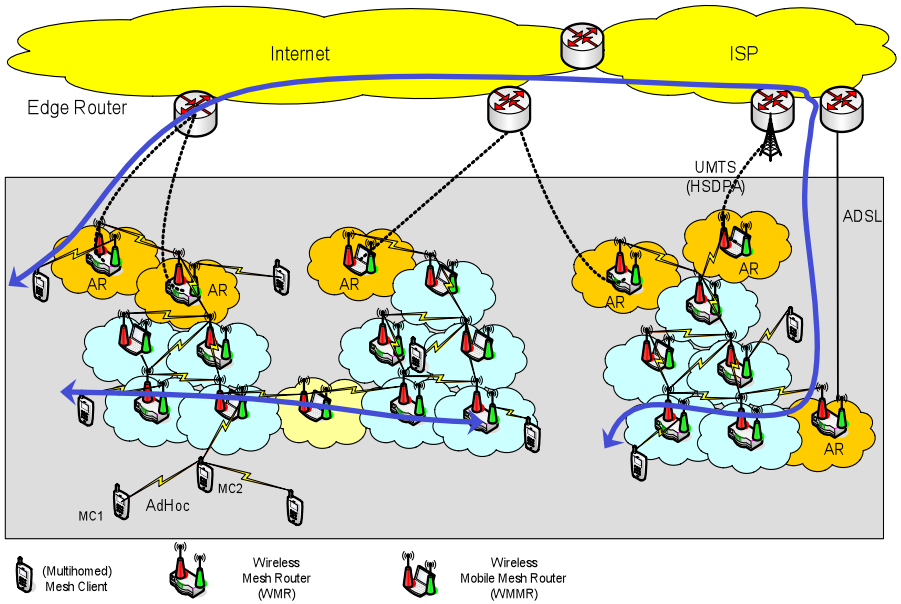
Terminology
Gateway to Internet Links

- Wired
  - Ethernet, TV Cable, Power Lines
- Wireless
  - 802.16 (again meshed possible)
  - Proprietary
- Point to Point or Point-to-Multipoint
- Also called backhaul links
- If properly designed, not the bottleneck

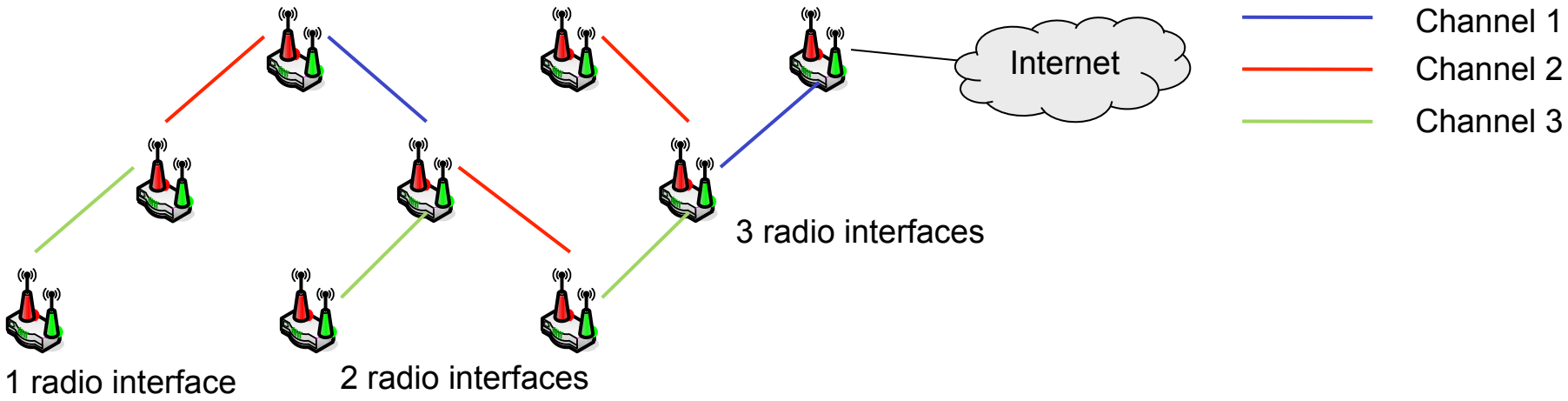


Terminology
Data Transmission

- User-Internet Data Flows
  - In most applications the main data flows
- User-User Data Flows
  - In most applications a small percentage of data flows



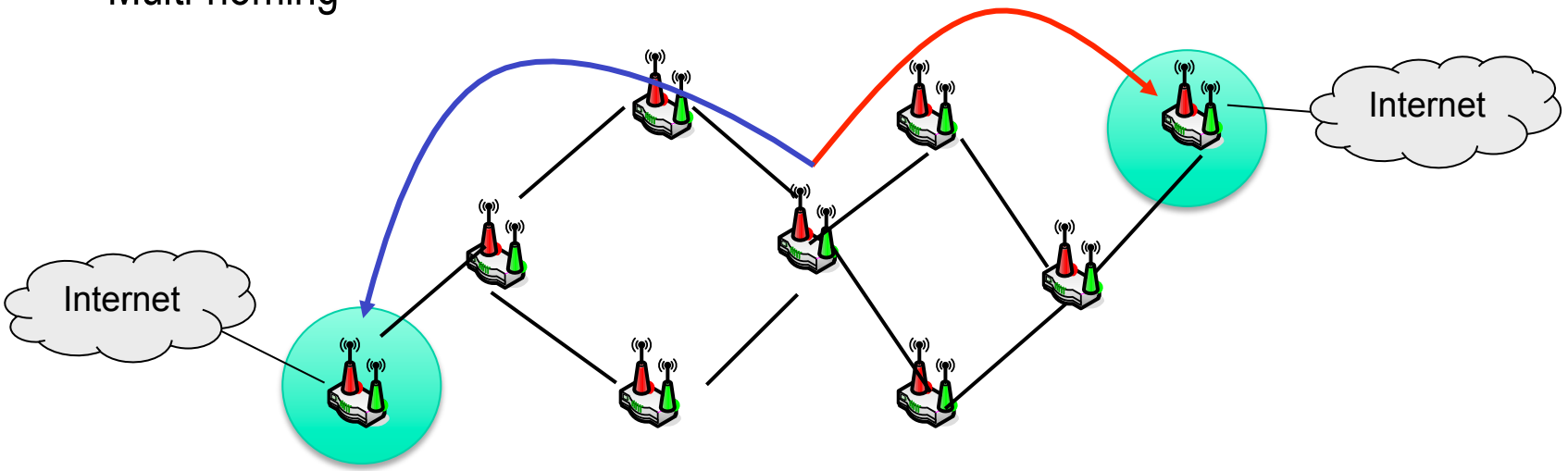
Terminology and Classification
Multi-channel Multi-Radio WMNs



- Multi-channel wireless mesh networks:
  - in the context of 802.11: WMN utilizes transmissions on several typically non-overlapping 20MHz channels in the 2.4GHz band or 5GHz band
  - in a general context multi-frequency mesh networks
- Multi-radio wireless mesh networks:
  - mesh network where some of the nodes have multiple (at least two) radio interfaces which might be used independently
- Typical scenario:
  - backbone: 802.11a (5GHz) client connectivity: 802.11b/g (2.4 GHz)

Terminology and Classification
Multi-Gateway WMNs

- Wireless mesh networks with multiple gateways to the Internet
  - keep routes to the Internet short (few hops)
  - increase access capacity
- Problems:
  - Gateway detection
  - Routing
  - Multi-homing

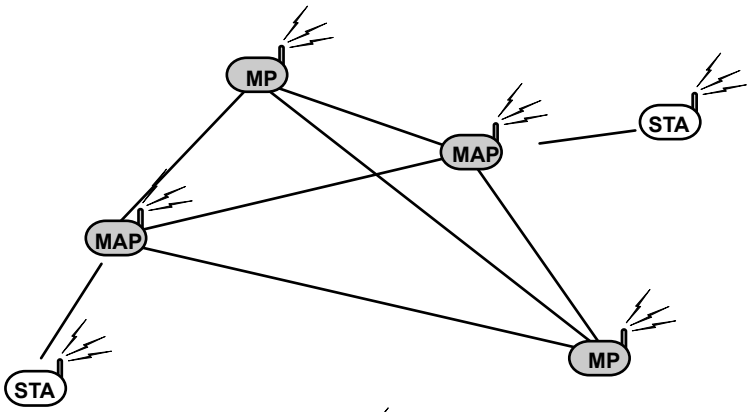


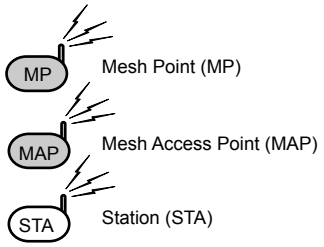
Standardization
IEEE 802.11

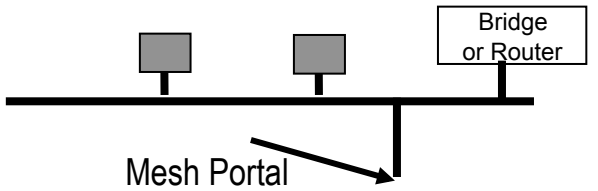
- IEEE 802.11a,b,g
  - standards for Basic Service Set (BSS), i.e. Access Point plus clients
  - can be used for establishing mesh networks
  - no cooperation on MAC layer
  - independent routing or bridging protocol
- IEEE 802.11s
  - mesh standard with own terminology (converged solution as of march 2006)
  - flexibility to define protocols / mechanisms and scenario-specific optimizations
  - Allows future extensions
  - supports both single-radio and multi-radio platforms.
  - enhanced MAC layer based in EDCA (IEEE 802.11e)
  - MAC layer routing
  - Security based on 802.11i link security, support for distributed and centralized authentication
  - interworking

Standardization
IEEE 802.11s Terminology

- Mesh Point (MP):
  - establishes links with other MP neighbors, full participant in WLAN Mesh services
- Mesh AP (MAP):
  - MP, plus provides BSS services to support communication with STAs
- Mesh Portal (MPP):
  - point at which MSDUs exit and enter a WLAN Mesh
- Station (STA):
  - outside of the WLAN Mesh, connected via Mesh AP (no new BSS functionality specified)





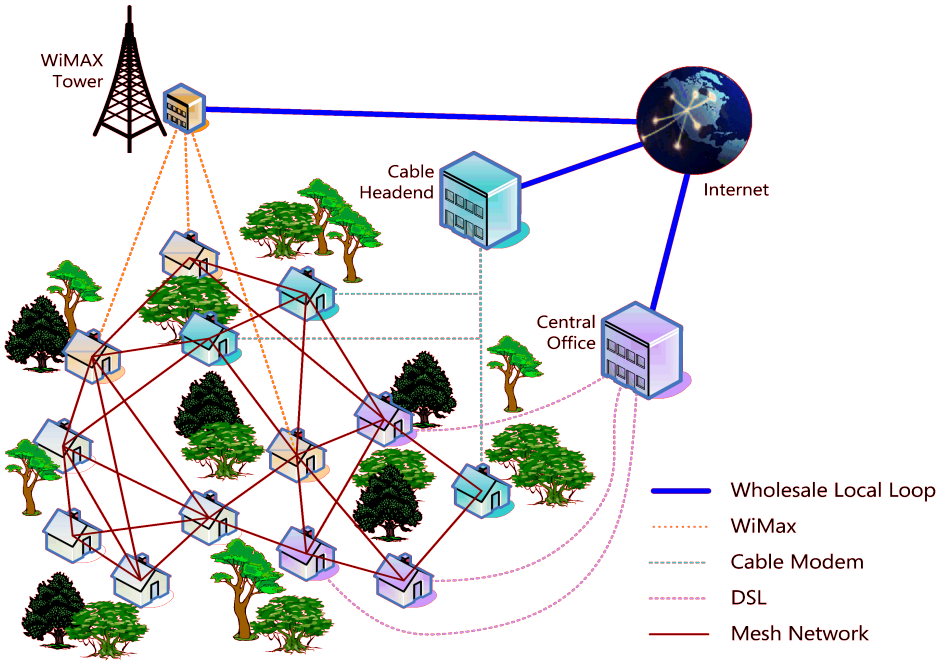


Standardization
WiMax based Meshes

- IEEE 802.16-2004 for developing area/rural use
  - defines point-to-multipoint and mesh mode
  - MAC and OFDM256 Physical Layer
  - explicit resource reservation
  - *not certified by WiMAX Forum, no further development*
  - Needs market momentum to be more efficient in terms of size, power, performance and cost
- IEEE 802.16j – Multihop Relay Specification
  - working group on multi-hop relay specification, draft standard exists
  - more relay than mesh
    - tree structure
    - less self-configuration
- Characteristics
  - WiMAX requires high-power towers or lots of towers: (→ cost goes up) in low density deployments
  - In NLOS environments, reduced modulation leads to low datarate availability
  - WiMAX cards still expensive but going to be included in Intel Wireless chips

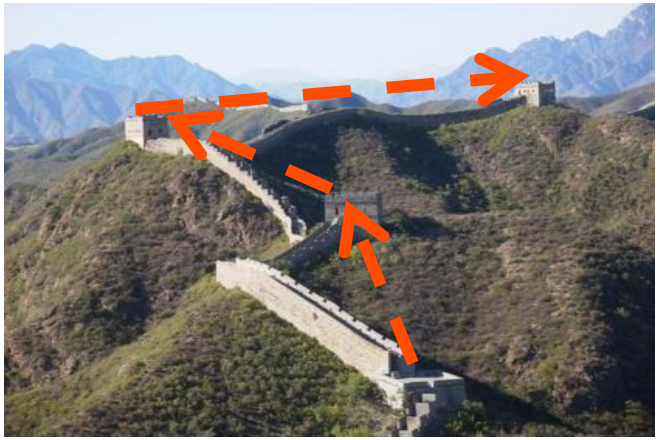
Standardization
Multi-Technology WMNs

- WiMAX can be a good solution as Mesh Backhaul
  - Multi-hop WLAN meshes to reach WiMAX tower or SS
  - WLAN Mesh greatly reduces equipment cost
  - WLAN Mesh can be very robust due to spatial diversity
- Wireless mesh networks built on mesh links from multiple technologies
  - IEEE 802.11 and 802.16
  - IEEE 802.11a and IEEE 802.11b/g



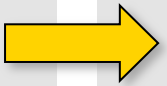
Key Research Issues and Challenges
Main Mesh Functionality

- Medium access control
  - data transmission/scheduling
  - buffering and forwarding
- Routing
  - find path to destination/gateway, optimize path
  - coordination with MAC-Layer (cross layer design)
- QoS and Ressource Management
- Capacity Increase
  - Multiple Channels Multiple Radios
  - Topology Control
- Network entry
  - neighbor detection
  - gateway detection
  - network association



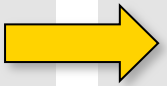
Summary and Overview
Mesh vs. MANETS vs. Sensor

- MANET
  - Mobility of nodes
  - No infrastructure available
  - Ad-hoc peer to peer communication



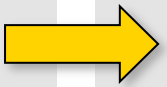
- Objectives
  - Provide Connectivity
  - Automatic operation
  - Cope with moiblity and link breaks

- Sensor Network
  - Mostly Fixed nodes
  - Battery operated
  - Sensor delivery data to portal



- Objectives
  - Minimize energy consumption
  - Cope with infrequent data transmissions

- Mesh Network
  - Fixed deployment
  - Combination of Ad-hoc and infrastructure links
  - Client to (client and gateway)
  - Medium to high node density/traffic



- Objectives
  - Maximize throughput
  - Minimize latency
  - Exploit available diversity (frequency, path, ...)
  - Cope with interference