Introduction on Mobile Wireless Networks

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http://www.irit.fr/~Georges.Da-Costa/cours/addis/
1. Introduction

2. 802.11 Networks

3. Ad Hoc Networks

4. Mesh Networks
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 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!

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Introduction on Mobile Wireless Networks
**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 exist 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

<table>
<thead>
<tr>
<th>Band</th>
<th>Frequency range</th>
</tr>
</thead>
<tbody>
<tr>
<td>UHF ISM</td>
<td>902-928 MHz</td>
</tr>
<tr>
<td>S-Band</td>
<td>2-4 GHz</td>
</tr>
<tr>
<td>S-Band ISM</td>
<td>2.4-2.5 GHz</td>
</tr>
<tr>
<td>C-Band</td>
<td>4-8 GHz</td>
</tr>
<tr>
<td>C-Band satellite downlink</td>
<td>3.7-4.2 GHz</td>
</tr>
<tr>
<td>C-Band Radar (weather)</td>
<td>5.25-5.925 GHz</td>
</tr>
<tr>
<td>C-Band ISM</td>
<td>5.725-5.875 GHz</td>
</tr>
<tr>
<td>C-Band satellite uplink</td>
<td>5.925-6.425 GHz</td>
</tr>
<tr>
<td>X-Band</td>
<td>8-12 GHz</td>
</tr>
<tr>
<td>X-Band Radar (police/weather)</td>
<td>8.5-10.55 GHz</td>
</tr>
<tr>
<td>Ku-Band</td>
<td>12-18 GHz</td>
</tr>
<tr>
<td>Ku-Band Radar (police)</td>
<td>13.4-14 GHz and 15.7-17.7 GHz</td>
</tr>
</tbody>
</table>
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 everywhere 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
<table>
<thead>
<tr>
<th></th>
<th>Introduction</th>
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<tr>
<td>2</td>
<td>802.11 Networks</td>
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<td>3</td>
<td>Ad Hoc Networks</td>
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<td>4</td>
<td>Mesh Networks</td>
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</table>
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

<table>
<thead>
<tr>
<th>IEEE standard</th>
<th>Speed</th>
<th>Frequency band</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.11</td>
<td>2 Mbps</td>
<td>2.4 GHz</td>
</tr>
<tr>
<td>802.11a</td>
<td>up to 54 Mbps</td>
<td>5 GHz</td>
</tr>
<tr>
<td>802.11b</td>
<td>11 Mbps</td>
<td>2.4 GHz</td>
</tr>
<tr>
<td>802.11g</td>
<td>up to 54 Mbps</td>
<td>2.4 GHz</td>
</tr>
</tbody>
</table>

- **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

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**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.

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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

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

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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 have 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

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**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

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Introduction

802.11 Networks

Ad Hoc Networks

Mesh Networks

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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

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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.

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Concept

- Each node serves as a client and a router
- Each node 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-Seqenced Distance Vector (DSDV)

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

- Each node 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.

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TORA algorithm

- Each node has a list of known destinations, tagged with the distance.
- When a node tries to contact some node it doesn’t know, it:
  - Sends a Query in the network.
  - When a node with a route to the destination receives it, it broadcasts 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

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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
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

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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)

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That’s all Folks!
Main sources

- *802.11 Wireless Networks: The Definitive Guide* By Matthew Gast, Publisher O’Reilly.
- *A Survey on Wireless Mesh Networks* Ian F. Akyildiz

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