LECTURE 1

Introduction

Things we need to know

- CS 164
  - Qualitative idea of telecommunication networks and protocols – the OSI stack
  - what TCP/IP is, etc.
  - Routing protocols

Broad overview of course contents

- Wireless Systems
  - Wireless Wide Area Networks (WWANs)
  - Wireless Metro Area Networks (WMANs)
  - Wireless Local Area Networks (WLANs)
  - Wireless Personal Area Networks (WPANs)
  - Ad hoc and mesh networks

Beware of Acronyms!

- Lower Layers
  - Physical Layer (PHY)
    - Radio Propagation
    - Modulation
  - Access layer (MAC)
  - Deployment
- Higher Layers
  - Routing
  - Transport
  - Mobility Management (MM)

Course Objectives

- Learn architectural differences between various wireless systems
- Examine how wireless affects protocol design and development
- Uncover network operation, deployment, and application issues

Textbook and references

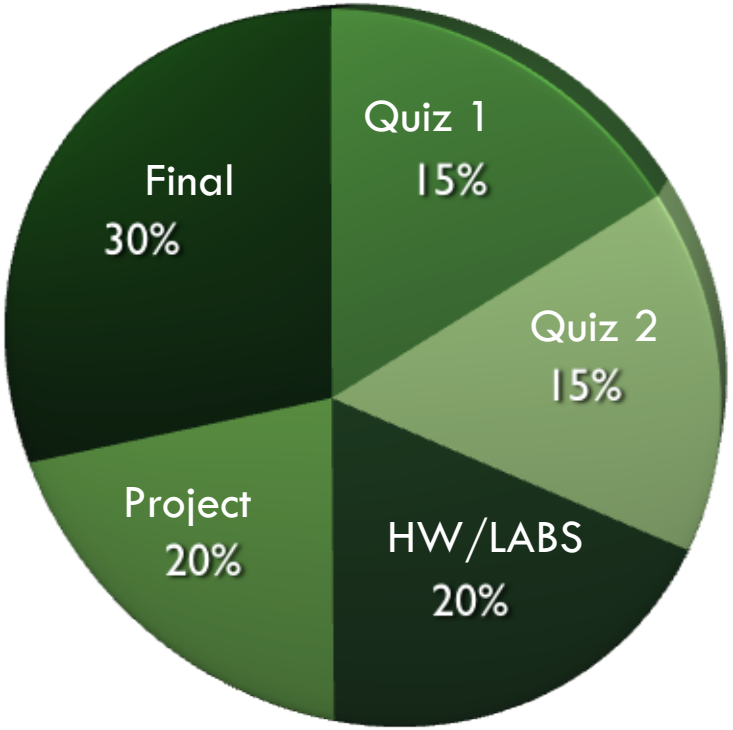
- Textbook
  - Mobile Communications 2nd edition, Jochen Schiller, Addison Wesley
  - However, I may draw things from other sources.
  - Refer to slides – should have the content you are responsible for.
- Other references
  - Papers from journals and magazines
  - Principles of Wireless Networks – Kaveh Pahlavan and Prashant Krishnamurthy, Pearson

Contact

- Srikanth Krishnamurthy
- Location
  - 324, Engineering II
- E-mail: krish@cs.ucr.edu
- Web: www.cs.ucr.edu/~krish
- Office Hours: Fridays 11.00 – 12.00 (or by appointment)
- TA: Kittipat Apicharttrisorn kapic001@ucr.edu

Grading

- Homework 10%
- Labs 10 %
- 3 Quizzes 15% each
  - We will choose the best two.
- Project 20%
- Final 30%



Undergraduates?

Labs and Project

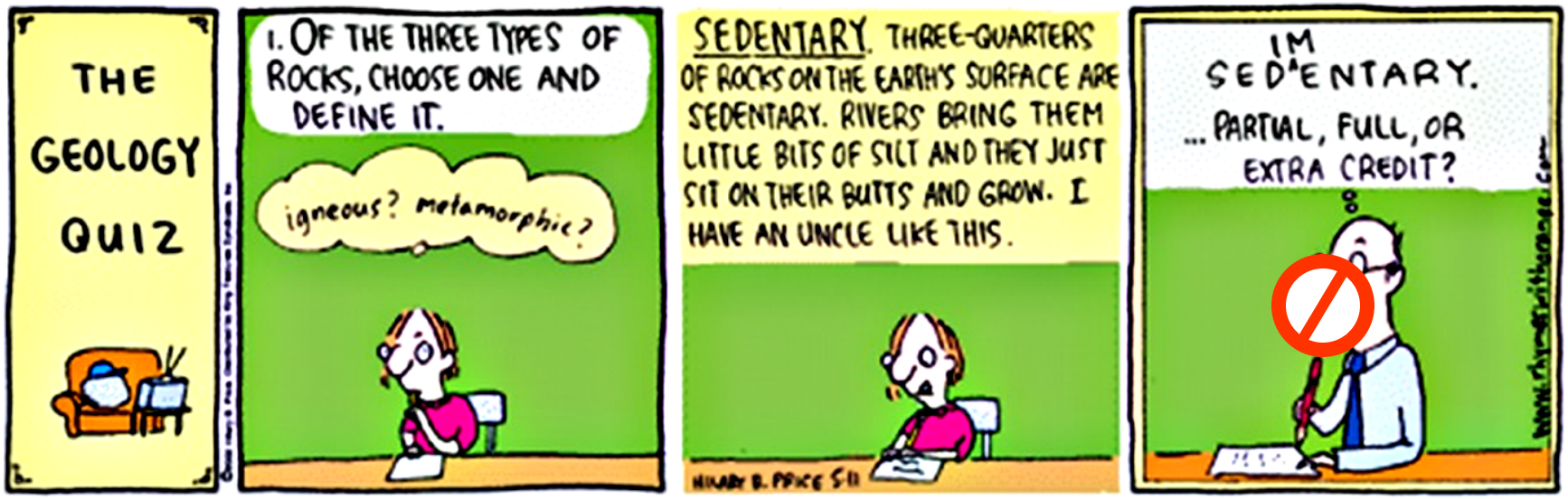
- Lab attendance is mandatory for first 6 weeks.
  - You will lose points for each lab missed.
- First six labs : you will do ns3 simulations
  - Simple experiments
  - Learn the simulator.
- Last four labs – project
  - Will be assigned by Week 6
  - No groups – do this individually.
  - No cooperation whatsoever.
  - Take help from TAs as needed – attend labs as needed.

Homework

- Pick up in lab – turn in next lab.
- In the last four weeks, you will have the option of e-mailing a pdf to your TAs if you cannot attend.
- We will also post it on web.

Clarity and Legibility are Very Important

Rhymes with Orange – by Hilary Price



- There will be no credit for vague answers or unclear steps
- I should be able to understand what you were trying to do without your verbal explanation later

INTRODUCTION TO WIRELESS SYSTEMS

Quick Overview

Wireless Communication Systems

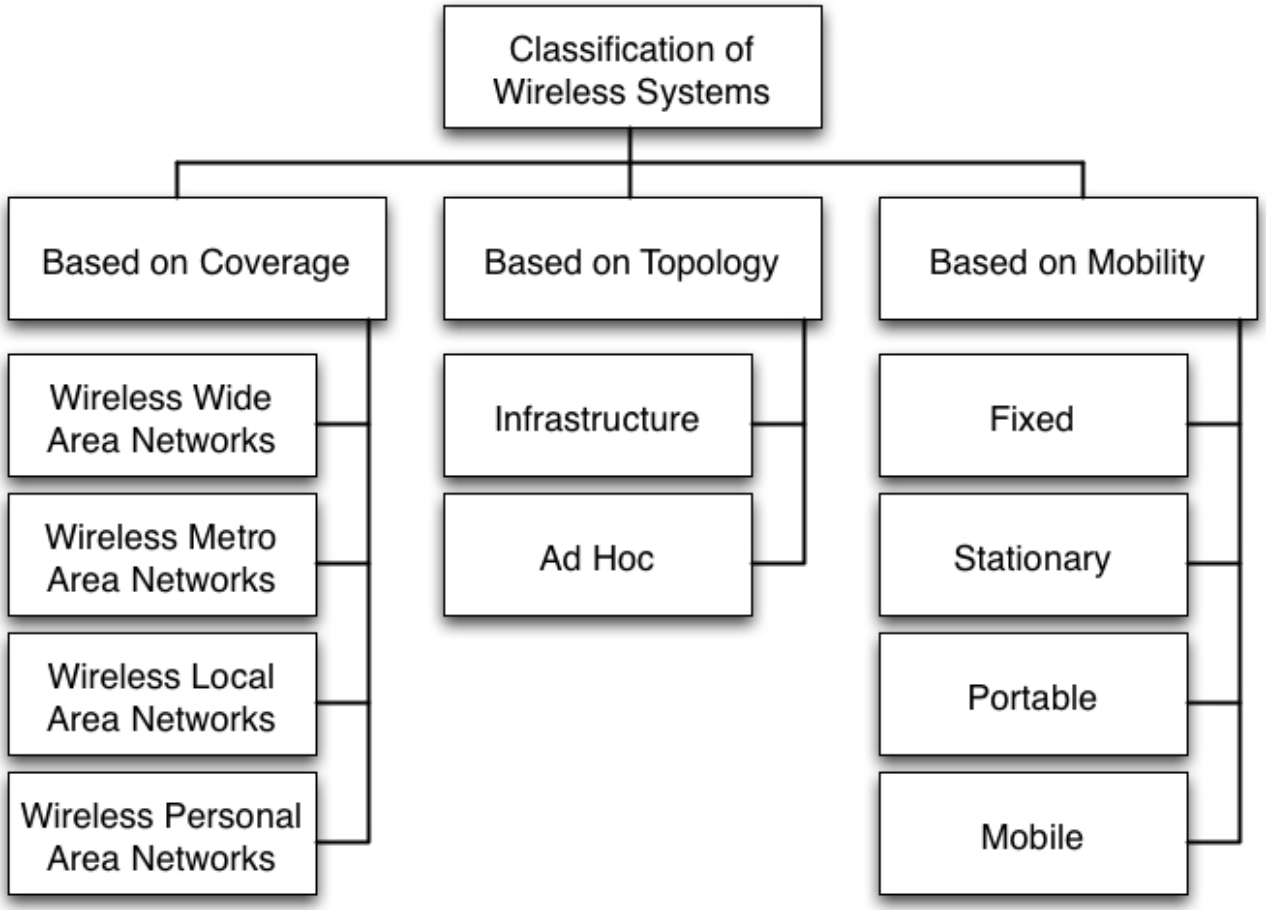
- Wireless communication system
  - Any electrical communication system that uses a naturally occurring communication channel, such as air, water, earth.
- Examples:
  - Cell phone, sonar, ground penetrating radar
  - Broadcast: (one way)
    - Radio, TV, pagers, satellite TV
  - Two Way:
    - Walkie talkie, cell phones, satellite phones, WiFi, Bluetooth
- Fundamentally different from wired networks

Mobile Vs. Wireless

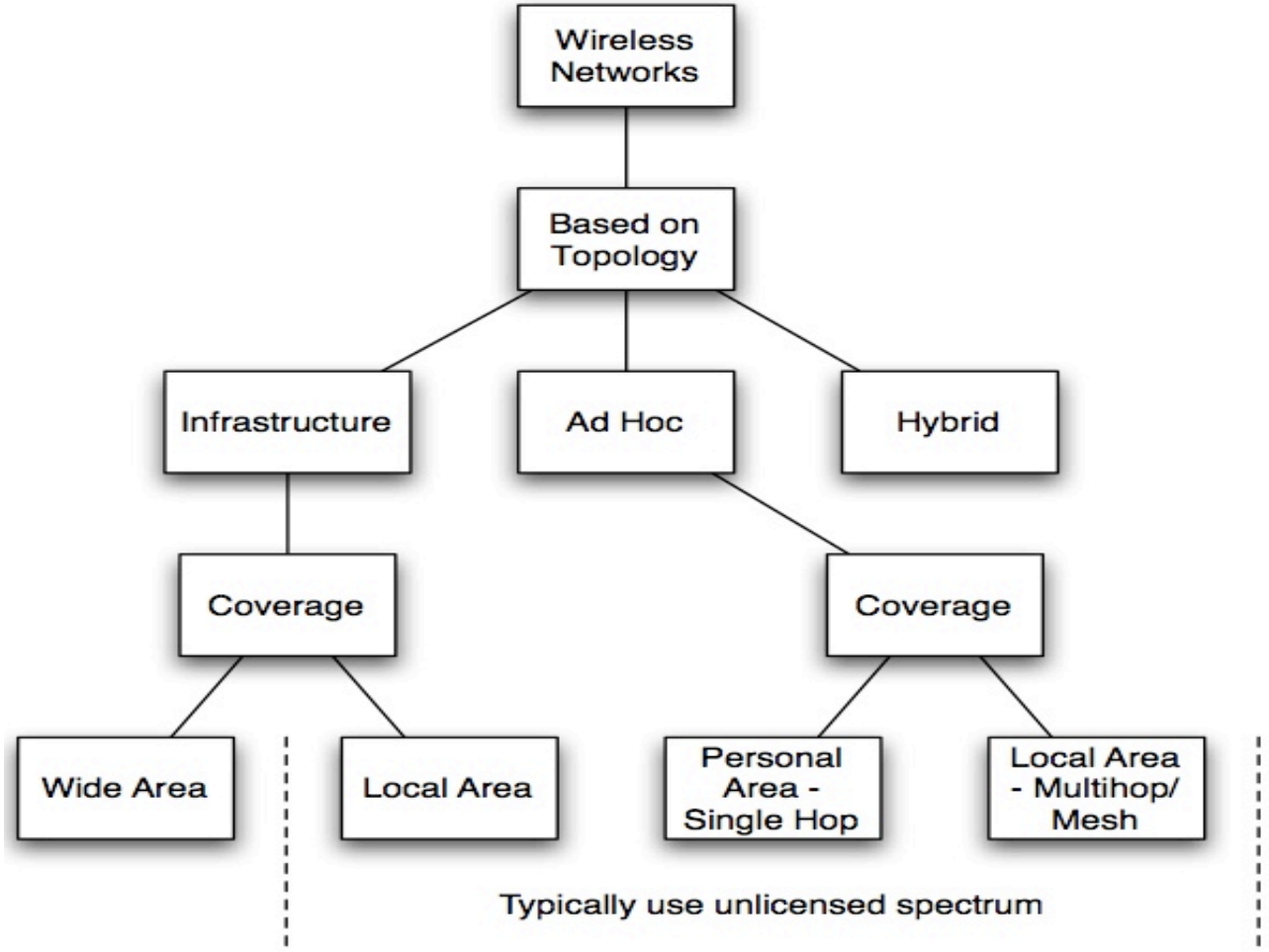
- Mobile and Wireless are not interchangeable
- *Mobile* and *wireless* communication systems
  - Communicate over the air via radio-waves
  - Support some form of user mobility

Mobile	Wireless	Example
✗	✗	Stationary computer, pay phone
✗	✓	Wireless local loop
✓	✗	Calling card, call forwarding
✓	✓	Cell phone, laptop with WLAN

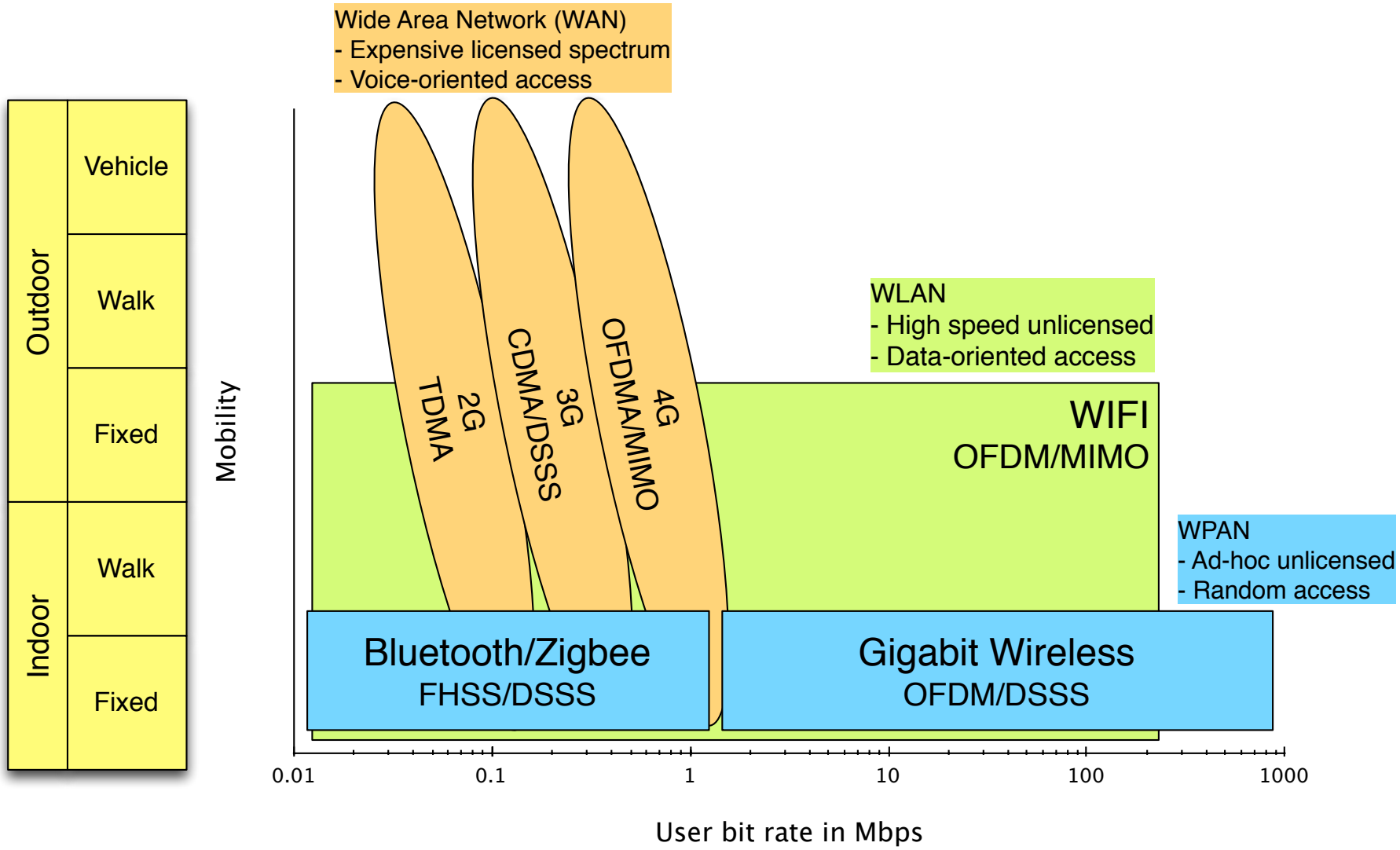
Classification of Wireless Systems



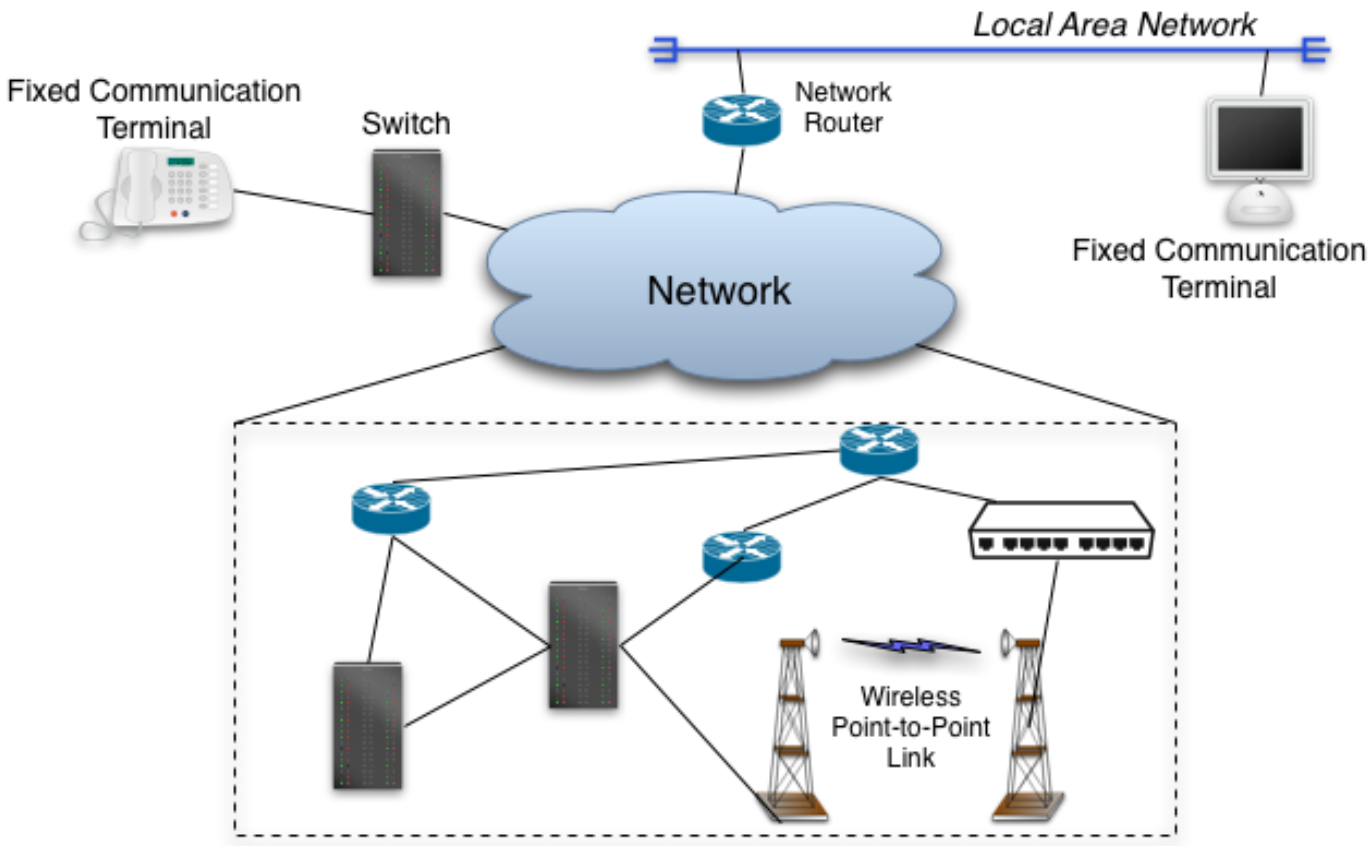
Classification of Wireless Systems



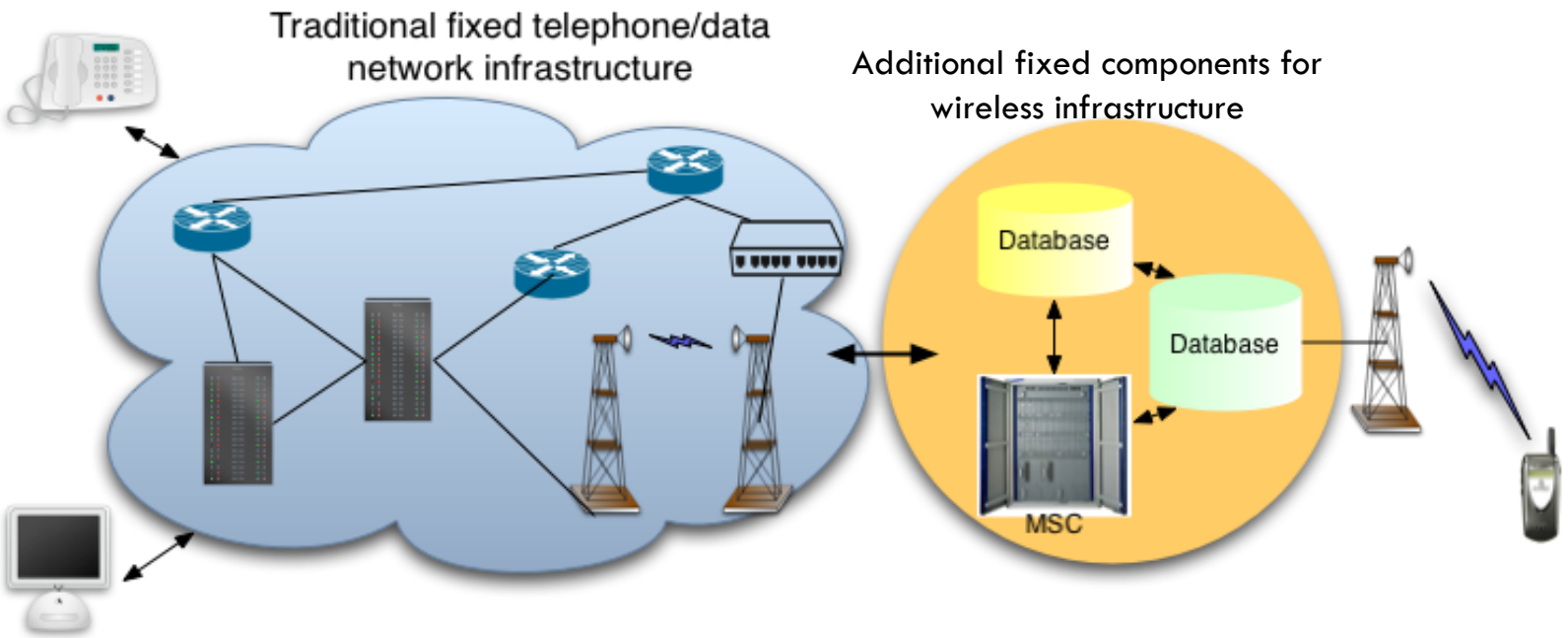
Classification based on data rates and technologies



Traditional Wired Networks



Positioning of Wireless Networks



Ad hoc clusters

Infrastructure Topology

- Basics
  - A wired (fixed) infrastructure supports communications between wireless devices and between wireless devices and fixed devices
- Base Stations (BSs) or Access Points (APs) form the point of access to the network
  - Each BS covers an area called a “cell”
  - Multiple BSs are interconnected to cover a larger geographical area
- Star topology
  - The BS or AP is the hub
  - Any communication from a wireless device to another has to be sent through the BS or AP
  - The BS or AP manages user access to the network

What is extra?

- Wireless transceivers
  - Base stations – BSs and Access points – APs
  - Mobile stations - MSs
- Spectrum
  - Frequency bands for uplink and downlink
  - Air interface
- Management Entities
  - Mobility management
  - Power management
  - Radio resource management
  - Security
- Deployment
  - Frequency reuse
  - Network design

Examples of Infrastructure Wireless Networks

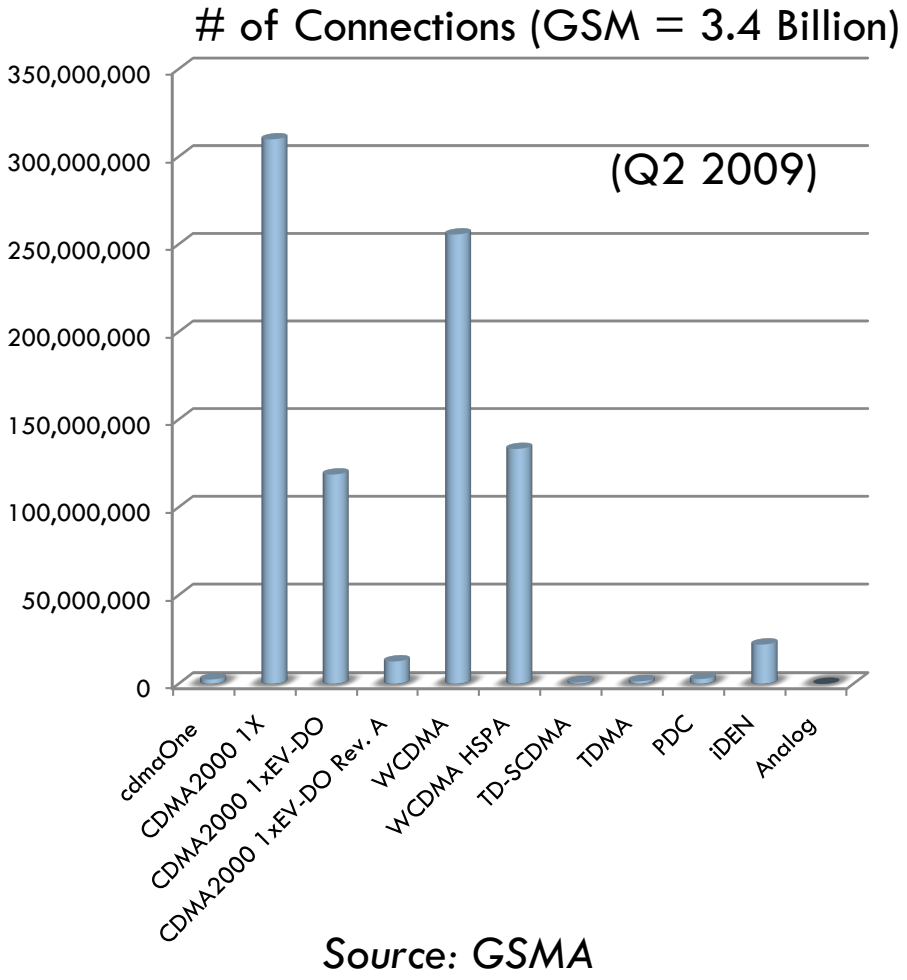
- Wide area
  - Voice oriented - Cellular telephone systems
  - Data oriented - Mobile data systems
- Local Area
  - Voice oriented - Wireless PBXs
  - Cordless phones
  - Data Oriented - Wireless LANs

History of Wireless Voice Networks

Year	Event
1970s	Exploration of first generation mobile radio at Bell Labs
Late 1970s	First generation cordless phones
1982	Exploration of second generation digital cordless CT-2
1982	Deployment of first analog cellular system: NMT
1983	Deployment of first US analog cellular system: AMPS
1983	Exploration of 2G digital cellular GSM
1985	Exploration of wireless PBXs and DECT
1988	Initiation of GSM development
1988	Initiation of IS-54 development
1988	Exploration of Qualcomm's CDMA technology
1991	Deployment of GSM
1993	Deployment of PHS/PHP and initiation of IS-95
1995	PCS Band auction
2000	Wireless Web, Wireless Application Protocol, GPRS
2002	3G Networks
2011 and beyond	Voice over LTE (VoLTE), Smartphones

The Cellphone Industry

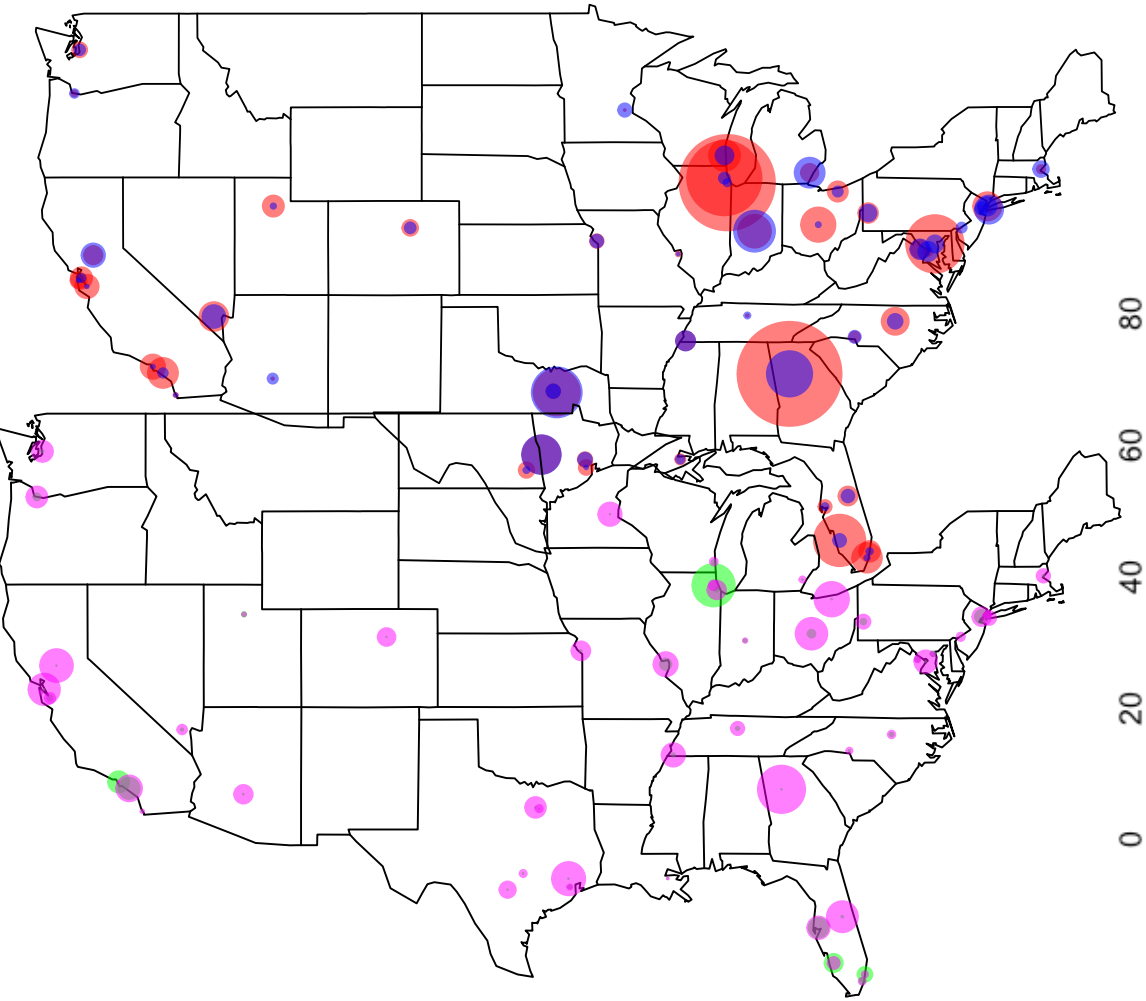
- Mobile phone systems
  - Support communication to mobile users via wireless radio channel
- Fastest growing technical device EVER!
  - Variety of systems
    - 4.3 Billion Connections (Q2 2009)
    - Analog: NMT, AMPS, TACS
    - Digital: GSM, USDC, IS-95 (cellular CDMA), PDC
- Scope of services and coverage areas growing
  - Focus now on wireless data, apps and location aware services



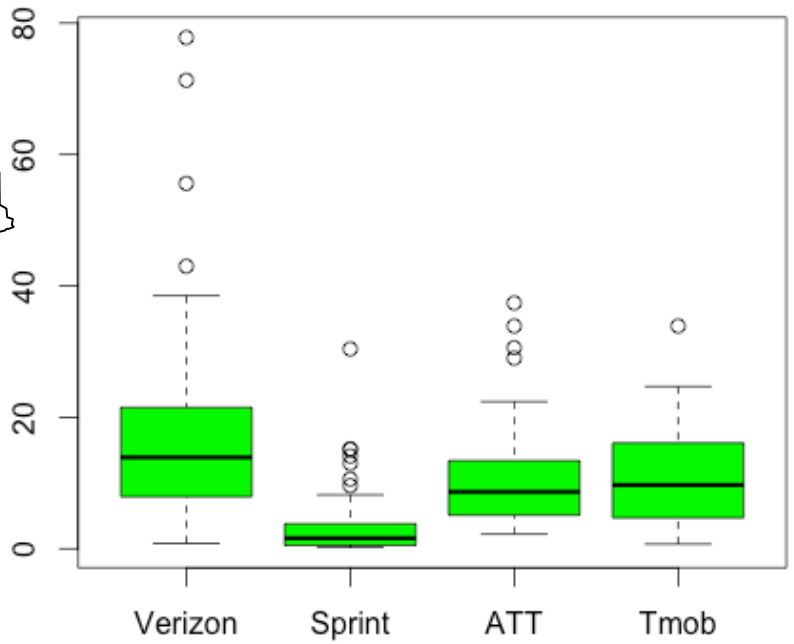
Source: GSMA

Data Source: RootMetrics/CNN (2014)

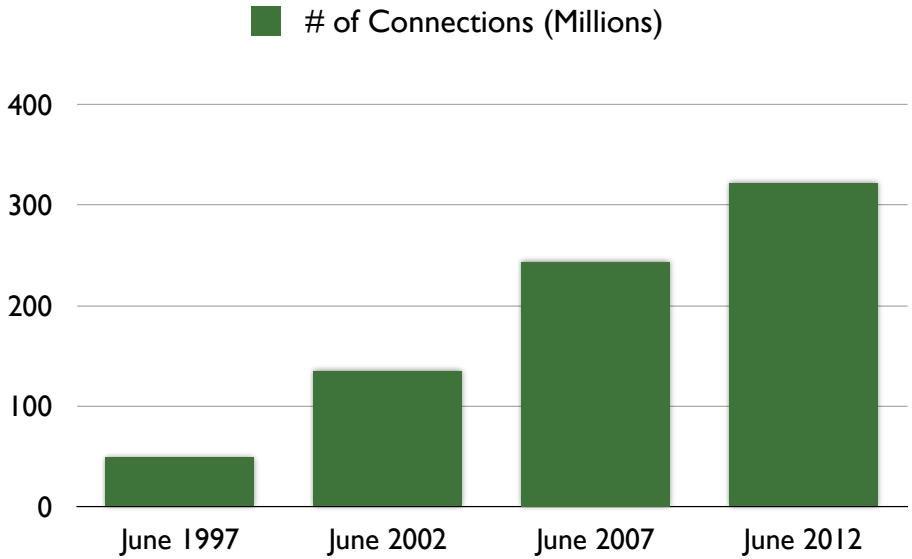
Example: 4G Data Rates in US Airports

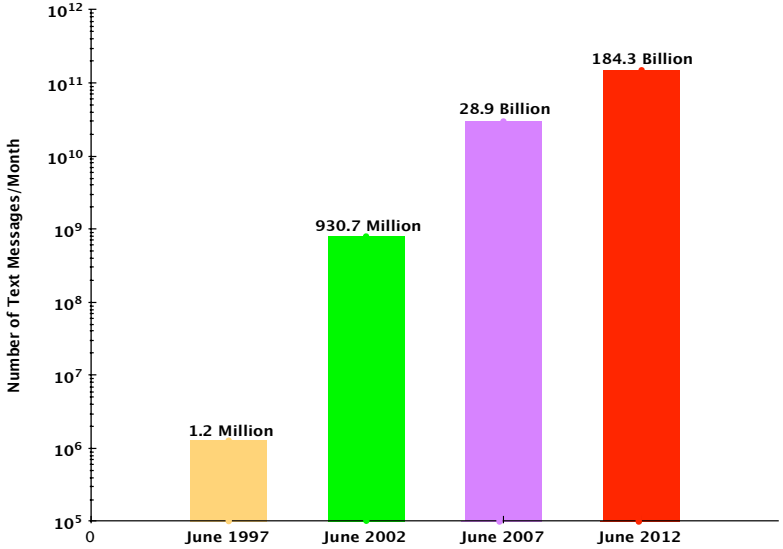


Verizon, ATT, Sprint, T-Mobile



US Statistics





34% of Households are "Wireless Only"

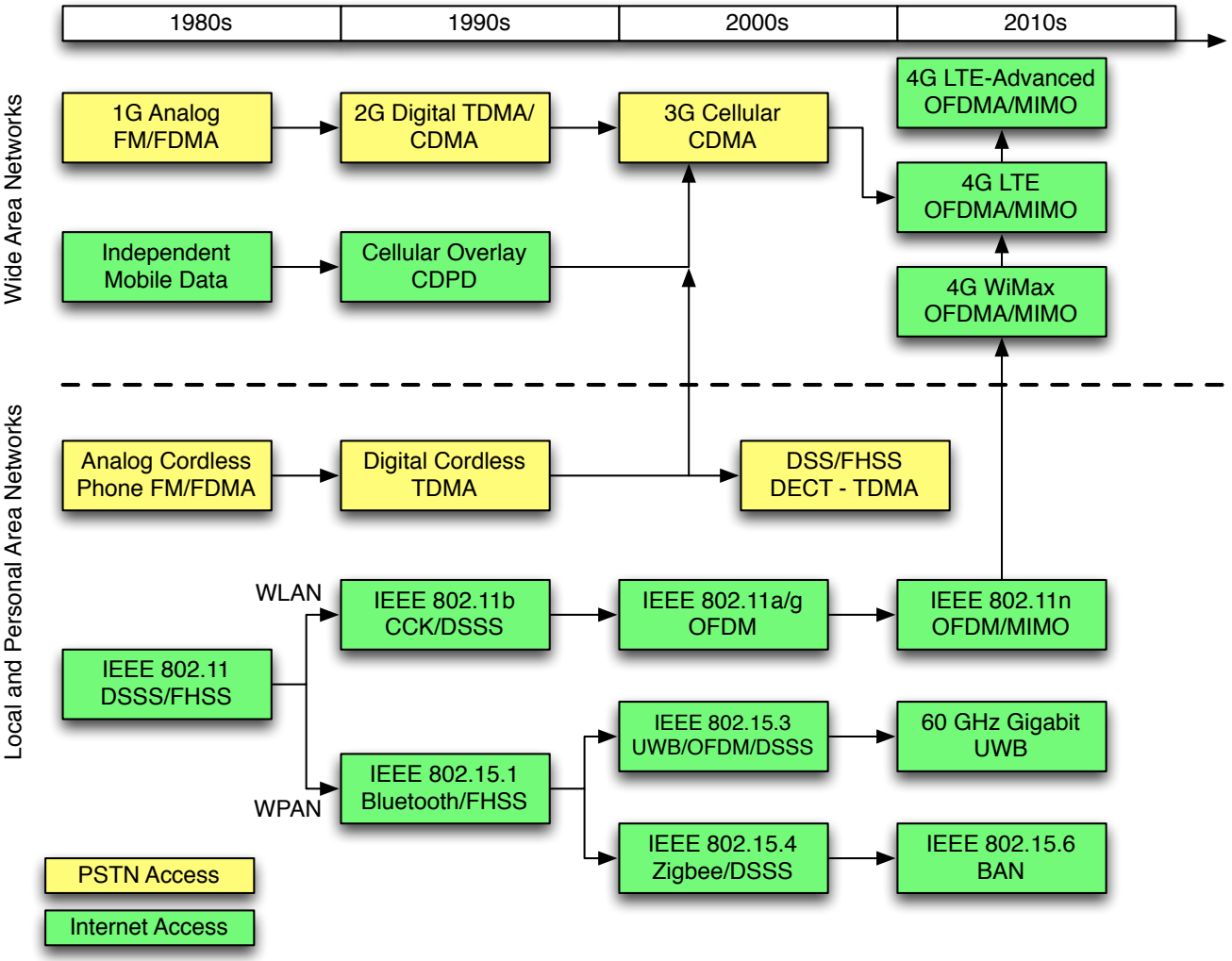
Annual Total Wireless Revenues in 2012: $ 178.4 Billion
Annual Revenues from Data Traffic in 2012: $ 68.3 Billion

Data Source: CTIA - http://www.ctia.org/advocacy/research/index.cfm/AID/10323

Generations of mobile communications

Feature/ Decade	1980s	1990s	2000s	2010s	2020s
Generation	**First**	**Second**	**Third**	**Fourth**	**Fifth**
Keywords	Analog	Digital Personal	Global World Standards;	MIMO, High data rate; IP-Based	Cognitive? Open spectrum? high mobility
Multiple Access	FDMA	TDMA CDMA	CDMA, OFDM	OFDMA	Mixed?
Cellular Systems	Analog Cellular	Digital Cellular	UMTS cdma2000 (3G-Cellular) Rates approaching 10Mbps	LTE, WiMax	5G-Cellular, ITS
Local/Home systems	Analog Cordless	Digital Cordless	Digital Cordless	Min. data rate > 100 Mbps	Minimum Data rate Gbps?
Data Systems		Mobile Data Early WLAN	3G Data, 802.11b, a, g, n	4G Data, 60 GHz WLANs? UWB?	

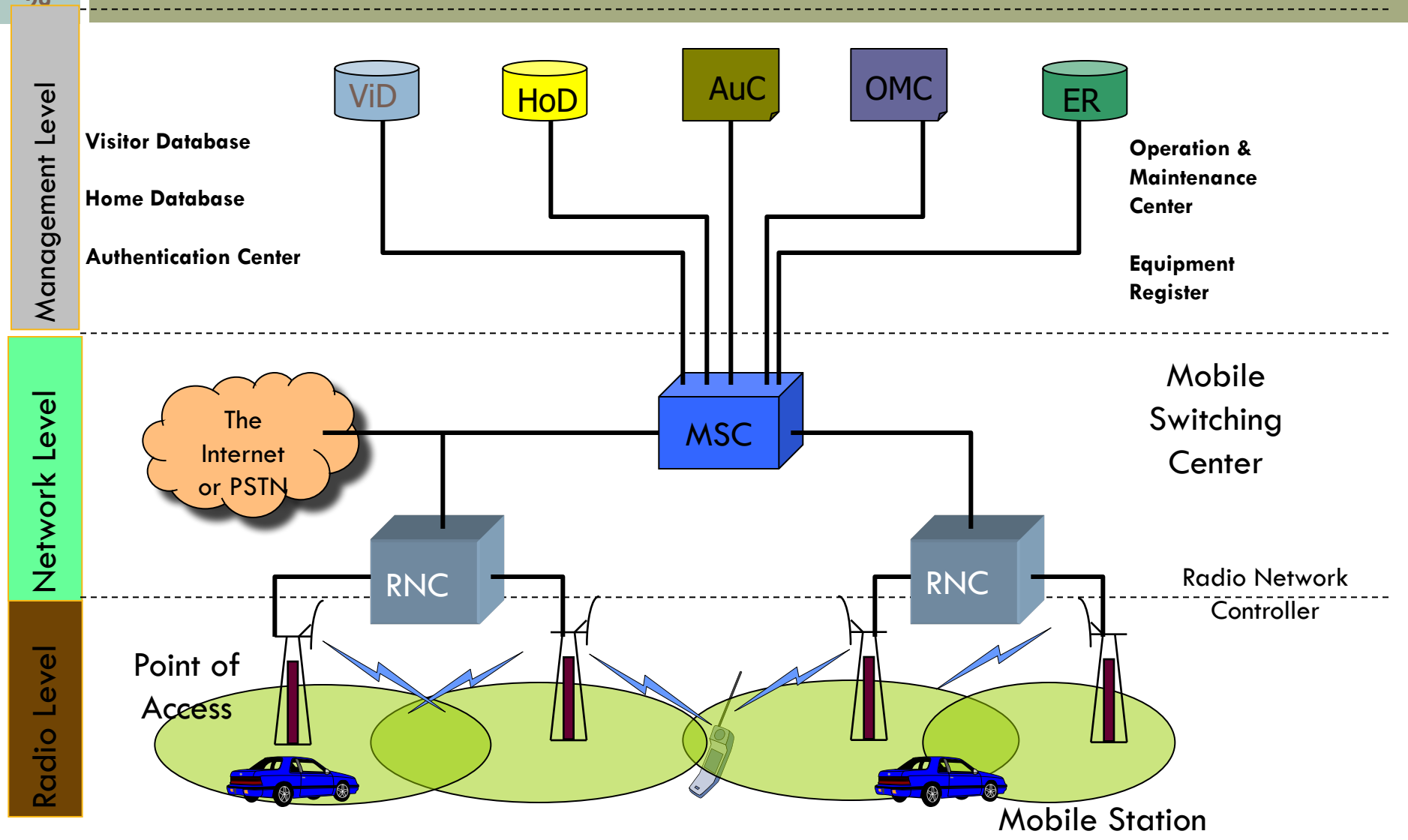
An evolutionary view of wireless technologies



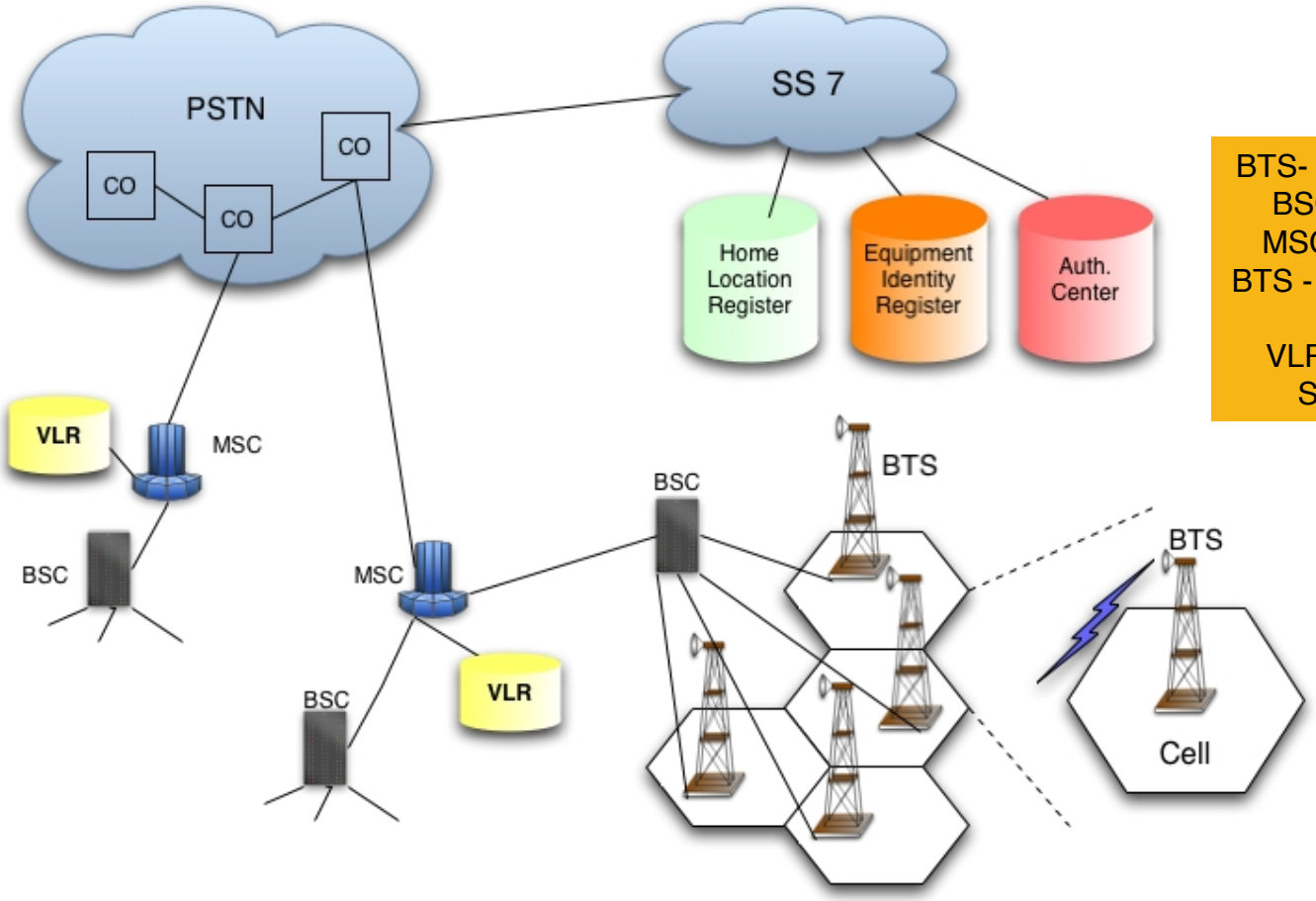
History of Wireless Data

Year	Event
1979	Diffused Infrared (IBM Labs in Switzerland)
1980	Spread Spectrum using SAW Devices (HP Labs in California)
Early 80s	Wireless modems (Data Radio)
1983	ARDIS (Motorola/IBM)
1985	ISM Bands for Spread Spectrum Applications
1986	Mobitex (Swedish Telecom and Ericsson)
1990	IEEE 802.11 starts, Announcement of WLAN products
1991	RAM Mobile (Mobitex)
1992	Formation of Winforum, ETSI's HIPERLAN in Europe
1993	Release of 2.4, 5.2 and 17.1-17.3 GHz bands in EU
1993	PCS licensed and unlicensed bands
1993	CDPD - (IBM and 9 operating companies)
1997	IEEE 802.11 finalized
2000	General packet radio service (GPRS)
2002	Wireless PANs and EDGE, CDMA Data
2007	HSDPA and 3G Data services
2012	Wimax and LTE

Generic Architecture - WWANs



2G Cellular Network Architecture



BTS- Base Transceiver Subsystem
BSC - Base Station Controller
MSC - Mobile Switching Center
BTS - Base Transceiver Subsystem
CO - Central Office
VLR - Visitor Location Register
SS 7 - Signaling System 7

Not all elements from the generic architecture exist in all technologies & the exact functionality of the elements may be different

Terms and terminology

- Mobile Station (MS)
  - Mobile Terminal – MT, Mobile End System – M-ES, Mobile Node – MN, Mobile Device, Handheld Device, Wireless Device, etc.
- Point of Access
  - Base Station (BS), Base Transceiver Subsystem (BTS), Mobile Data Base Station (MDBS), Access Point (AP), Node B, E-Node B
- Radio Controller
  - Base Station Controller – BSC, Radio Network Controller – RNC
- Mobile Control Center
  - Mobile Switching Center – MSC, Mobile Data Intermediate System – MD-IS, Gateway GPRS Support Node – GGSN
- Visiting Database
  - Visiting Location Register – VLR, Mobile Serving Function – MSF, Serving GPRS Support Node – SGSN, Foreign Agent – FA
- Home Database
  - Home Location Register – HLR, Mobile Home Function – MHF, GPRS Register – GR, Home Agent - HA

Functionality (I)

- Point of access
  - The physical radio transceiver
  - Creates the air interface
    - Transmits signals to MSs
    - Receives signals from MSs
    - Involved in multiplexing on the link – medium access
- Radio Network Controller
  - Again link level
  - Manages the air interface
    - Which RF carrier should I tune to?
    - What transmit power level should I use?
    - Is the carrier I want to use capable of providing acceptable quality?
    - When should I make a handoff?

Base Stations (BS)

- Provides radio channels between mobile units and network
- Pico-cells : (indoor – 0-.5 Km) support 8-20 channels
- Micro-cells: (outdoor – 0-1 Km), Macro-cells: (1-30 Km)

Base Stations and Radio Network Controllers

- Base Transceiver Subsystem (BTS)
  - Houses radio units
- Base Station Controller (BSC)
  - Manages a cluster of BS, channel assignment, handoff, power control, some switching, etc

BTS

BSCs

Functionality (II)

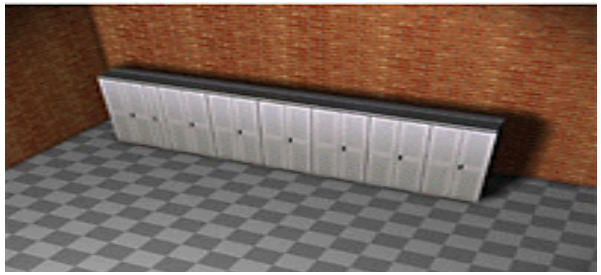
- Mobile Switching Center
  - Manages mobility of devices
    - Routes packets to and from MSs
  - Keeps track of the location of the MSs
    - Location means “in which cell or group of cells” the MS may be located i.e., which points of access may be probable candidates for pinging the MS
    - How does it do this? Using the home database and visiting database
  - Ensures security
    - Uses the authentication center and equipment registers to authenticate the MS and to prevent fraudulent/stolen devices from using the network
  - Accounting and Billing
    - Operations and maintenance center

Mobile Switching Center

- Mobile Switching Center (MSC) (MTSO)
  - Provides switching functions , coordinates location tracking, call delivery, handoff, interfaces to HLR,VLR, AUC, etc.
  - Size of central office switch

Home and Visitor Databases

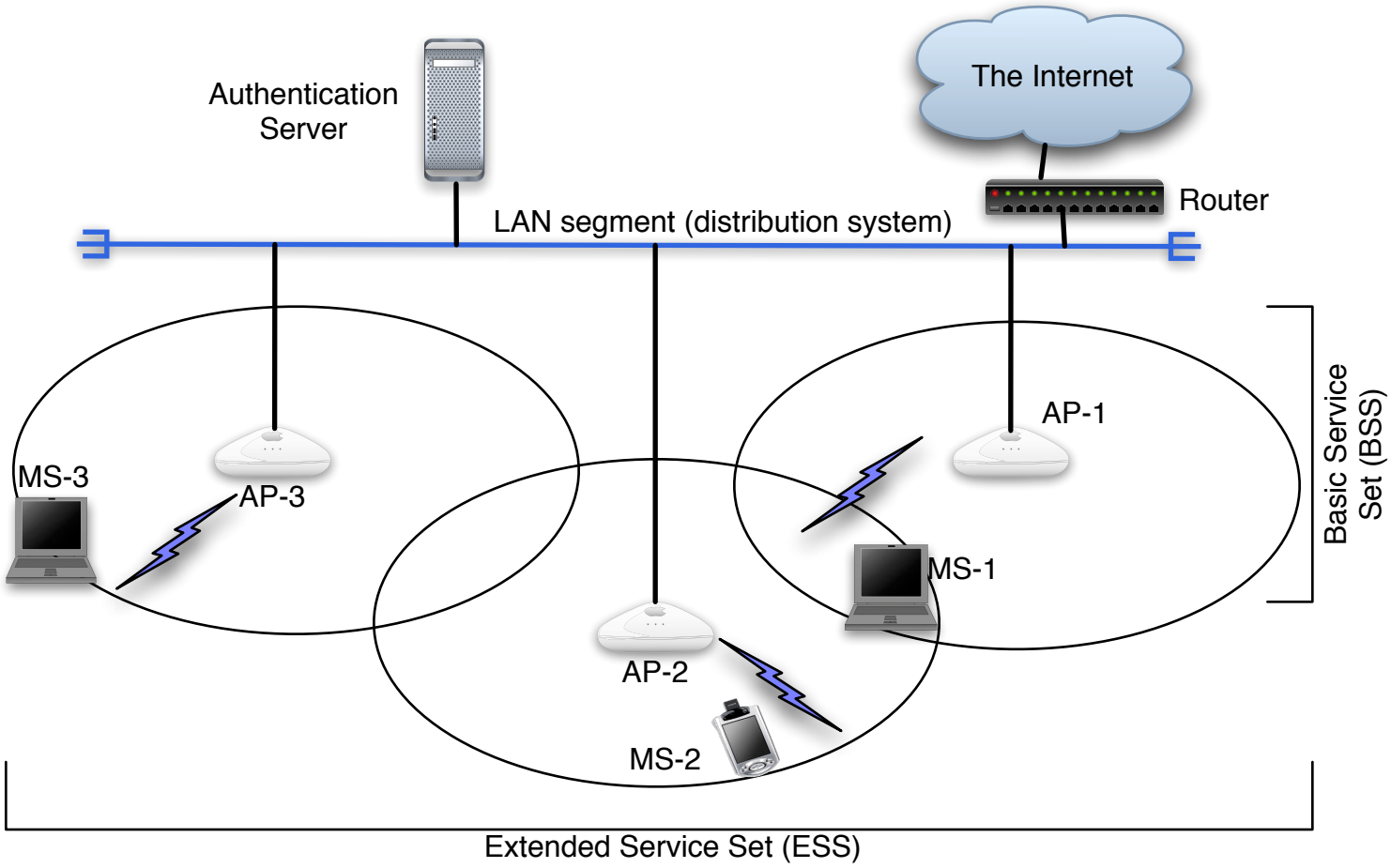
- Home Location Register (HLR)
  - Specialized database server contains billing info, service profile and general location of a mobile user
- Visitor Location Register (VLR)
  - Similar to HLR contains location of users and their service profile of all users in a metro type area



Wireless Local Area Networks

- Used primarily in smaller areas
  - Homes, campuses, coffee shops, businesses
  - Support communication to mobile data users via wireless channel
- Standards
  - IEEE 802.11 a, b, g, n standard (wireless Ethernet)
    - 1Mbps, 2Mbps, 11Mbps, 54 Mbps, >100 Mbps rates
      - Use Barker codes, CCK, OFDM, MIMO
    - Infrastructure based and Ad-Hoc based networks
  - HIPERLAN 1 and 2
- Typically use unlicensed spectrum

Generic Architecture - WLANs

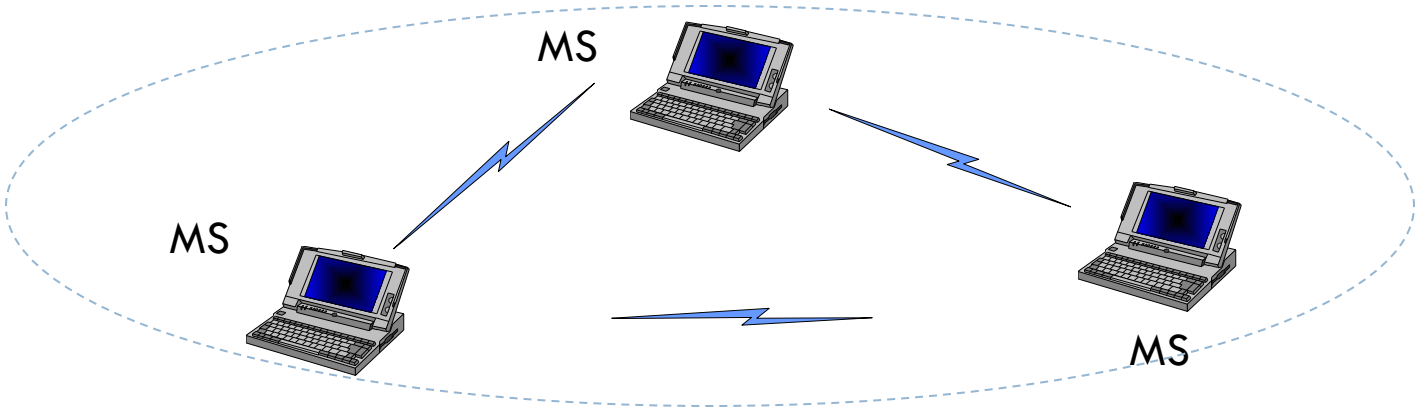


Ad hoc network topology

- Distributed topology
  - Devices communicate between each other directly (like walkie-talkies)
- Characteristics
  - Reconfigurable networks
  - No need for a wired infrastructure
  - Suitable for rapid deployment
- Need to “discover” communicating parties, services, methods of routing data, and so on

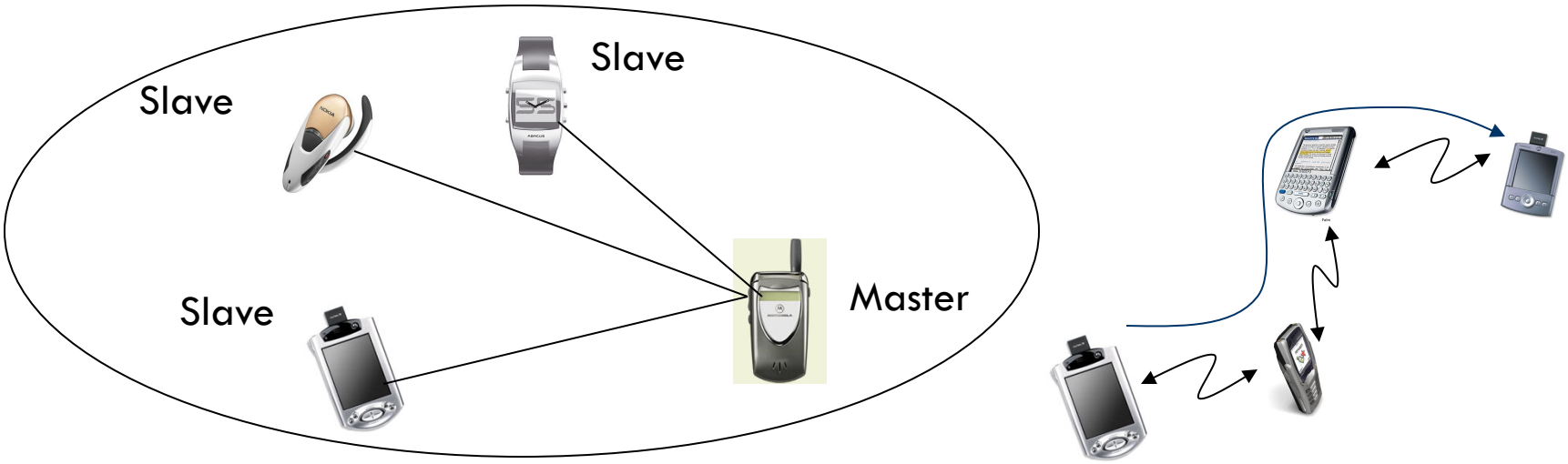
Ad Hoc WLANs

- MSs communicate in a peer-to-peer manner
  - Single-hop: They have to be in range of one another
    - Most vendors support only this option
  - Multi-hop: MSs can act as "relay nodes"
    - HIPERLAN/1 supports this, but there are no real products



Independent Basic Service Set (IBSS) in 802.11 WLANs

Generic Architecture - WPANs



- Ad-hoc topology
- Bluetooth: A “cell” or “piconet” is defined by a Master device
  - The master controls the frequency hopping sequence
  - The master also controls the transmission within its piconet
- Others
  - Sensor networks, RF-IDs, mobile ad hoc networks

PHY Layer Issues

- The radio channel is harsh
  - Cables and wires have "predictable" and time-invariant transmission characteristics
  - The radio channel is dynamic and harsh
  - Examples of problems
    - Fading
    - Multipath dispersion
    - Signal attenuation due to rain or snow
    - Interference (again!)
- Physical layer issues
  - Coverage
  - Harshness of the radio channel
    - High error rates need mitigation
    - Effect on protocols
- Spectrum Regulation
  - The medium of transmission is air
  - The medium cannot be duplicated and it must be shared by ALL applications
    - Communications, broadcast, emergency services, television, military, etc.
    - Sharing is achieved by allocating separate "bands" of spectrum to users of different applications
      - Broadcast radio: 520-1605.5 kHz – AM Radio
      - Broadcast radio: 87.5 – 108 MHz – FM Radio
    - A band of spectrum refers to a range of electromagnetic frequencies
  - The FCC regulates the spectrum allocated to vendors

MAC layer Issues + Network Design & Deployment

- There is LIMITED spectrum for different applications
- The frequency bands are not "contained" as in the case of wired transmissions
  - There is some interference between signals transmitted in one frequency band and another
  - Same thing is true if you choose to split the band for an application (think AM)
- Capacity is limited and we need novel methods to improve capacity
- SUMMARY
  - Spectrum and hence bandwidth is limited
  - Radio transmissions can cause interference
- MAC layer issues
  - Shared "broadcast" medium
    - Need for a simple decentralized medium access mechanism
  - Performance
    - Throughput, delay and QoS
- Network design and deployment
  - No single type of wireless access is available everywhere
  - Spectrum is scarce
    - Coexistence, interference, planning
  - Frequency reuse and cellular topology

Multiple Access Techniques

- Orthogonal waveforms
  - Frequency division multiple access (FDMA)
    - Separate users in frequency
    - Analog 1G systems – AMPS, NMT, TACS etc.
  - Time division multiple access (TDMA)
    - Separate users in time
    - Digital 2G systems – IS-136 and GSM
- Random (pseudo) and orthogonal waveforms
  - Code division multiple access (CDMA)
    - Separate users in "code"
    - Digital 2G system – IS-95
    - All 3G systems – IMT-2000 (W-CDMA and cdma2000)
- Long term evolution (LTE) uses OFDMA

Radio Resource Management

- Resource limitations
  - Radio resources
  - Power:
    - A mobile device does not have a constant power supply and relies on battery
    - Transmissions consume energy!
      - The battery must last as long as possible before being charged
      - The transmission scheme MUST be efficient in terms of energy consumption
- Radio resource and power management
  - Assignment of radio channels and transmit power
  - Admission control, power control and handoff decision

Mobility Management

- Wireless devices are popular because they do not need to be tethered to a place like wired devices
- Wireless devices are continuously changing locations
  - The connectivity changes
  - Devices may move out of coverage of a service
  - Someone should keep track of where the device is to deliver information to it
  - Someone should make sure that the connection is not broken as a wireless device moves
- In wired communications the "address" of the device identifies its location – this is no longer true with wireless devices
- A moving device will "see" a harsher channel!
- Mobility management
  - Location management
    - Tracking where a MS is
  - Handoff management
    - Routing calls/packets as a MS moves
  - Routing in ad hoc networks
  - Database issues

Operations and Security

- Management and Security
  - Mobile end host is no longer confined to the home network
  - Wireless links can be easily "tapped"
  - Fraud
  - Accounting and billing
  - Conflicts with other issues
- Network operations and management
  - Accounting and billing to charge subscribers correctly
  - Access to resources and services on the network
- Service discovery and data management
  - Sensors and RF-IDs
    - How is data maintained?
    - Where should data reside?
    - How can it be efficiently accessed?

Mobile Device

- Form factor and capabilities
  - A mobile device has to be light weight, durable, have long battery life and yet be capable of performing complex tasks
  - Energy efficient design of software and protocols
- Usability
  - User characteristics (size, dexterity, knowledge, etc.)
  - Environment characteristics (temperature, degree of mobility, etc)
  - Device Characteristics
    - Start up time
    - Data integrity and security
    - cpu speed and memory size
    - Power supply
    - User interface (keypad, stylus, voice)

Summary - I

- Spectrum is scarce
  - We need to squeeze as many data bits as possible in a given bandwidth
  - The more data bits you squeeze in the more stringent are the system requirements
    - Example: Squeezing in more data => larger signal to noise ratio requirement => larger transmit power => lower battery life
    - Example: multipath dispersion is not a problem at low data rates
    - Example: complex processing can result in large form factor

Summary - II

- Physical layer makes wireless communications unreliable and erroneous
  - Contributes greatly to the complexity of the system
  - Impacts all other aspects of a wireless system
- Fundamentally different from wired networks
  - Resource issues
  - Mobility issues
  - Design issues