Introduction on Mobile Wireless Networks

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Goal of this Lecture

- See each level of Mobile Wireless Networking
  - From hardware level to applications
- Understand key principles
- Have an interaction between us

It is not about

- How to administrate
- Infrastructure dimensioning

A small definition

A Mobile Wireless Network is an hardware and software infrastructure allowing to connect wirelessly IT elements.

A possible plan

- Introduction
- WiFi
- Ad Hoc systems
- Mesh Networks
- Security
- Network tools
- Peer to Peer
- Embedded programming
- Presentations... Your turn !

Comparison with Wired Network

Your opinion ?

Comparison with Wired Network

- **Mobility** User move but what they want to access cannot move with them.
- **Ease and speed of deployment** Wireless infrastructure is easier to deploy and manage. In certain place it is even impossible to deploy a wired infrastructure.

Comparison, cont

- **Flexibility** No wires means no re-wiring ! Wireless makes moving between offices a triviality. Extension is easy and most of the time not even necessary.
- **Cost** Infrastructure is cheaper as there are only a few wires necessary. It is even possible to make direct connexions between buildings.

Trade off

- Wireless networks allow remote operation
    - remote services
    - remote data operation
- In extreme case everything is done remotely, apart from interface
- It allows energy efficient systems that are really wire-free, and thus mobile

Expanding possibilities

Technology creator are always overwhelmed by their creature

- Facebook and Twitter *vs* wired network
- Which will be the killer app in wireless ?
    - Smartphone revolution ?
    - Intelligent houses ?

Unplug and Play

Moves adding an element from wires to only authorization

- Physical changes only if the structure is overloaded, so every 10ths of users

Allows Hot-Spots

- Coffee shops, Airports
- Only in hotels with wired networks

Allows network in historical buildings

Interoperability

Specialized systems

- Sensor networks : fire, temperature or intrusion detection
- RFID tags
- smart energy metering

Generic systems

- Computers
- Smart phones

Heterogeneous systems

Some systems are composed

- Bluetooth GPS receiver
- Zigbee smart meters
- X10 home element
- Custom badge detectors

Some standards exists depending on their scope

Standards

Only a part of the picture

- Wifi
- CellPhone 3G/GSM/...
- Bluetooth
- Zigbee
- Laser
- Satelite

Question: *What are their characteristics/usage ?*

Radio Spectrum

- Basic resource Radio frequencies
- Need some space
  - Mobile phone : 20KHz
  - Analog TV : 6MHz
- Under heavy regulation by national offices

US Radio Spectrum

Band	Frequency range
UHF ISM	902-928 MHz
S-Band	2-4 GHz
S-Band ISM	2.4-2.5 GHz
C-Band	4-8 GHz
C-Band satellite downlink	3.7-4.2 GHz
C-Band Radar (weather)	5.25-5.925 GHz
C-Band ISM	5.725-5.875 GHz
C-Band satellite uplink	5.925-6.425 GHz
X-Band	8-12 GHz
X-Band Radar (police/weather)	8.5-10.55 GHz
Ku-Band	12-18 GHz
Ku-Band Radar (police)	13.4-14 GHz and 15.7-17.7 GHz

Regulation

- To use a part of the spectrum it is necessary to have a license
- One important exception: S-Band ISM (Industrial, Scientific and Medical) if used at low power
  - Microwaves
  - Wifi Networks

Resource limits

Not yet perfect

- Bandwidth limit (54Mb/s max *vs* 1Gb/s for wired networks)
- Number of channel limited by the spectrum width

Question: *What are the other limits of Wireless Networks ?*

Worse in a real world

- Radio waves cannot go every were and through everything, leading to packet loss
- Radio waves suffer from interferences and multi-path
- Security is tricky as no physical modification is necessary to enter the network

Standard/History

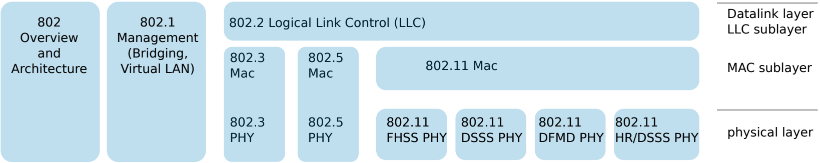
- In early 2000 three standards were emerging
  - Bluetooth
  - 3G
  - WiFi
- The first to succeed was WiFi (Apple pricing move)
- Wireless Ethernet Compatibility Alliance (WECA) certify WiFi systems

Zoom into 802.11 family

IEEE standard	Speed	Frequency band
802.11	2 Mbps	2.4 GHz
802.11a	up to 54Mbps	5 GHz
802.11b	11 Mbps	2.4 GHz
802.11g	up to 54 Mbps	2.4 GHz

- 802.11 First standard (1997). Featured both frequency-hopping and direct-sequence modulation techniques. Added and forgotten: IR Layer
- 802.11a Second standard (1999), but products not released until late 2000
- 802.11b Third standard, but second wave of products. The most common 802.11 equipments
- Slow to be standardized, leading to incompatible systems at first

802.11 from an OSI point of view



- MAC is a set of rules to determine how to access the medium and send data
- Details of transmission and reception are left to the PHY

Rq: 802.3 is (globally) Ethernet and 802.5 is Token Ring

Nomenclature

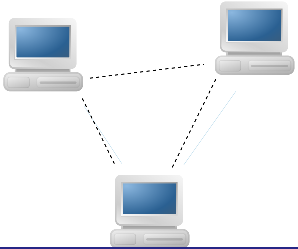
- Distribution system: links the access points
- Access points: makes the wireless to wire bridges
- Wireless medium: Initially two radio frequencies and an IR one
- Stations: elements that need to communicate

Operation Mode

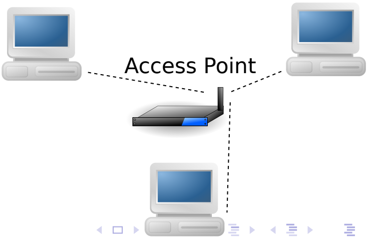
Basic element: BSS (Basic Service Set)

- A set of stations that communicate together (independent BSS)
- An access point and its affiliated stations (infrastructure BSS)

Independent BSS



Infrastructure BSS



Independent BSS

Ad-Hoc Networks

- Usually short time lived
- Dynamic
- Focused purpose (due to limitation)

Question: Find 3 type of use for IBSS in an university

Some IBSS

- Classroom or conference to share slides
- Connect to a nearby printer
- Command the video projector

Infrastructure BSS

- Classical network in an university
- Generic usage
- Really like an wired solution
  - station associate with access point (like to plug a wire)
  - access point accept or deny network access
- Cons
  - No context
  - Less dynamic

RQ: stations can be at the same time in a IBSS and in a IBSS

Extended Service Set

- Typical range of an access point or a station is in the 10th of meters, how to manage a whole building ?
- ESS: Several BSS linked together (ie access points linked by wires)
- Provides link-layer mobility between BSS
- If not sufficient, a VLAN is necessary

Distribution system

Part of the protocol that manages stations across the whole network

- Track where stations are physically
- Delivers frames
- Uses MAC address as unique identifier
- Uses backbone Ethernet as a distribution medium
- Remaining part (the intelligence) is inside access points

Access Points

- Access points use association
- Each access point share its associated stations (IAPP)
- IAPP (inter-access point protocol) was not standardized during a long time

Mobility

In the standard three different mobility are explored

- No transition: occurs when stations move inside a BSS or connexion quality changes over time
- BSS transition: Inside a ESS, mac layer mobility is provided
- ESS transition: No mobility is provided at this level. It has to be managed at higher level (IPv6 by instance)

I'm a Mac, I'm different

Mac layer in 802.11 has been completely patched and looks like a patchwork because of:

- Mobility
- Non-symmetry

Compared to Ethernet or token ring, WiFi assumes nodes can move

Collision detection vs avoidance

- Difficult to detect a collision as everyone does not has the same vision of the system (*fig*)
- Usage of systematic positive ack (*fig*)
- WiFi can use RTS/CTS (Request to send/Clear to send) for large frames (*fig*)
- NAV (Network allocation vector) is used to warn for WiFi occupation on each frame
- Like ethernet, packet emission occurs after random timeouts

Mac layer Optimization

- Lots of messages
- Lots of energy consumed

How to reduce energy ? Your vision ?

Some current researches

Some ongoing works

- Rendez-vous
- Pre-allocation based on Unique Identifier (Mac Address)
- Pre-allocation based on prediction

Introduction

- Let's rise a level: routing !
- Let's go down a level: sensor networks

Sometimes you need to go to the next *hop*

Examples

- Fire detector
- Humidity/temperature sensor in a field
- Emergency management after a hurricane or earthquake
- Location of soldiers on a battlefield

Question: *What do they have in common ?*

Common ground

- No (or not dense) dedicated infrastructure
- Large scale systems
- Energy is an important resource
- Space is an important resource too

Difficulties

- To administrate
- Manage failures
- Share and/or process content

Solution: Ad Hoc Networks

Definition

An ad hoc network is a collection of wireless mobile nodes dynamically forming a temporary network without the use of any existing network infrastructure or centralized administration.

Concept

- Each nodes serves as a client and a router
- Each nodes participates in the Ad Hoc Routing
  - Find multi-hop paths between neighbors (*fig*)
  - Manage failures along paths
  - Manage dynamism of neighbors

Naive Routing Algorithm

flooding (*fig*)

- When a node wants to communicate it forwards all its neighbors
- When a node receive a request
  - If it is for it, it receive it
  - Otherwise it forwards it to all its neighbors (if Time to live is not expired)

Question: *Why is it a naive algorithm ?*

Naive, so Naive

- A requests will travel all around the network
- Communication number is linear in the number of nodes
- If the node is too far away, it won't be contacted

Bellman Ford

- It is the algorithm used in Internet
- It consists in two processes:
  - Routing table Management
  - Communications

Bellman Ford: Management

- Each node regularly discover its direct neighbors
- Each node regularly send its routing table to its neighbors
- Each node add information from indirect neighbors to its routing table

Question: *Compare to flooding*

Evaluation

- Heavily dependent on timeouts
- Large memory requirements (routing table) to be efficient
- Works well if the network is not too dynamic
- Can lead to loops if the network is dynamic

Main problem: no geographical naming

Evaluation

- Depends on the goal, several metrics
- Global Energy
- Energy consumption balancing
- Latency, Number of hops
- Number of lost packets
- Protocol Overhead

Generic Geographic Routing

Assumptions

- Each node is geographically tagged
- Destination of a packet is a geographical tag
- High Density of nodes

In this case, geographic routing is efficient

Geographic Routing algorithm

- Management
  - Each node discover regularly its neighborhood
- Packet routing
  - Packets are forwarded to the neighbor that minimize the distance

Geographic Routing analysis

- Efficient but not optimal (local vision)
- Can fall in dead-ends
- Trade-off between freshness and overhead
- Possible loops
- Management is simple

Finding good routing algorithms is still an open research field

Destination-Sequenced Distance Vector (DSDV)

- Improves Bellman Ford.
- Guarantees loop free routing.
- Integrate a metric

DSDV Algorithm

- Each nodes keeps a table of the next hop for each destination it knows of
- Each entry is annotated with two elements:
  - The metric (by instance number of hops) infinite if there is a failure
  - A sequence number
- Each entry is updated if a new route is received and either
  - The sequence number increased
  - It is equal and the metric is better
- Each node publish an ever increasing number for himself

DSDV remarks

- Manages dynamism better than Bellman Ford
- Still the same advantages, no geographical knowledge required
- Reactivity is linked to updates message rate

Temporally-Ordered Routing Algorithm (TORA)

- Discover routes on demand
- Provide multiple routes to a destination
- Establish routes quickly
- Minimize communication overhead by localizing algorithmic reaction to topological changes when possible

Rq: Shortest-path routing is not one of the main objectives, contrary to reducing the overhead of discovering newer routes.

TORA algorithm

- Each node has an list of known destination, tagged with the distance
- When a node tries to contact some node it doesn't know, it:
  - Send a Query in the network
  - When a node with a route to the destination receive it, it broadcast an Update
  - All nodes receiving the Update update their knowledge

Dynamic Source Routing (DSR)

- Instead of taking local decision at each forward, all nodes to go through are in the header
  - Goal: reduce overhead of route maintenance
  - On demand creation of paths
- Based on two algorithms
  - Route discovery
  - Route maintenance

DSR: algorithms

Route discovery

- A node broadcasts a *Request Route*
- A *Route Reply* is sent back following the same path
- A system of cache is used to answer sometime before arriving to destination

Route maintenance

- If a node is absent, a new route discovery is started

Ad Hoc On-Demand Distance Vector (AODV)

- Combination of both DSR and DSDV.
- On-demand mechanism of Route Discovery and Route Maintenance from DSR
- Hop-by-hop routing, sequence numbers, and periodic update from DSDV

Comparison of Ad Hoc routing algorithms

- DSDV delivers all data packets under low dynamism, and fails to converge as it increases
- TORA, with a high overhead work well even with dynamism but fails when loads rise
- DSR, is good even with high dynamism but adds a high overhead (due to the increased header)
- AODV matches DSR mobility wise and reduce overhead for most case, apart for high mobility one.

Definition

A Wireless Mesh Network (WMN) is a mix of nodes that cooperate to route packets using different networks using wireless technology

An ad-hoc network is a particular case of WMN

How to build a mesh network

- Two types of nodes and behaviors
  - Mesh routers (usually several interfaces) can be complex
  - Mesh clients (usually one interface) usually lightweight
- Routing is done using multi-hop algorithms

Quite generic

- Can accept wired network connected to routers using ethernet
- Broad spectrum of applications
  - Ad hoc networks
  - Broadband home networking
  - Community networking
  - Building automation
  - Highspeed metropolitan area networks
  - Enterprise networking

Toward a new standard

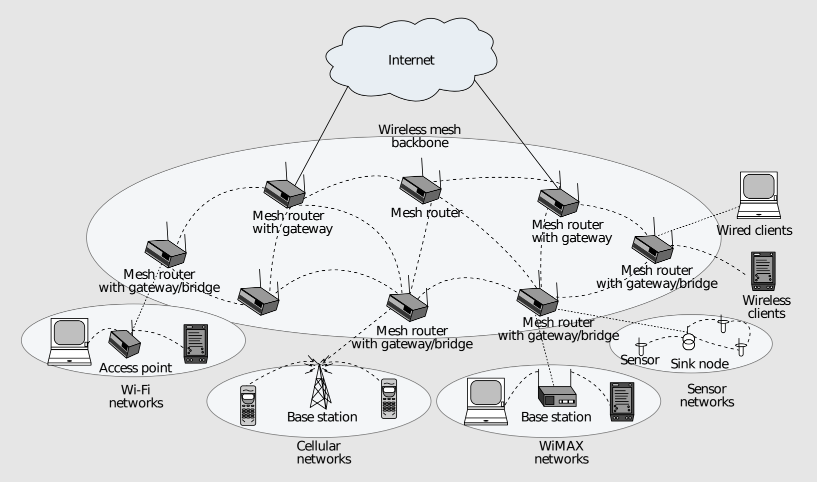
- Current implementation use mainly WiFi
- Industrial standards groups are actively working on new specifications for WMNs:
  - IEEE 802.11: wireless local area network (WLAN)
  - IEEE 802.15: Wireless Personal Area Network (PAN)
  - IEEE 802.16: Wireless Metropolitan Area Networks (WMAN)

Network Architecture

WMNs architecture can be classified in three types:

- Infrastructure/Backbone WMNs
- Client WMNs
- Hybrid WMNs

Infrastructure/Backbone WMNs



Infrastructure/Backbone WMNs (cont'd)

- Mesh routers form a mesh of self-configuring, self-healing links among themselves
- Using gateway functionality they can be connected to the Internet and provide this service to clients

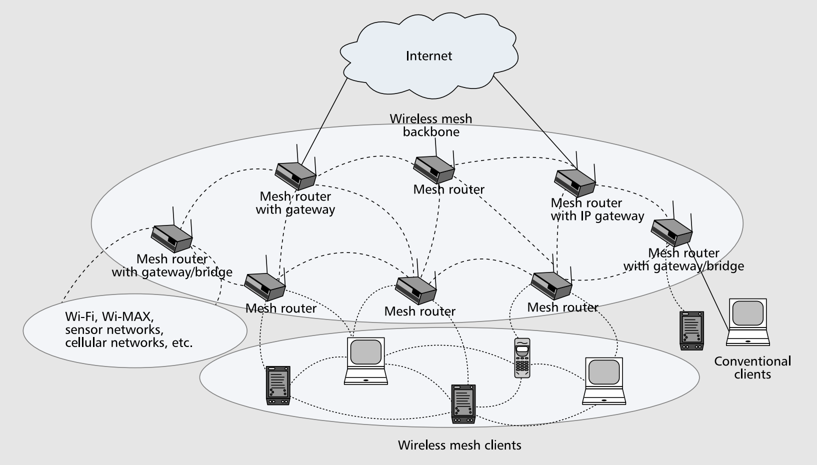
This system provides a backbone for conventional clients

Client WMNs

- Peer to Peer network between clients
- Clients serves as routers too
- No mesh routers are necessary
- Usually only one network technology
- Clients quite complex (have to manage self configuration and routing)

Welcome back : *ad-hoc* networks

Hybrid WMNs


Internet
Wireless mesh
backbone
Mesh router
with gateway
Mesh router
Mesh router
with IP gateway
Mesh router
with gateway/bridge
Mesh router
with gateway/bridge
Mesh router
Mesh router
Mesh router
Wi-Fi, Wi-MAX,
sensor networks,
cellular networks, etc.
Conventional
clients
Wireless mesh clients

Hybrid WMNs (cont'd)

Combination of the two previous approaches

- Client routing improves connectivity and coverage inside WMNs.
- May be the more complex to design

Keys features of Mesh Networks

Question: *What is the improvement of Hybrid Mesh Networks over Ad-Hoc networks*

Keys features of Mesh Networks

- Reduces management cost as a part of infrastructure is stable
- Mobility of end nodes is easy because of the infrastructure
- Mesh routers integrate transparently heterogeneous networks
- Clients can have a reduced energy consumption

Critical Design Factors

First generations were build over WiFi, but some requirements are different:

- Radio Technique
- Scalability
- Mesh Connectivity
- BroadBand and QoS
- Security
- Ease of use
- Interoperability

Radio Technique

Current researches:

- Improved hardware (Multi-antenna)
- Reconfigurable radio
- Frequency agile radio
- Software radio
- Interaction between MAC and PHY (to take advantage of underlying possibilities
- Multi-channel MAC (Single or Multi-Transceiver)
- Multi-radio

Scalability

One of the most complex problem:

- Current MAC layer are unsuitable for large scale systems
  - Throughput
  - QoS (delay,...)
- How to evaluate routing algorithm ?
- Integration of heterogeneity in the MAC layer to provide simple mobility

Routing and Transport

Important to use without abusing the router infrastructure. Current researches encompass:

- Multi-radio/channel routing
- Multi-path routing
- Hierarchical routing
- Geographic routing
- New metrics
- Cross-layer routing (from PHY to Routing or Transport layer)
- TCP wifi-aware (congestion is different from simple packet loss)

That's all Folks !

Main sources

- *802.11 Wireless Networks: The Definitive Guide* By Matthew Gast, Publisher O'Reilly.
- *A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols* By Josh Broch, David A. Maltz, David B. Johnson, Yih-Chun Hu and Jorjeta Jetcheva
- *A Survey on Wireless Mesh Networks* Ian F. Akyildiz