MSIT 413: Wireless Technologies

Week 1

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Outline

- Background and history
- Overview of current wireless services and standards

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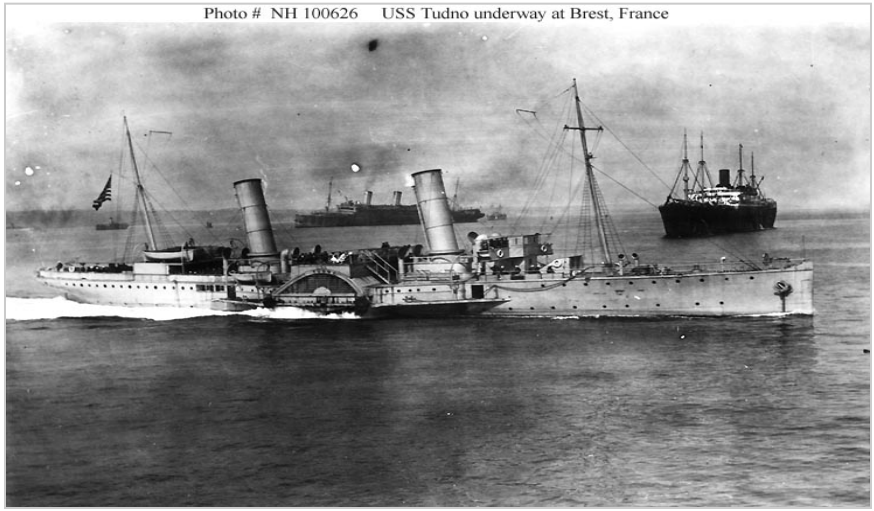
- Overview of current wireless services and standards

Early Wireless Communications

Beginning of Modern Wireless Networks

Guglielmo Marconi and his wireless telegraph machine.

First Applications



Earliest uses of wireless for ship-to-ship, ship-to-shore communications.

Broadcast radio begins in 1921.

Licenses issued by the Department of Commerce.

What is Wireless?

Examples of wireless communications systems:

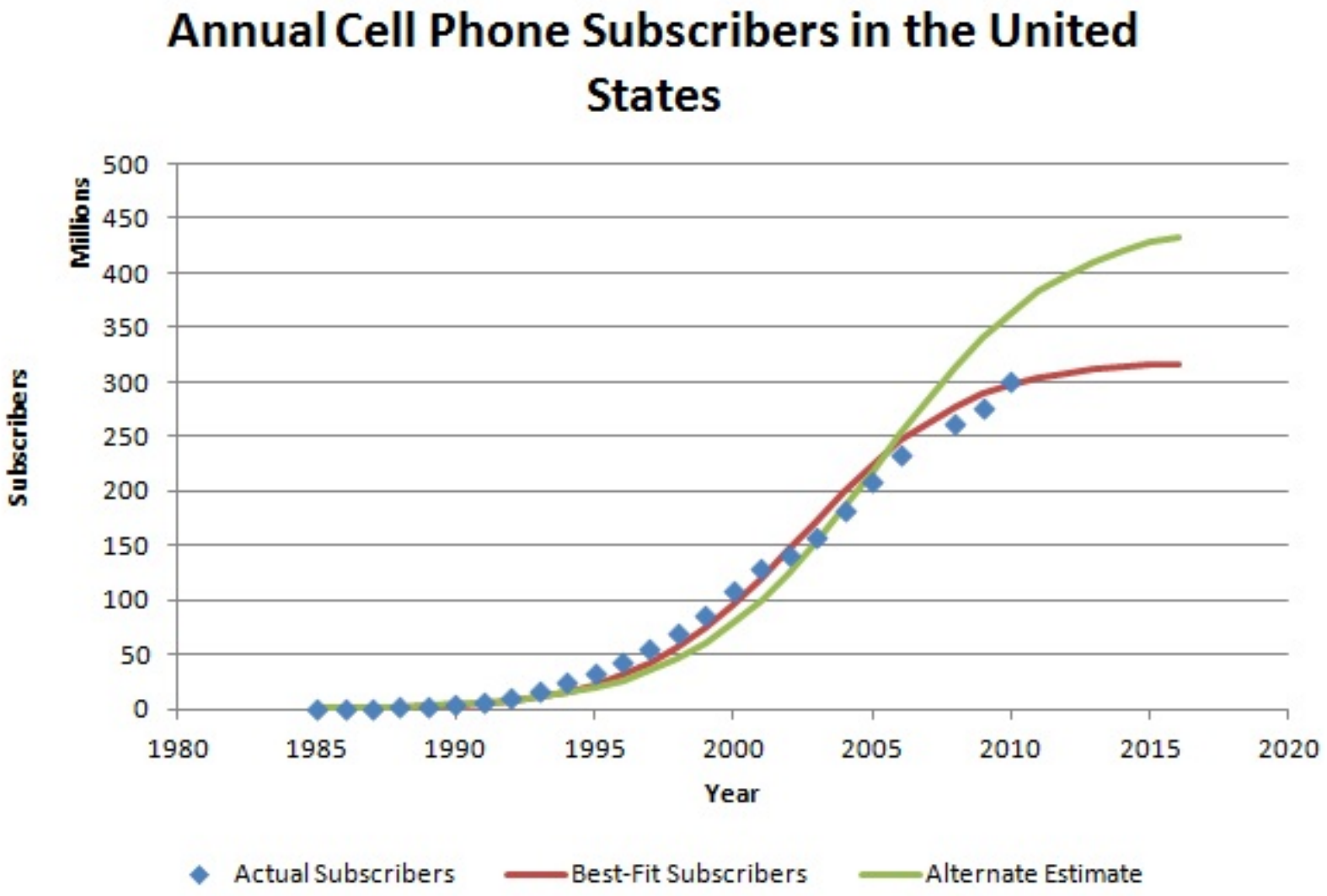
1. **Garage door openers**
2. **Remote controllers (TV, VCR, etc.)**
3. **Walkie-talkies**
4. **Broadcast TV, radio**
5. **Telemetry (RF tags)**
6. **Amateur radio, CB**
7. **Police radio, dispatch**
8. **Satellite systems**
9. **Cordless telephones**
10. **Cellular**
11. **Wireless Data (data entry, texts, email, internet)**
12. **Wireless Local Area Networks (LANs)**
13. **Wireless Personal Area Networks (PANs)**

Wireless Information Networks (8-14)

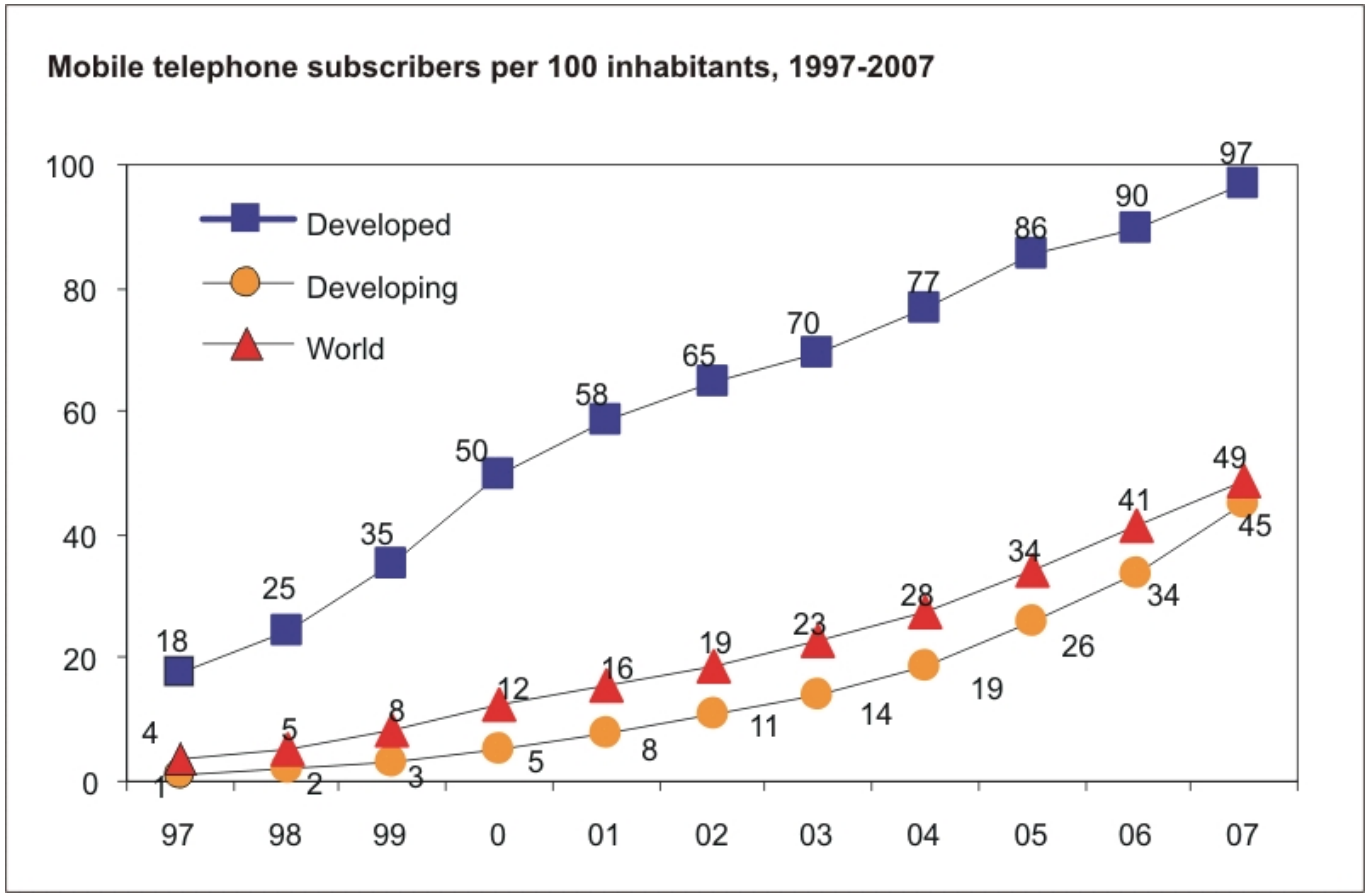
Properties:

- Mobility or portability
  ("tetherless" communications)

- Access to network resources
  - Public Switched Telephone Network (PSTN)
  - Internet
  - Local Area Network

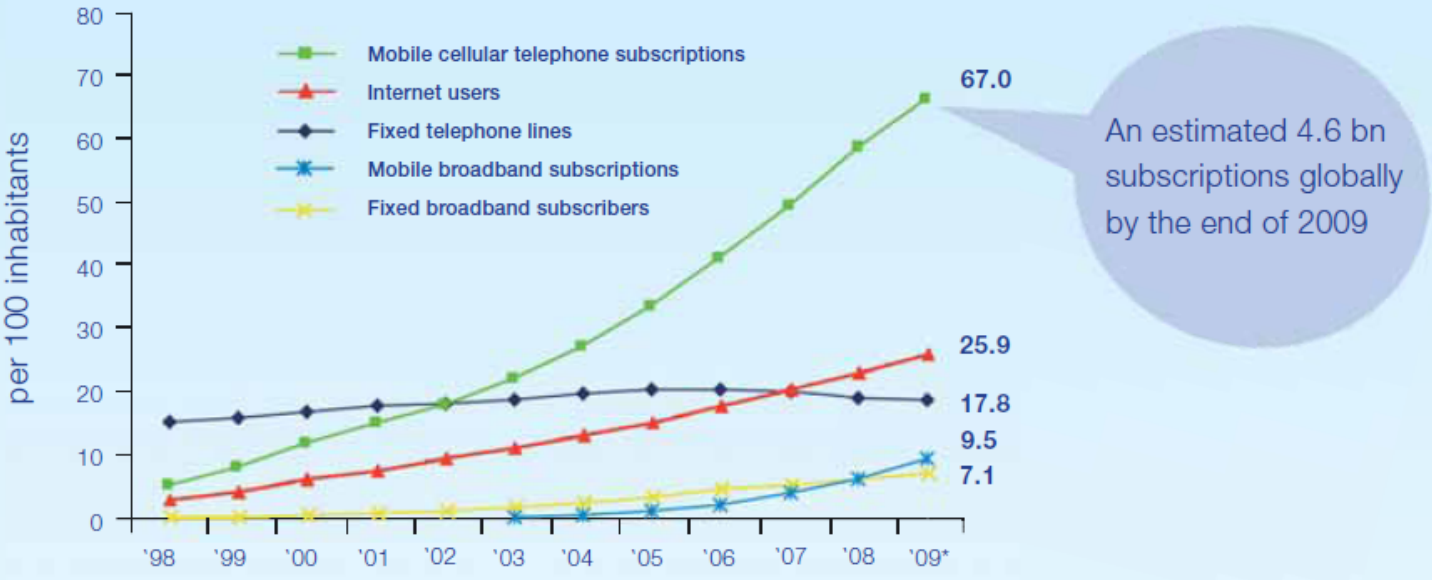

Annual Cell Phone Subscribers in the United States
Millions
Subscribers
500
450
400
350
300
250
200
150
100
50
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year
Actual Subscribers
Best-Fit Subscribers
Alternate Estimate

Cellular Subscriber Growth



Taken from http://www.itu.int/ITU-D/ict/statistics/ict/index.html

Comparison of Mobile and Fixed Access



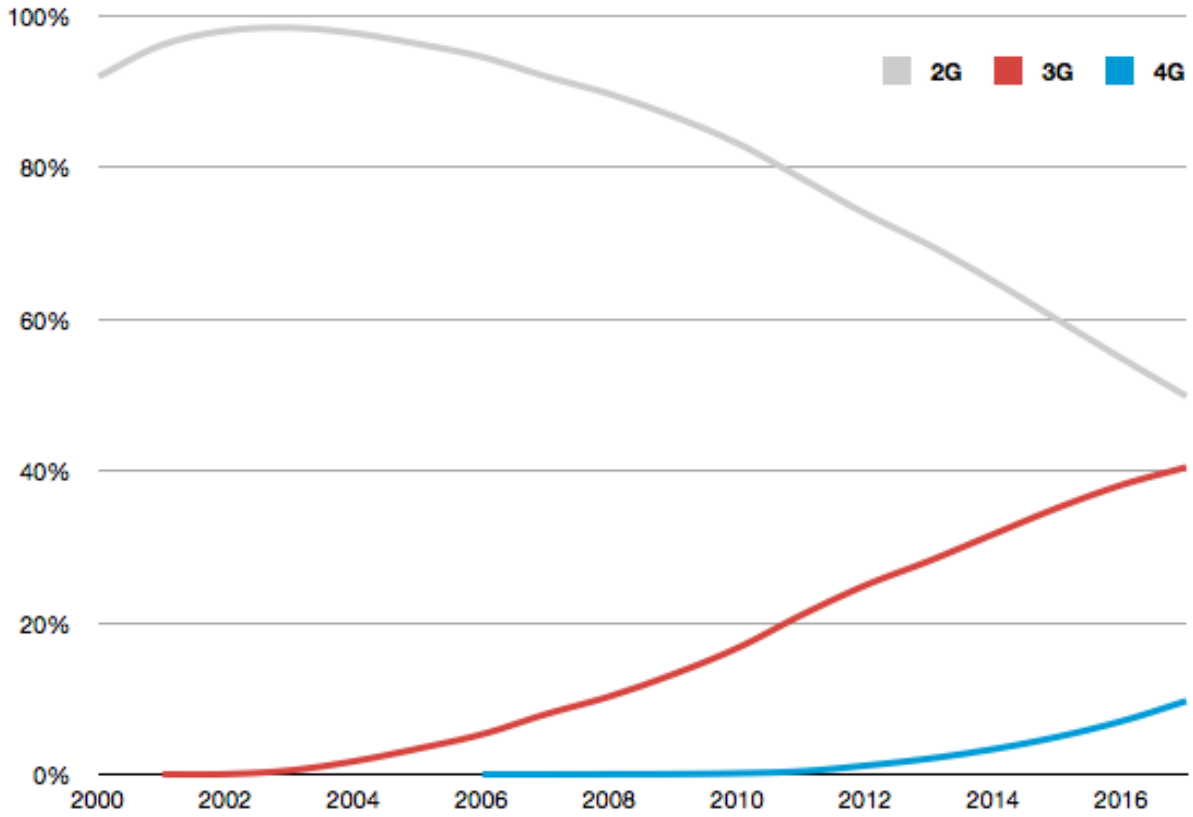
Source: ITU World Telecommunication/ICT Indicators Database.
** Estimates.*

- Mobile cellular has been the most rapidly adopted technology in history. Today it is the most popular and widespread personal technology on the planet, with an estimated 4.6 billion subscriptions globally by the end of 2009
- Mobile broadband subscriptions overtook fixed broadband subscribers in 2008, highlighting the huge potential for the mobile Internet

Market Trends

- Both cellular and cordless have experienced very rapid growth (>30% per year during the late 90's, 24% per year from 2000-2008)
- Number of subscribers exceeded 2B (billion) in 2006, > 4B in 2008, ~4.6B in 2010.
- Income of wireless industry exceeds income of wired telephone industry
  - Dominated by cellular revenues.
- Penetration exceeds 100% in the U.S., higher in Europe
- Continued growth due to new data services.
  - Social networking, video, broadband internet access
  - Voice over IP

Migration from 2G to 4G



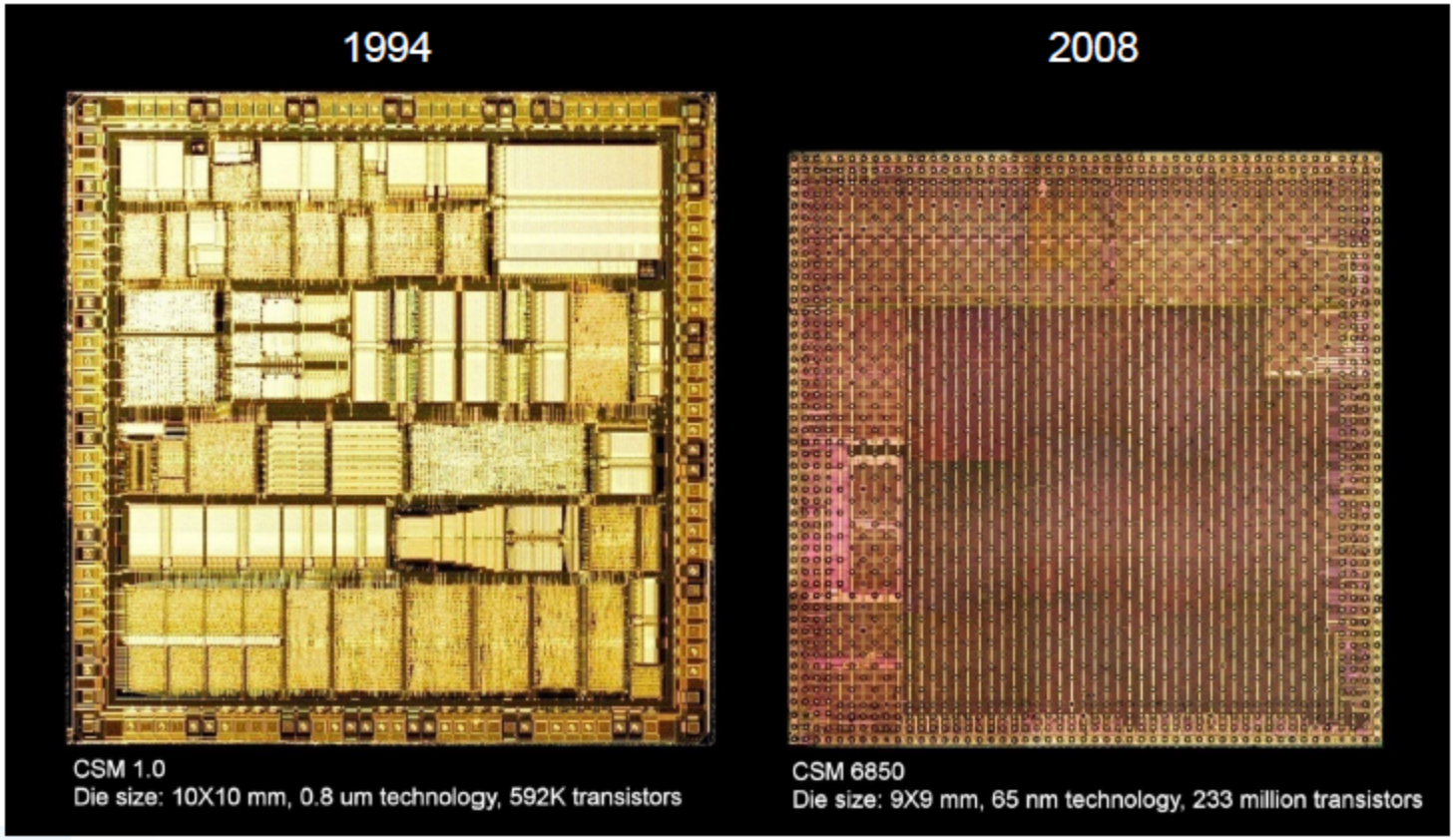
from https://gsmaintelligence.com/

Why So Much Growth ?

- Technological advancements
  - VLSI microprocessors, Digital Signal Processors (DSPs)
  - Low power Radio Frequency (RF) circuits
  - Rechargeable batteries
  - Signal processing algorithms (voice compression)
  - System concepts
    - *Cellular networks*
    - *Coding/modulation*
    - *Multiple-access*
  - Networking advancements
    - *Stored program (computer-controlled) call-setup/switching*
    - *Digital control of wireless links (channel assignment, handoff, call setup)*
- Market demand
  - Higher productivity (mobile office)
  - Increased dependence on mobile applications

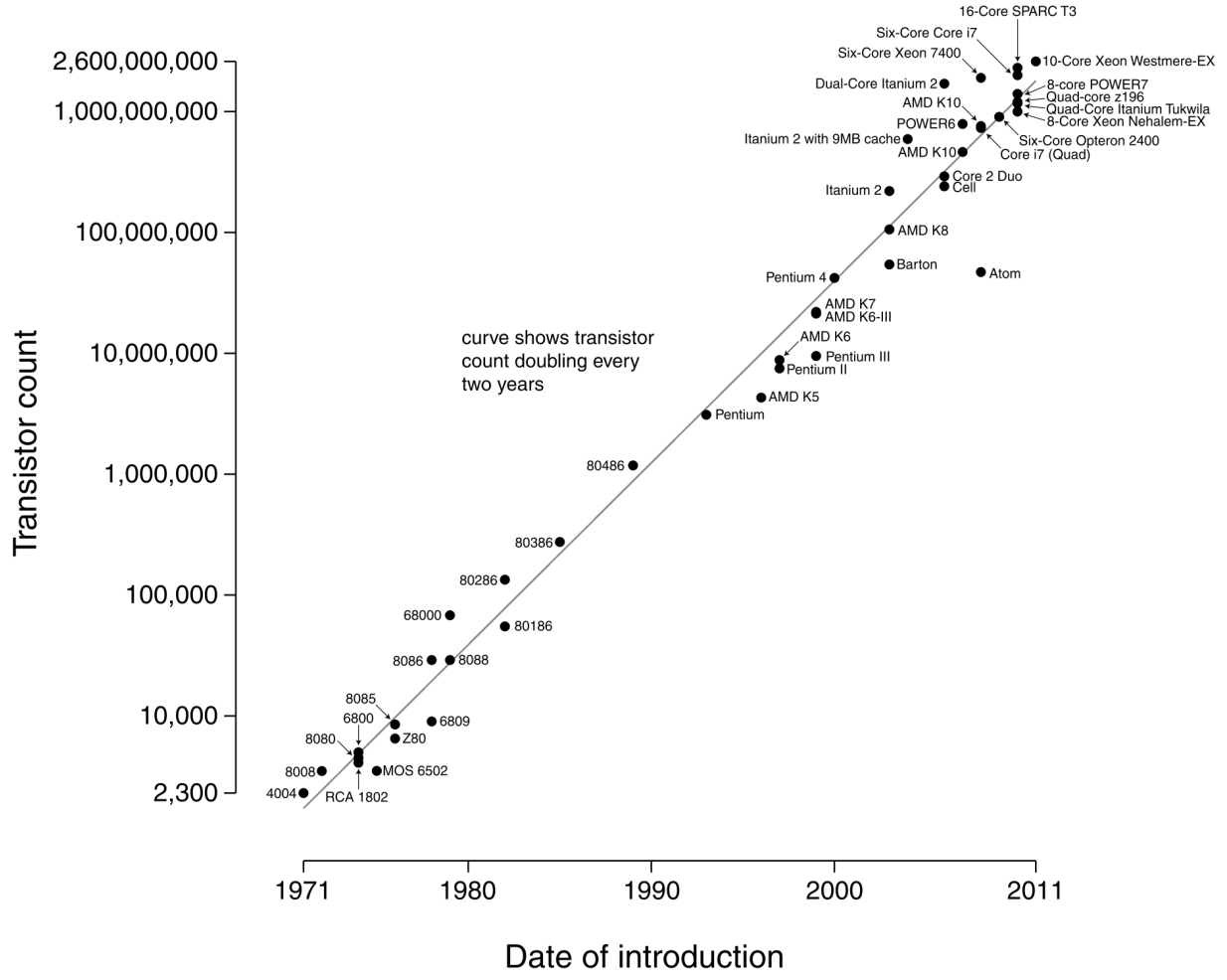
Why So Much Growth ?

- Technological advancements: microelectronics



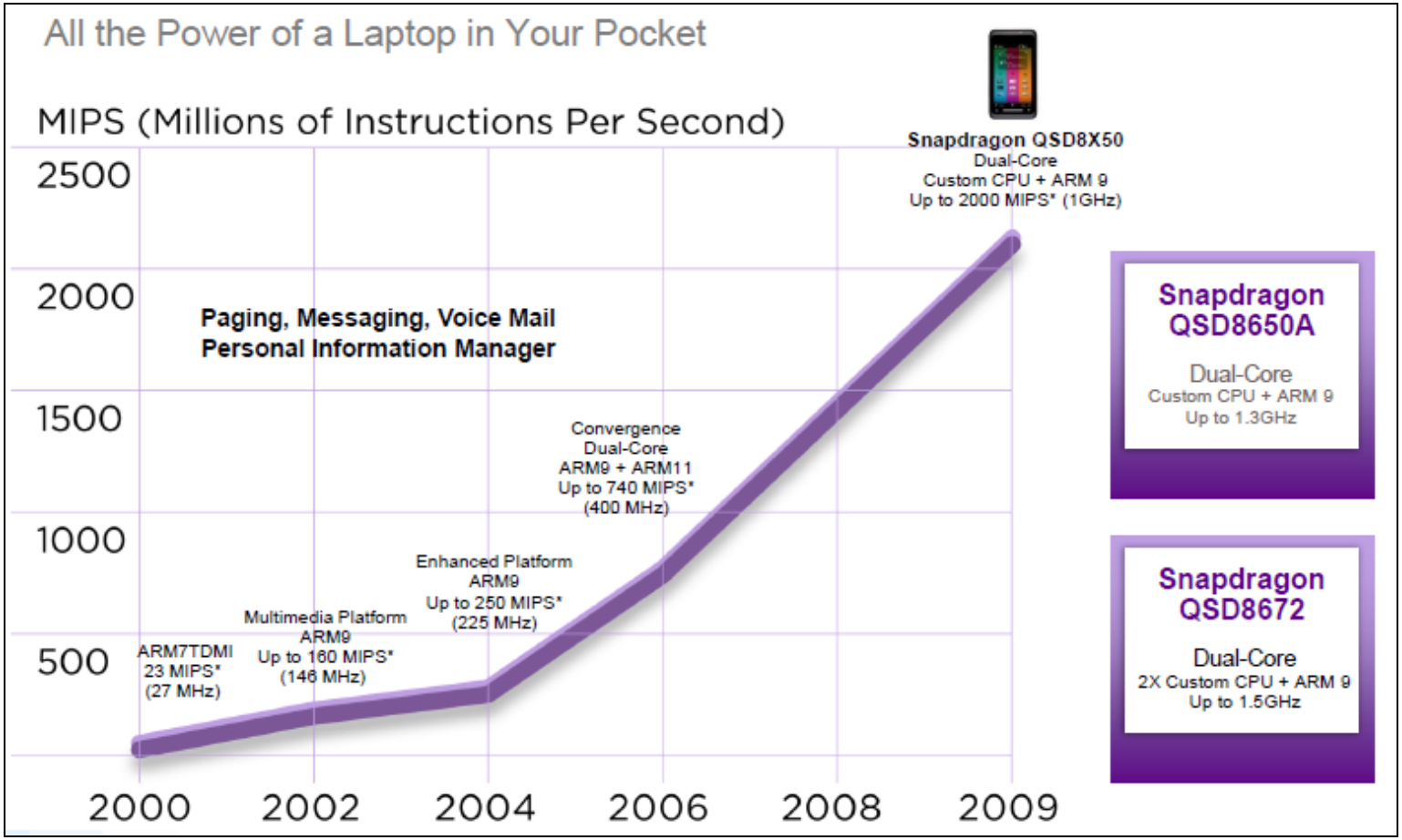
Network modem chips

Microprocessor Transistor Counts 1971-2011 & Moore's Law



Why So Much Growth ?

- Technological advancements: computing



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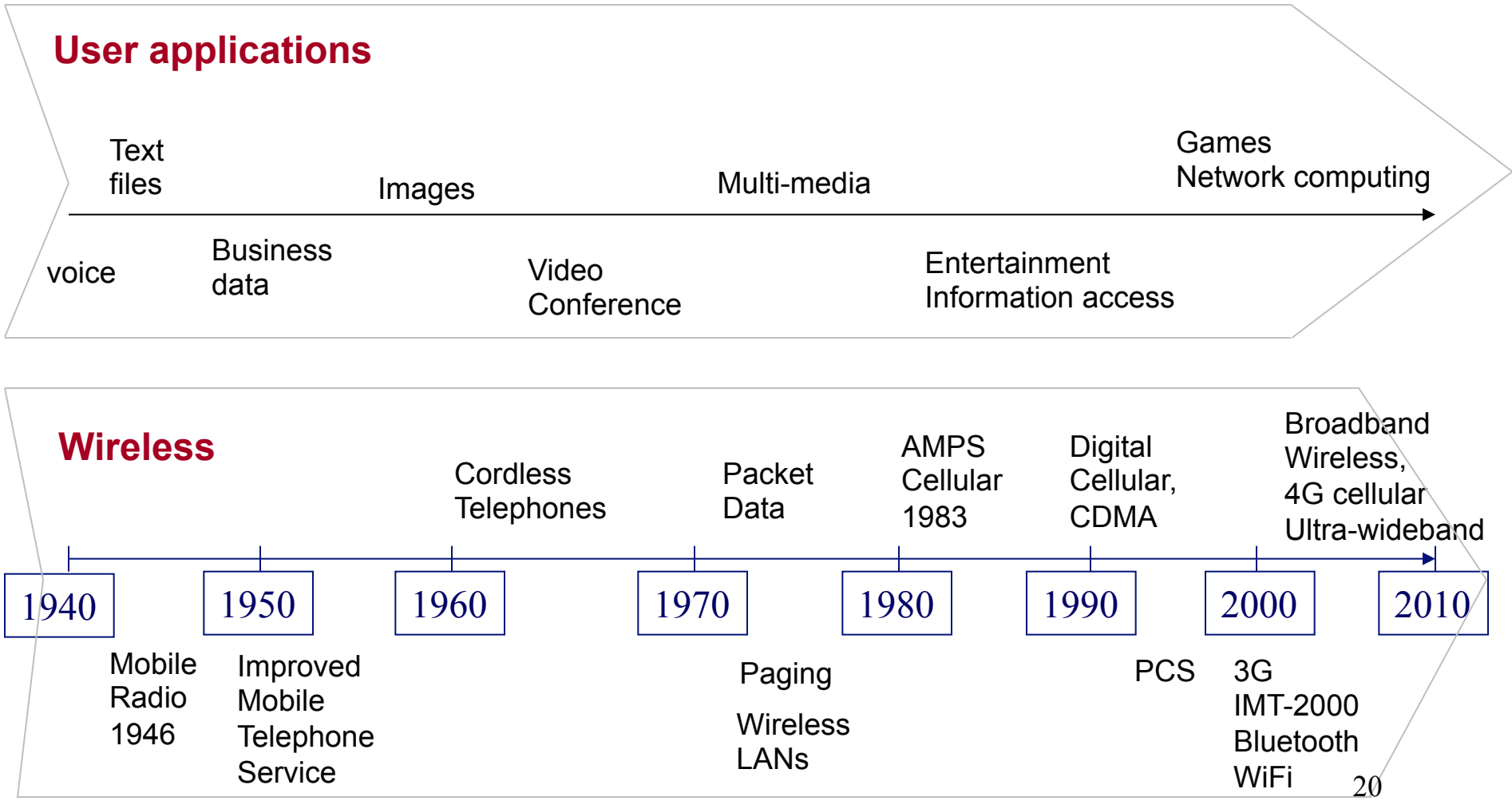
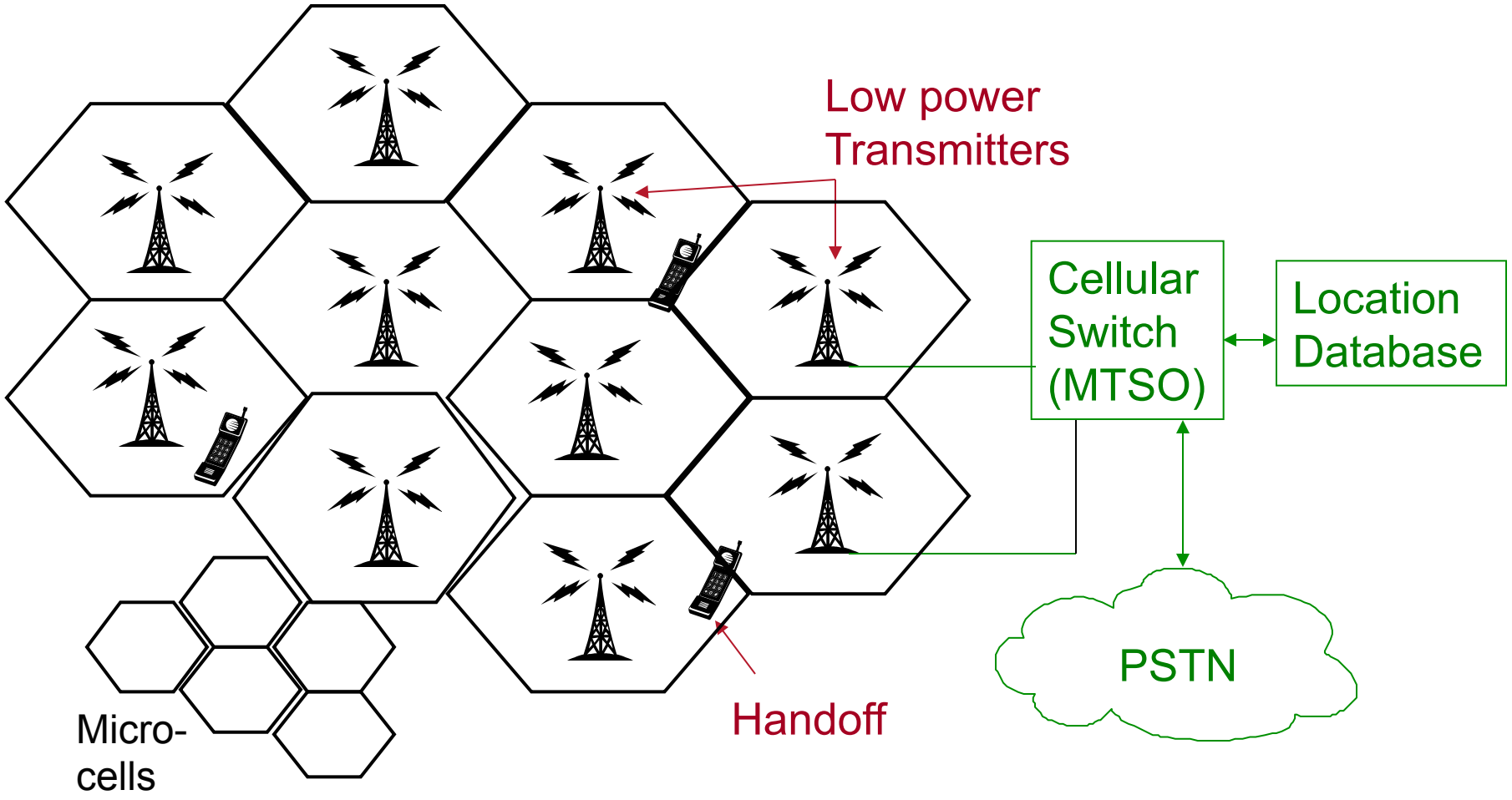
Communications Evolution



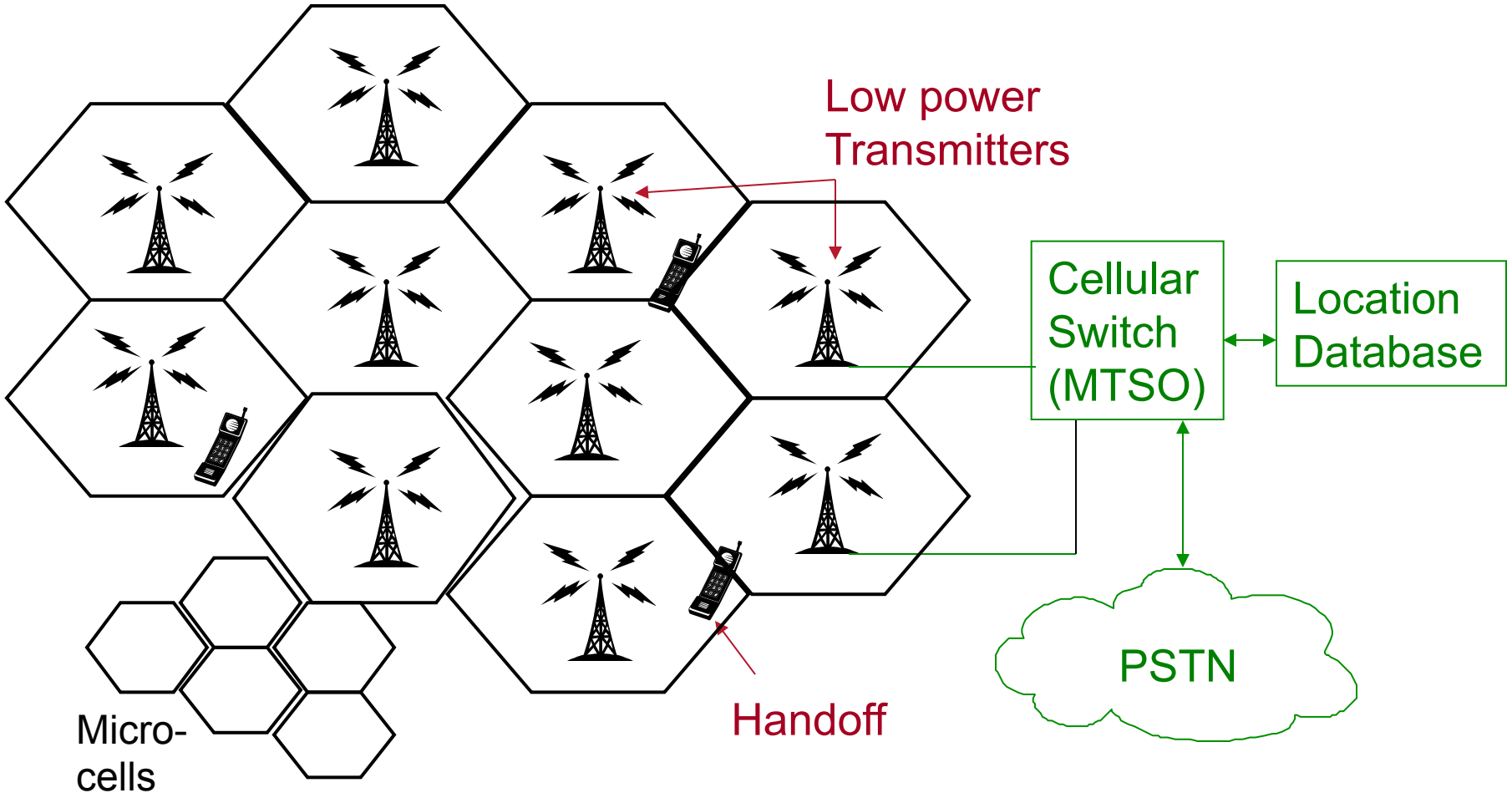
Historical Notes

- Original mobile radio systems used a single, high-powered transmitter to cover a radius greater than 50 km
- Early systems used FM with 120 kHz bandwidth for a 3 kHz voice signal. This was later reduced to 60 kHz, then to 30 kHz.
- Improved Mobile Telephone Service (IMTS) -- introduced trunking
  (Many mobiles shared a single channel)
- Demand for mobile telephony greatly exceeded system capacity:
  By 1976, Bell Mobile phone service for NYC market (approximately 10,000 people) had only 12 channels, and could serve 543 paying customers over 1000 square miles. The waiting list was > 3,700!
- The FCC finally allocated additional spectrum for mobile telephony in the late 70s by moving UHF TV channels

Cellular Concept

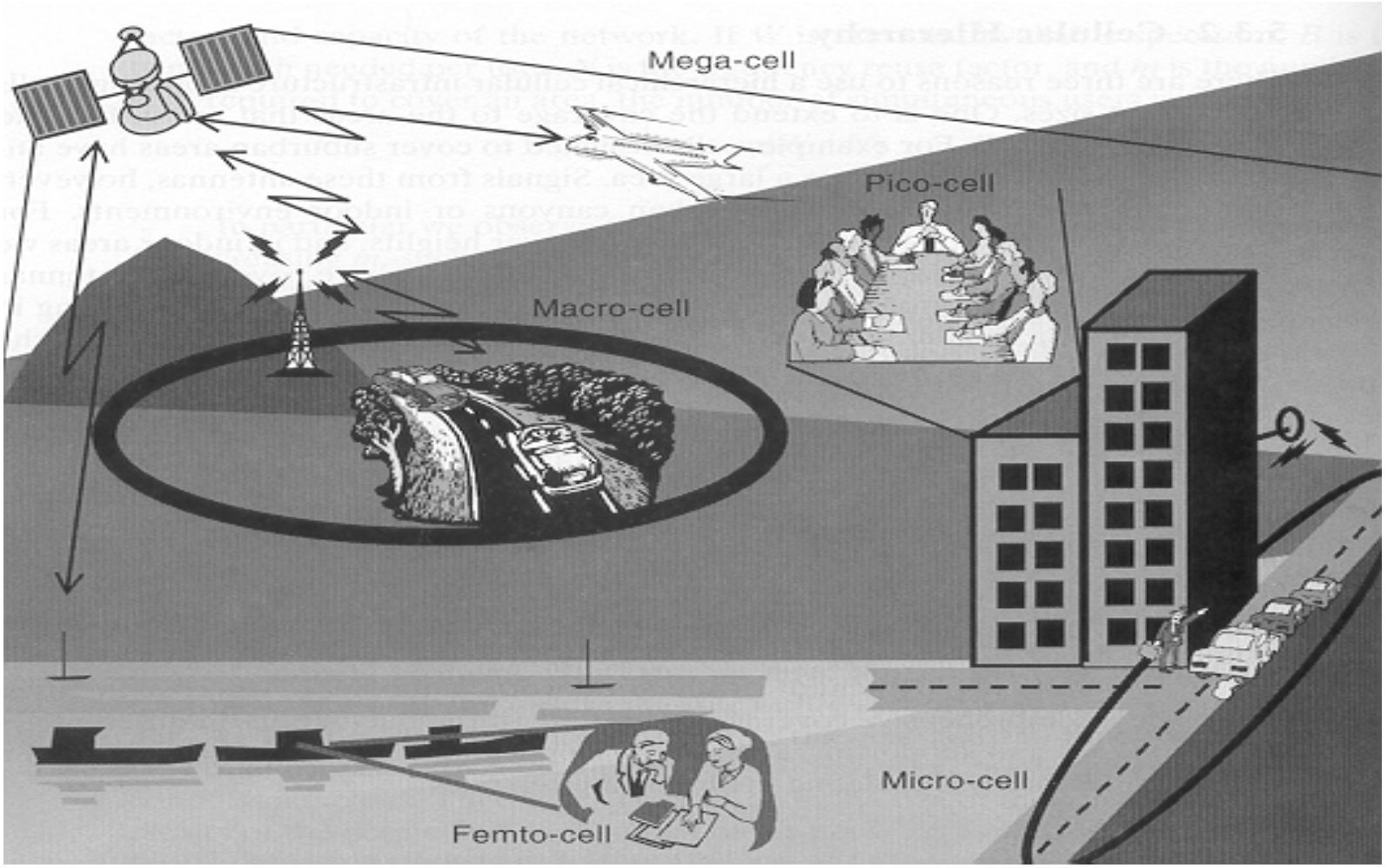


Cellular Concept

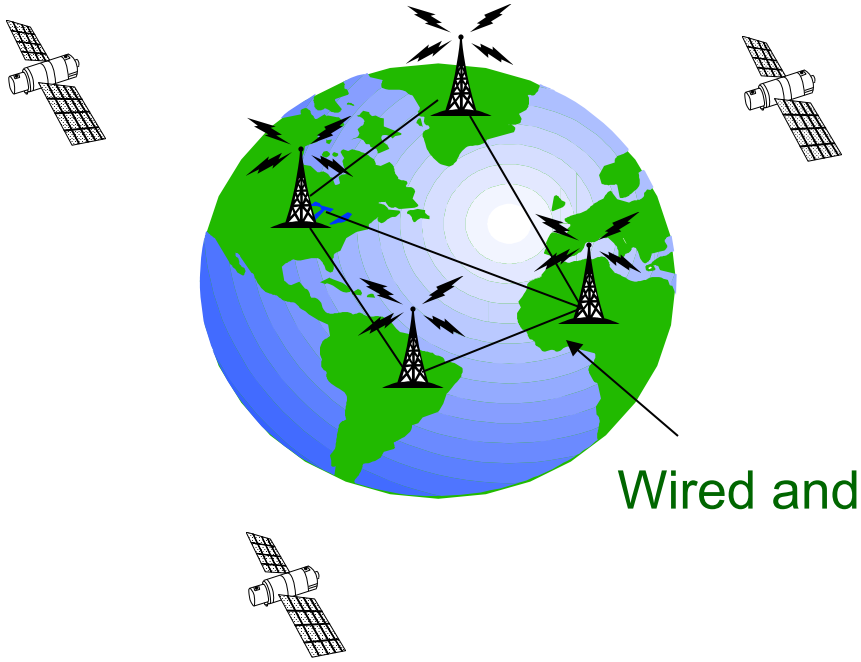


Enables frequency reuse!

Cellular Hierarchy



The Personal Communications Concept
(80's)



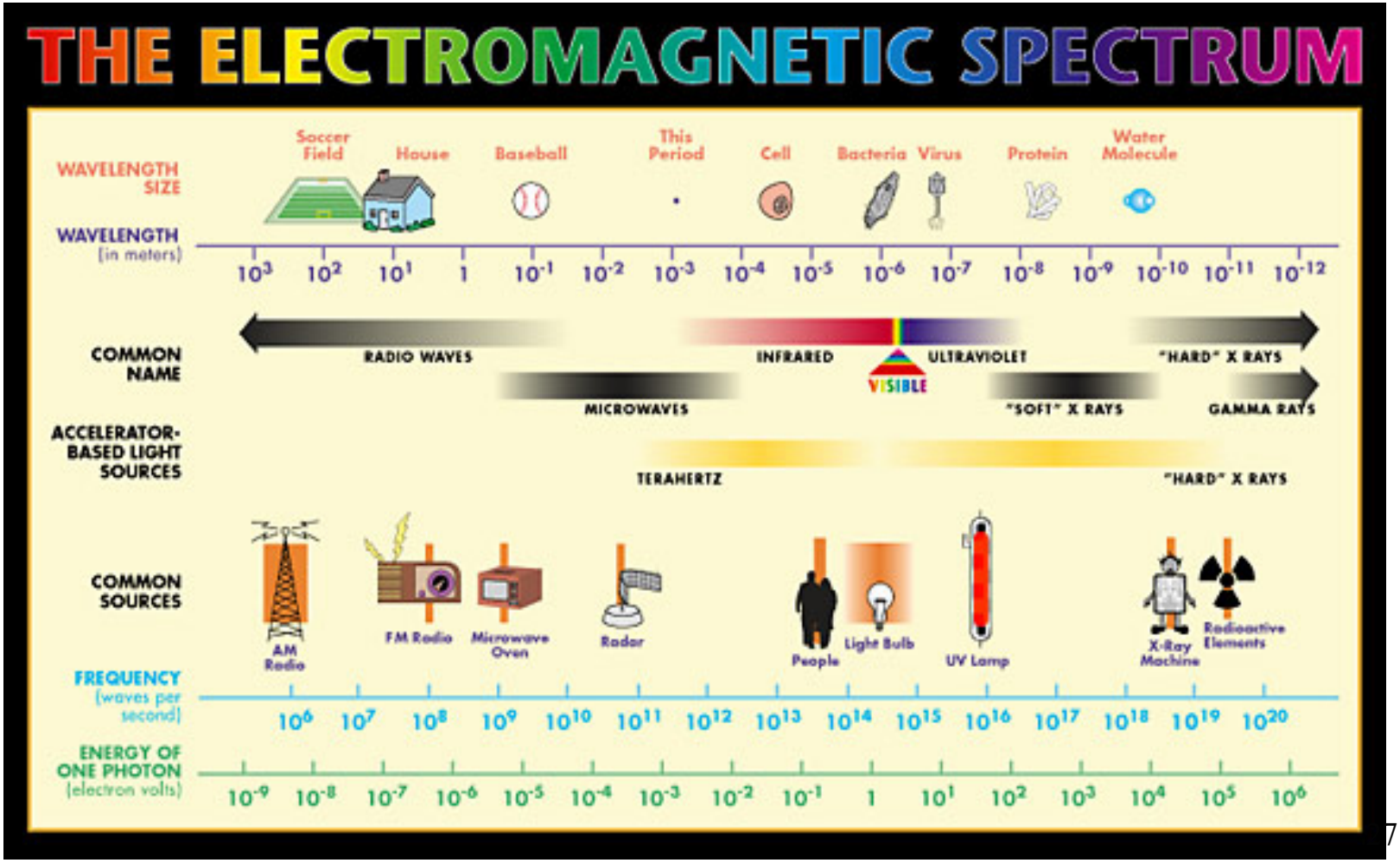
Wired and wireless networks

Communications between people and/or machines anytime, anywhere, any place.

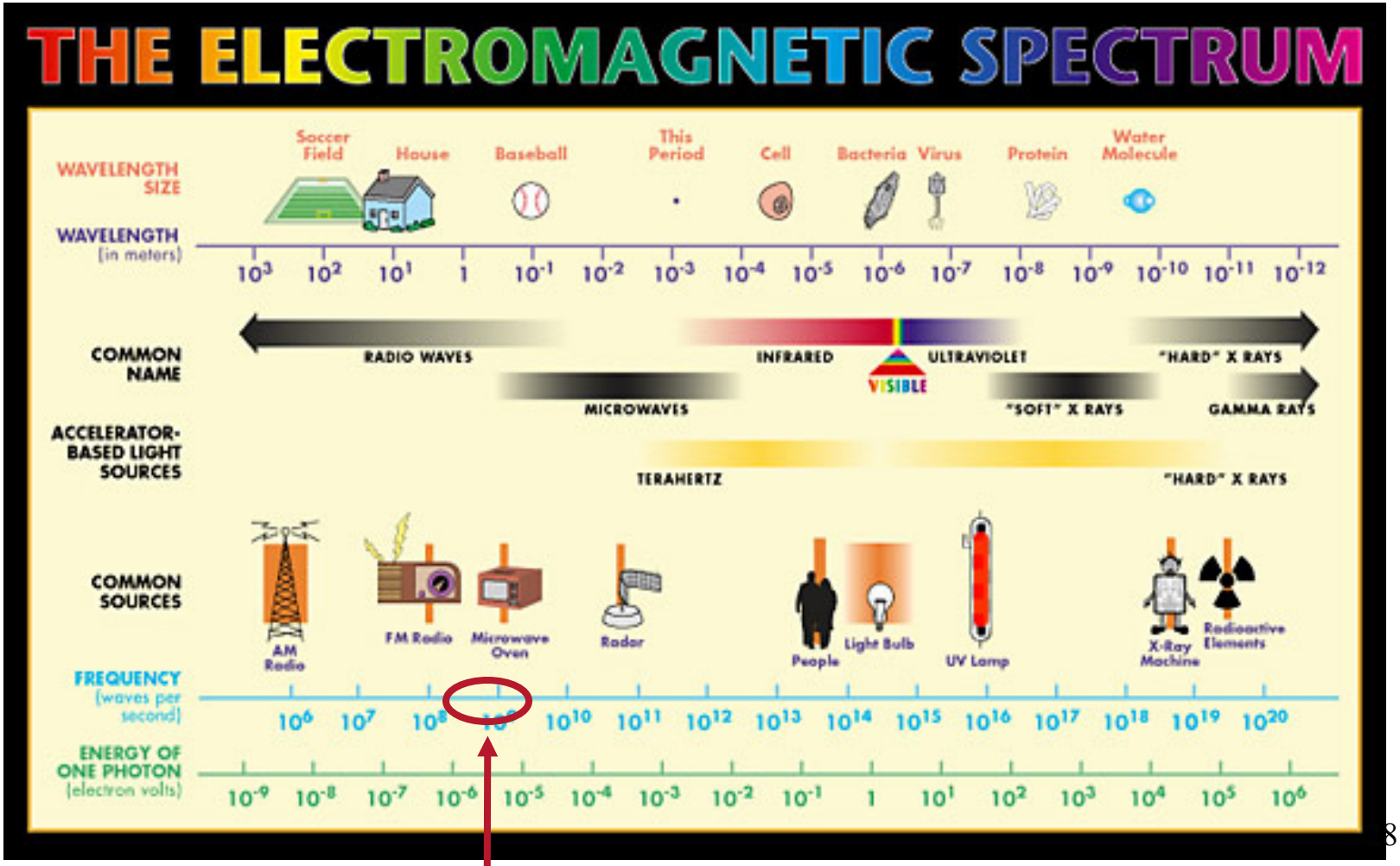
Personal Communications Services (PCS)

- Originally a vision for the extension and integration of wired and wireless telecommunications network capabilities (1980s).
  - *Wireless: cellular, cordless, paging, PBX, satellite, air-to-ground*
  - *Wireline: PSTN, internet, LANs, private networks*
- More than wireless (service concept)
  - *Service profile follows user.*
- Provides interoperability among wireline, wireless networks
- Encompasses all cellular hierarchies (pico through macro)
- Integrated services (voice, data, broadcast, multimedia)

PCS Challenges: 1. Spectrum Allocation



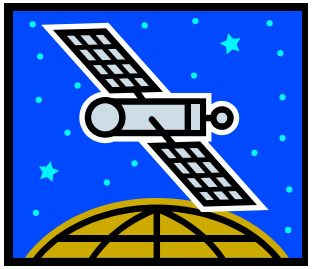
PCS Challenges: 1. Spectrum Allocation

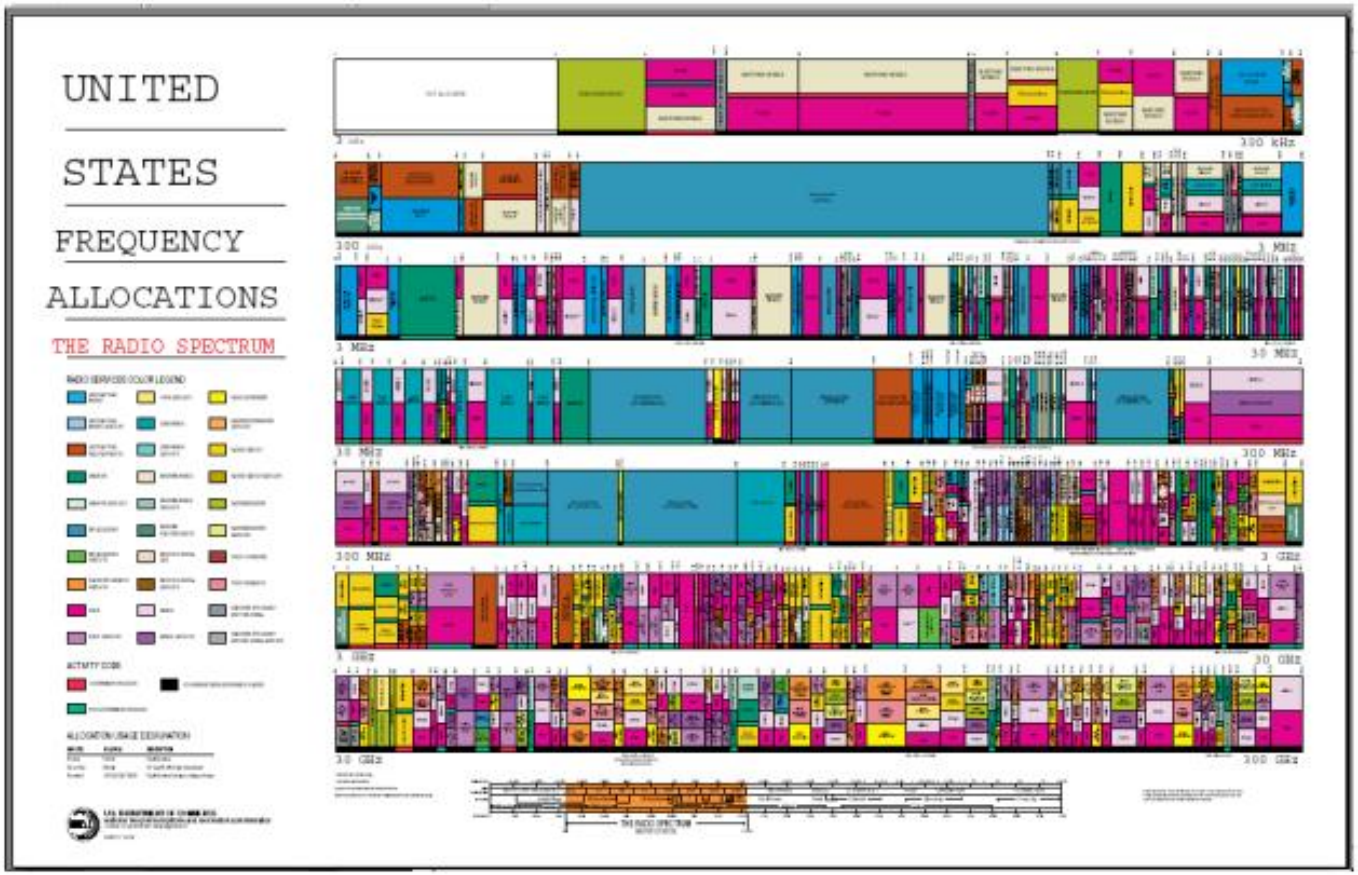


Useful for cellular services

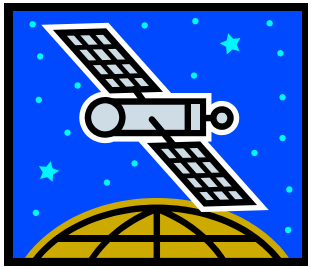
PCS Challenges:
1. Spectrum Allocation

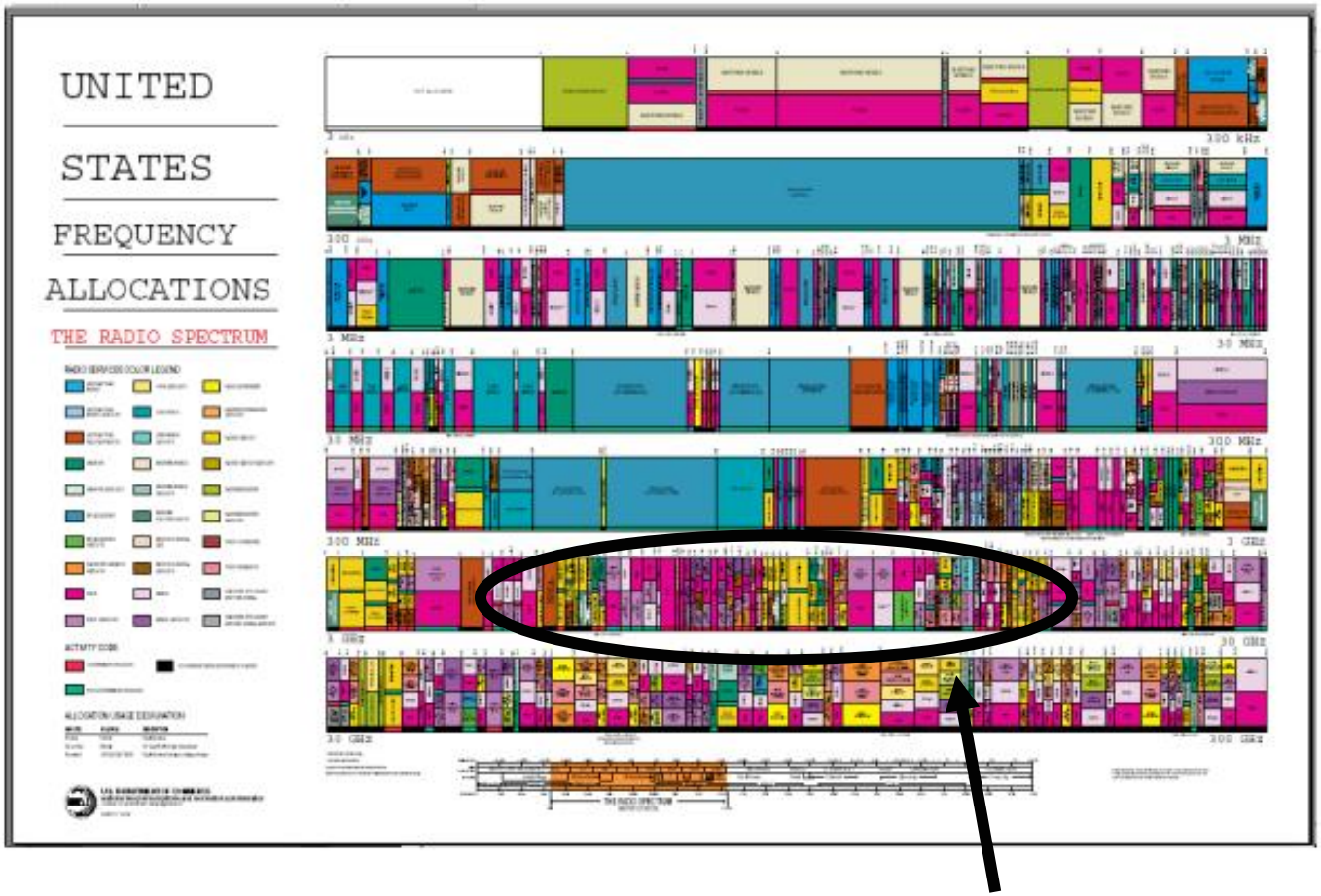
- Global, transparent service requires that the same spectrum be available everywhere.
- Must have an international standards body to allocate spectrum for this purpose.




UNITED
STATES
FREQUENCY
ALLOCATIONS
THE RADIO SPECTRUM


BYE
BYE





“beachfront property”:
Between ~ 700 and 900 MHz

International PCS Spectrum Allocation

- Task of the International Telecommunications Union (ITU)
  - Standards body for United Nations
  - Headquarters in Geneva, Switzerland
- International Mobile Telecommunications (IMT) 2000
  - Initiative for Third Generation mobile telephony within the ITU
- World Radiocommunication Conferences (WRC)
  - Targeted 230 MHz for IMT 2000 in 1992 (1885-2025 MHz, 2110-2200 MHz)
  - Targeted additional 329 MHz for 3G networks in 2000 (2500-2690 MHz, 1710-1885 MHz, 806-960 MHz)
  - Targeted 255 MHz in 5 GHz band for unlicensed spectrum (WLAN) in 2003
  - Targeted additional spectrum for cellular services in 2015.

Licensed Spectrum: For "Exclusive Use"

- Spectrum owned by government
  - Licensed to particular application, service provider (e.g., Broadcast TV, Verizon, AT&T, etc.)
  - Rigid use rules
- Spectrum is private property
  - Applications, technical constraints decided by markets

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- "Liberal" licenses (current cellular allocations)
  - Spectrum publicly owned, but licenses can be transferred, liberal use rules
  - Secondary markets (2003)

Unlicensed Spectrum: Open Access ("Commons")

- Open access (anyone can use the spectrum)
- Requires etiquette rules for sharing (e.g., power limits)

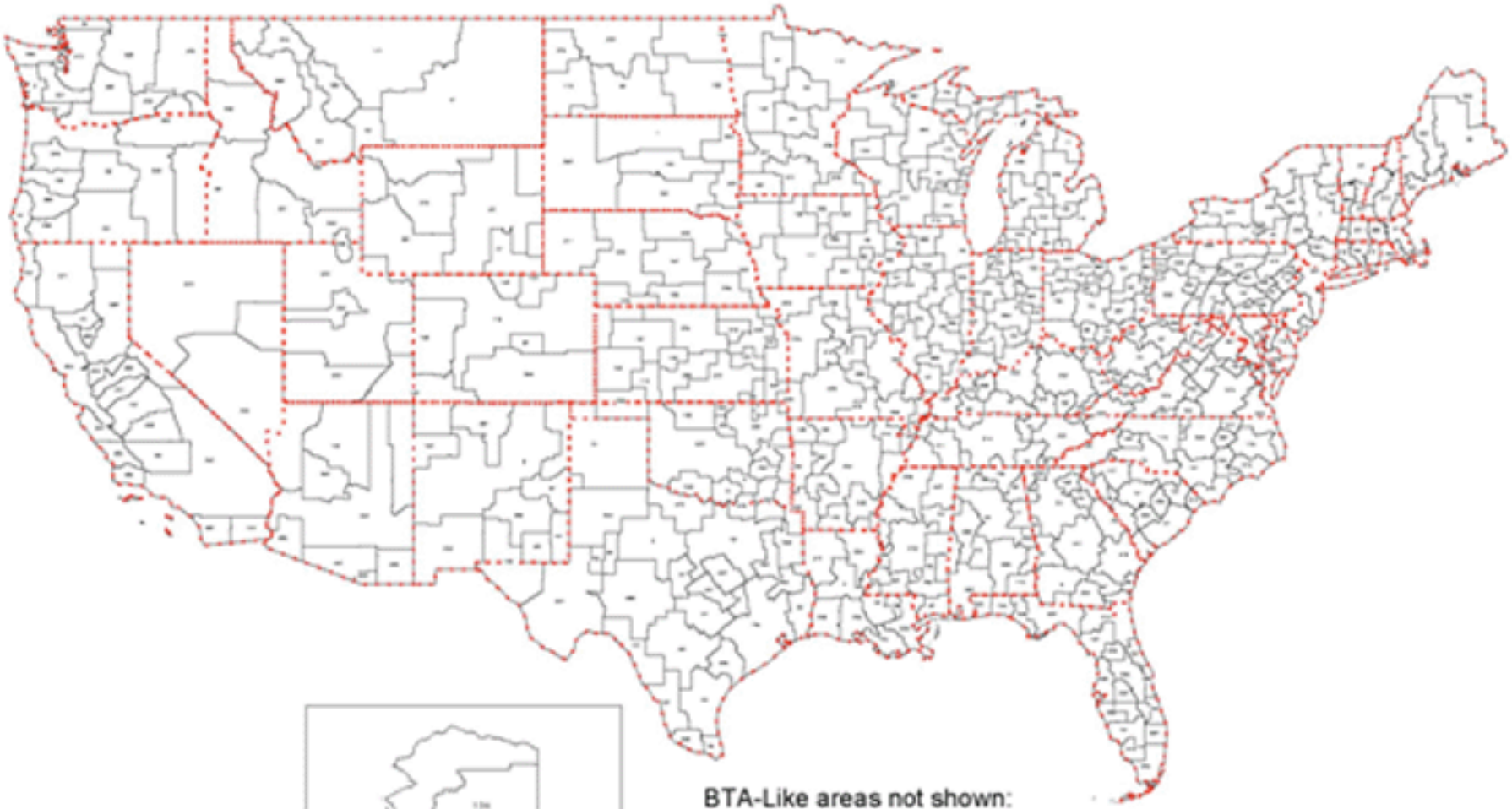
- Spectrum owned by government
- Etiquette rules part of industry standard (802.11)

Licensed vs Unlicensed Spectrum

- Licensed spectrum (cellular)
  - Licenses apply to separate geographic regions (e.g., “basic/major” trading areas)
  - Allocated via auctions managed by FCC
  - Substantial source of revenue:
    - *More than $30 B netted by U.S. government in mid-90s*
    - *England netted $35.5 B (5 licenses); Germany netted $46 B (4 licenses)*
    - *Nearly $20 B for 700 MHz auctions in 2008*
    - *$40B for AWS-3 auction in 2015*
    - *$20B for 600 MHz incentive auction in 2017*

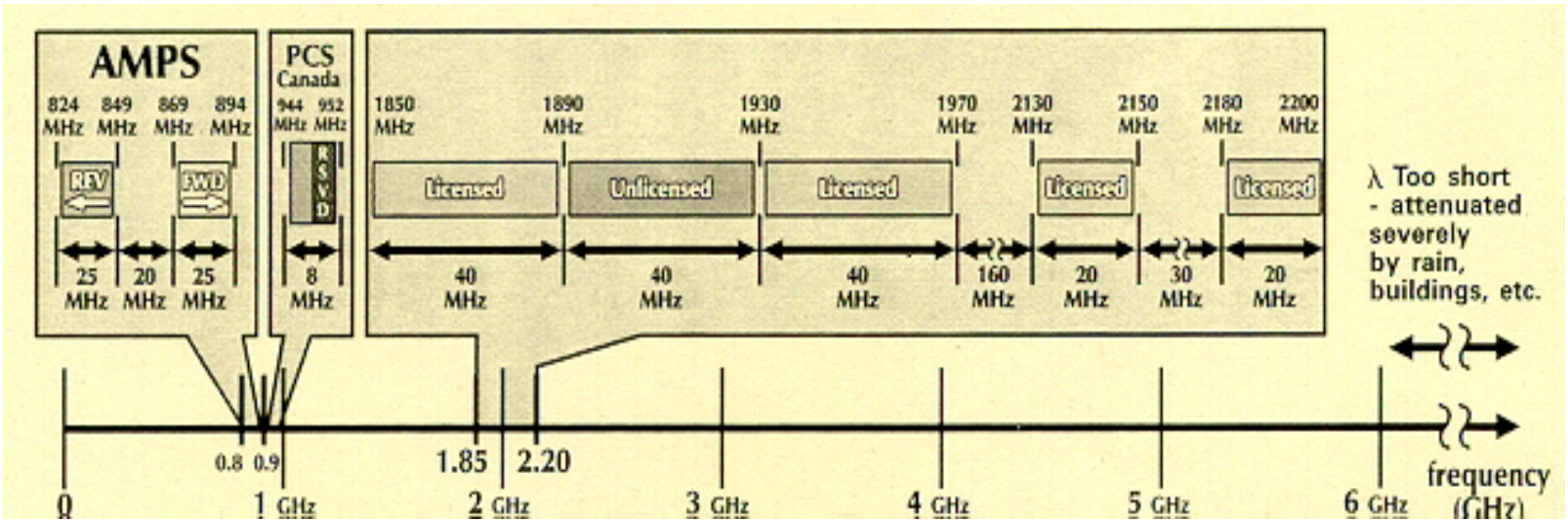
- Unlicensed spectrum (WiFi)
  - Industrial, Scientific, and Medical (ISM) bands (mid 80’s)
    - *902-928 MHz, 2400-2483.5 MHz, 5150-5350 MHz*
    - *Used by Wireless LANs (802.11), Bluetooth, Zigbee*
  - Unlicensed National Information Infrastructure (UNII) band *(1997)*
    - *Additional 300 MHz in ISM bands 5150-5350 MHz and 5725-5825 MHz*

Basic Trading Areas



BTA-Like areas not shown:
B488 San Juan, PR
B489 Mayaguez, PR
B490 Guam
B491 US Virgin Islands
B492 American Samoa
B493 Northern Mariana Islands

Cellular/PCS Spectrum Allocation (1993)



Wavelengths too long; propagates too far

802.11b/g (WiFi), 2.4 GHz

802.11a 5.2 GHz

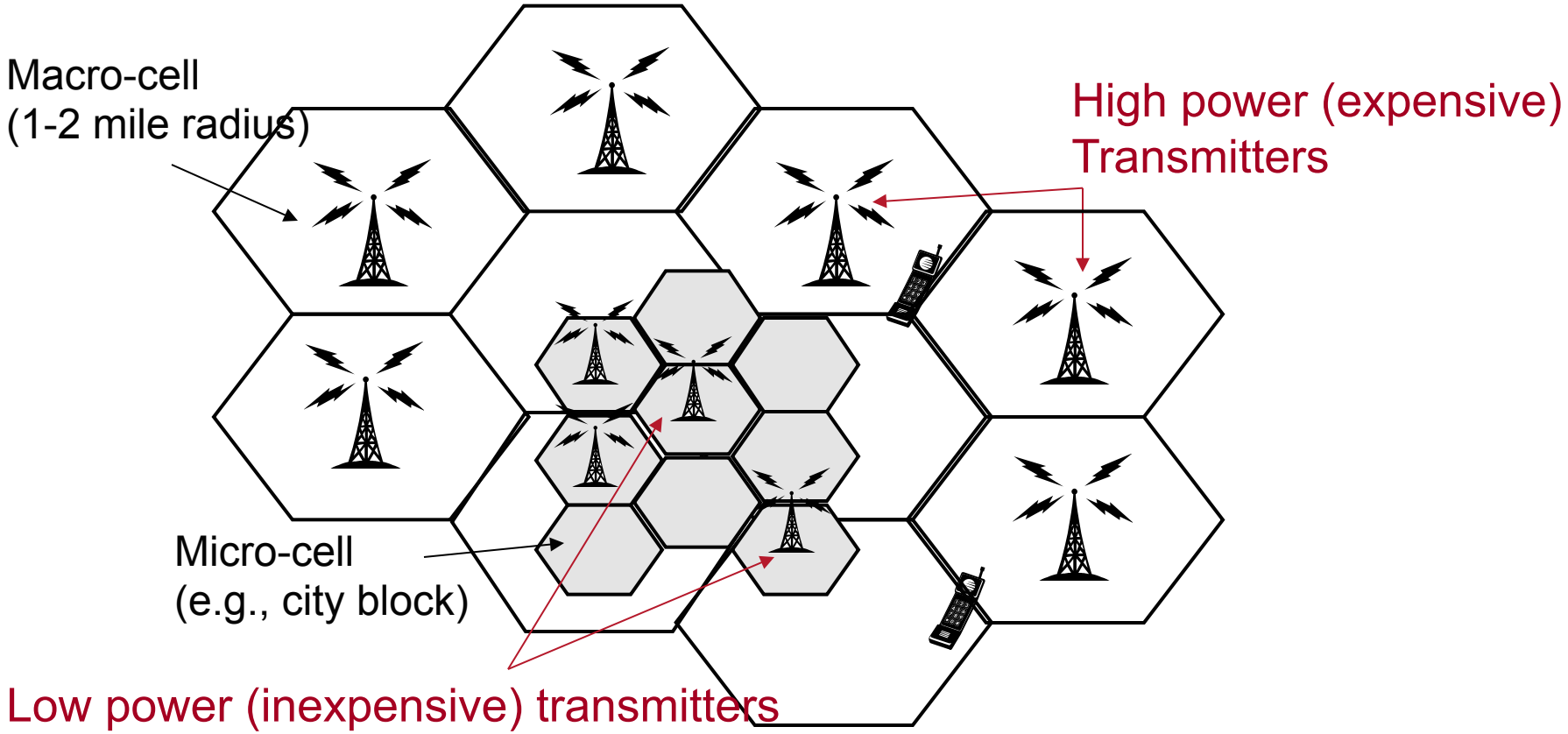
PCS Challenges: 2. Interoperability

- Multiple cellular standards (North American, European, Japanese, Chinese…)
- Multiple vendor-specific air interfaces.
- Heterogeneous network architectures with multiple vendors complicates control signaling, maintenance, network management, and security.

Potential Solution: Software Radio

- Radio functions implemented via digital signal processing and programmable hardware
- Ability to download an air-interface architecture and dynamically reconfigure the user terminal
- Could support multiple standards/transmission modes.
- Proposed implementations
  - *Real-time compiler of air-interference software*
  - *Smart cards*
  - *Universal control channel for accessing software*
- Increases lifetime of handset
- Evolution to *cognitive* radio
  - Automatically selects frequency band and configures transmitter to avoid interference; adapts to user preferences

Challenges to PCS: 3. Integration of Micro-/Macro-Cells



Handoffs and interference management are major issues!

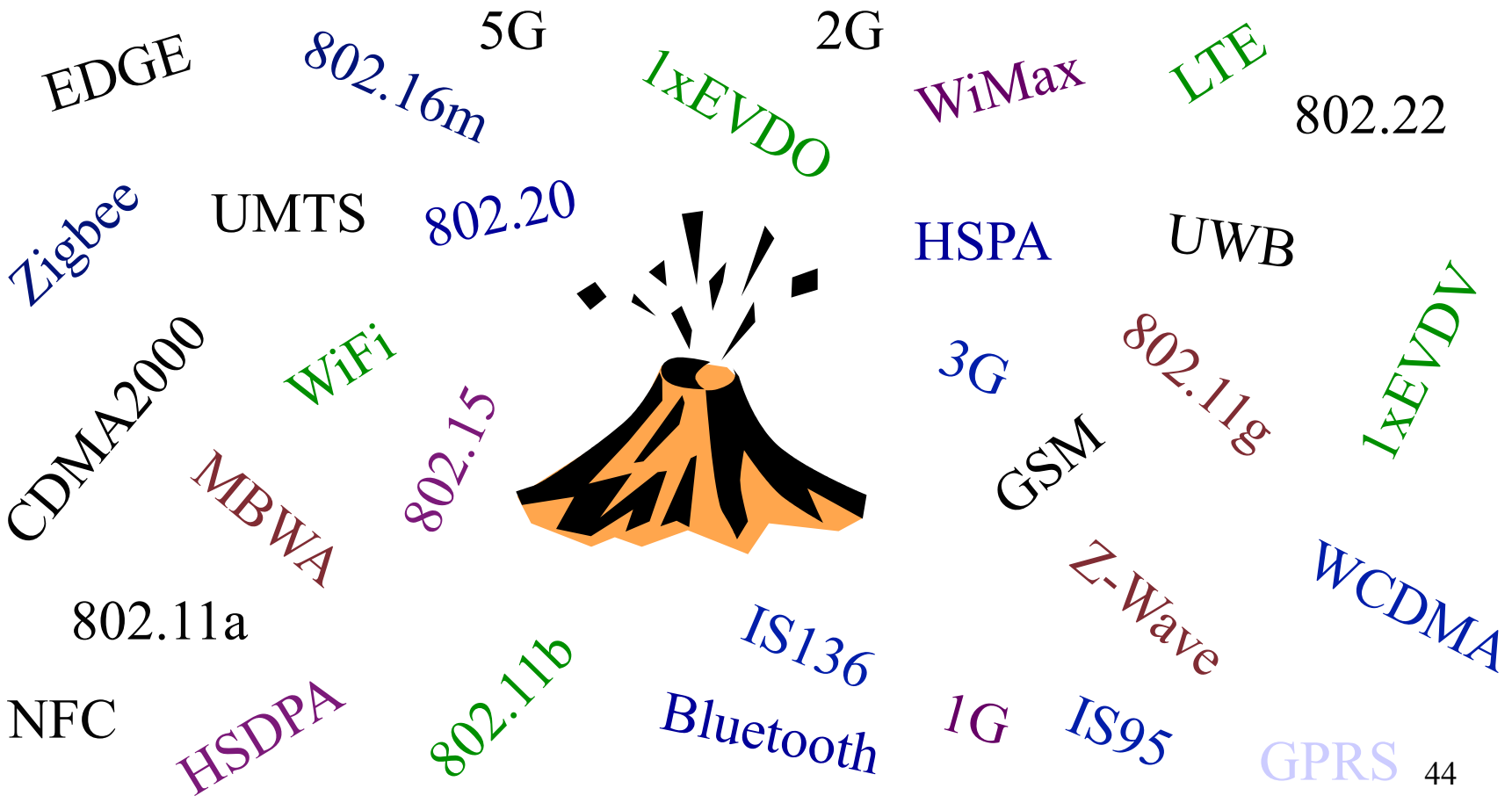
PCS Challenges: 4. Economics

- Providing a density of base stations is expensive!
- Demand for services is uncertain…

Outline

- Background and history
- Overview of current wireless services and standards
- What's on the horizon?

Wireless Standards: A Sampling



Wireless Standards: Our Focus

Cellular	LAN	MAN	PAN	Sensor/IoT
GSM	WiFi	802.16	Bluetooth	ZigBee
CDMA2000	802.11a/ac/b/g/n	WiMax		Z-Wave
WCDMA				NFC
UMTS				Sigfox
1xEVDO				Neul
1xEVDV				LoRaWAN
1G/2G/3G				
LTE (4G)				
3GPP/3GPP2				
5G				

Why Have a Standard?

Why Have a Standard?

- Allows equipment from different vendors to work together in a network.
  - Enables competition.
  - Provides more choices for service providers.
- Helps small companies (e.g., chip vendors, software houses) enter large markets.
- Create mass markets for equipment, economies of scale.
- Can potentially share intellectual property.

Standard Development Process

Implementation groups:
IEEE 802, T1

Regional organizations:
ETSI (Europe), TIA (U.S.),
ARIB (Japan)

Global organizations: ITU

Classification of Wireless Systems

- Cellular
- Wireless Local Area Networks (WLANs)
- Wireless Personal Area Networks (WPANs)
- Sensor Networks

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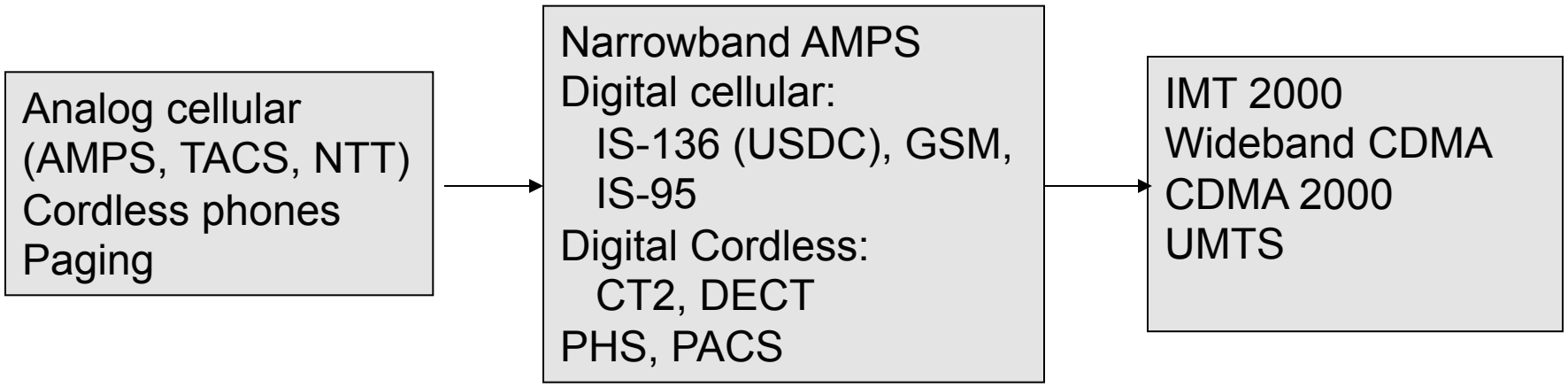
Four Generations of Cellular Systems (and counting)

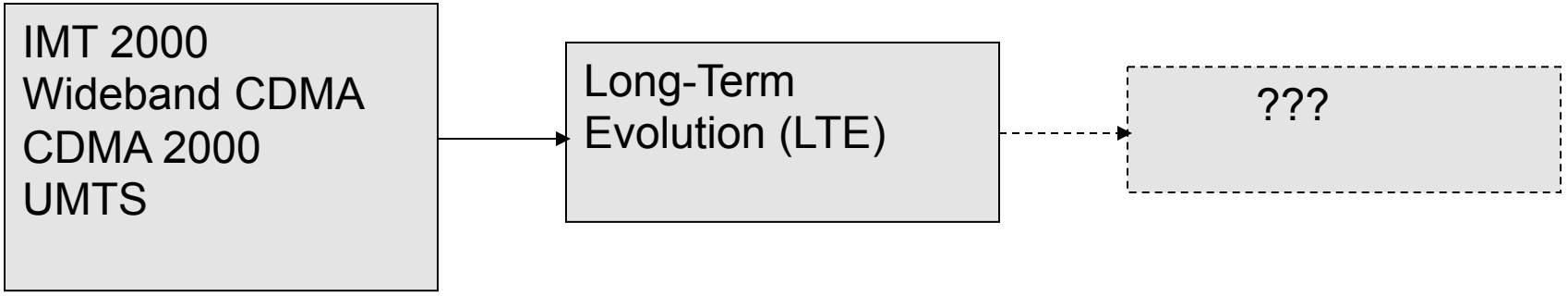


First (1970s, 1980s)

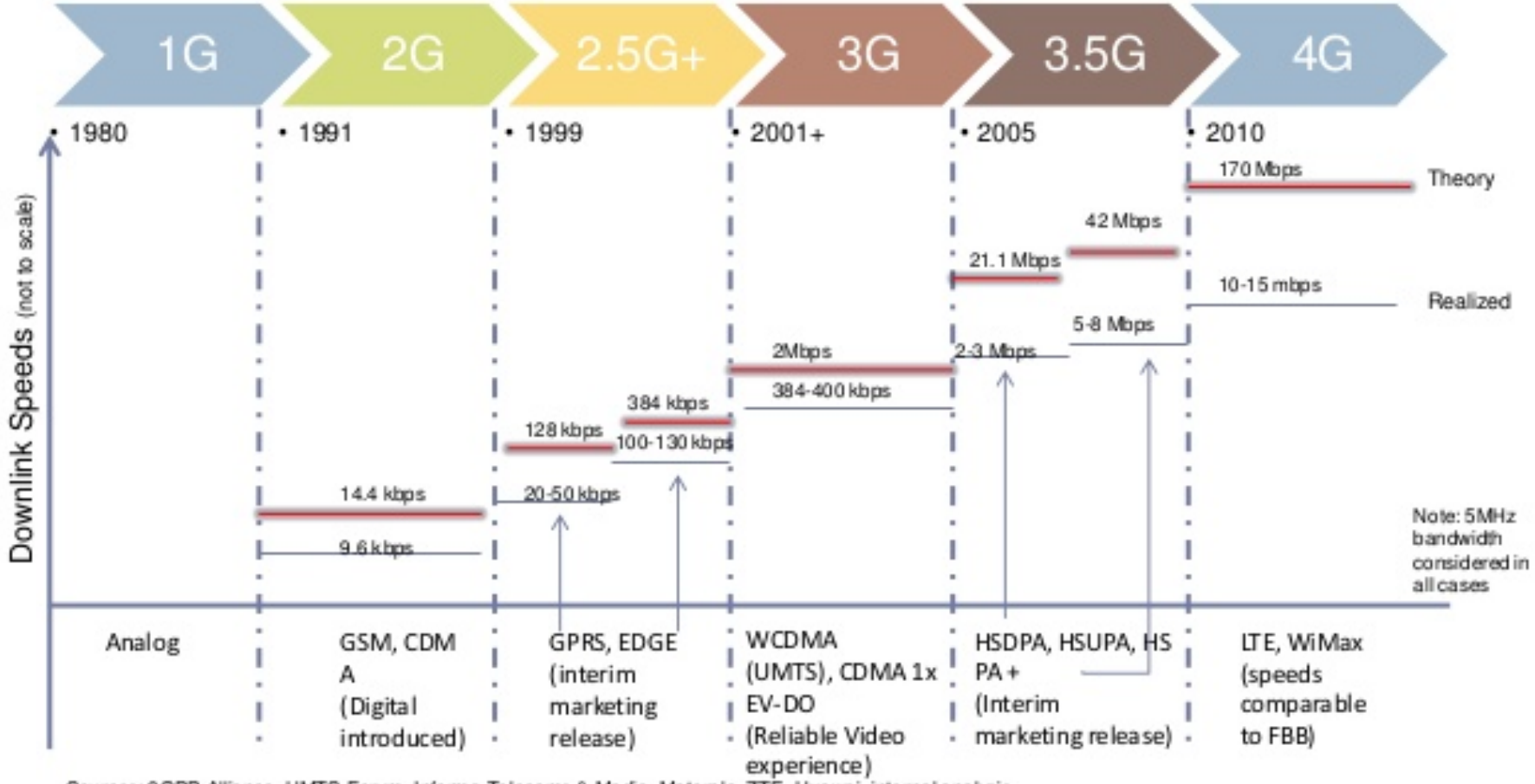
Second (early 1990s)

Third (2001)

Four Generations of Cellular Systems (and counting)



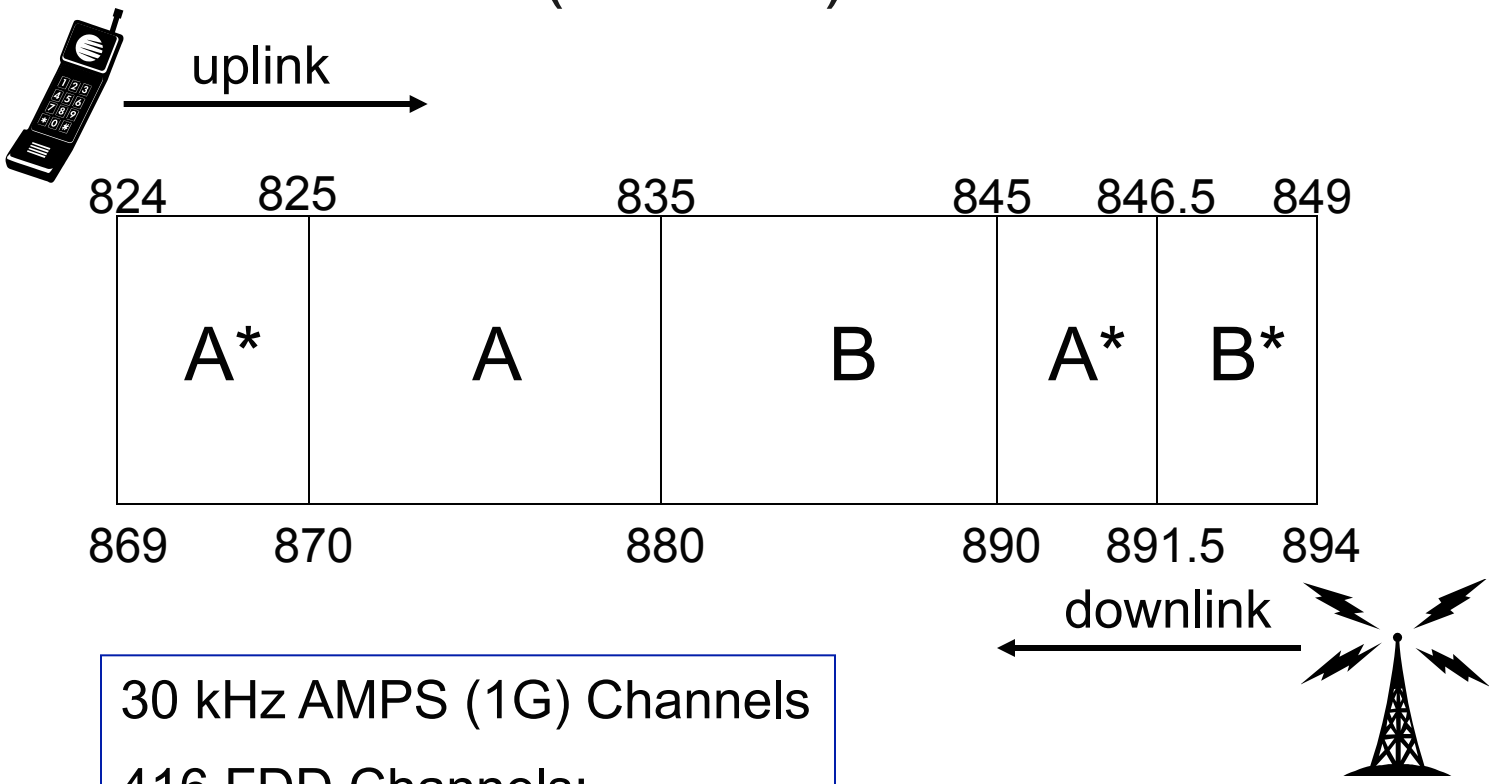
Mobile technologies have evolved from voice focused to data focused with speeds reaching 170 Mbps with 4G



Sources: 3GPP Alliance, UMTS Forum, Informa Telecoms & Media, Motorola, ZTE, Huawei, internal analysis

GSM: Global System for Mobile communications, TDMA: Time Division Multiple Access, GPRS: General Packet Radio Service, EDGE: Enhanced Data rates for GSM Evolution, (W) CDMA: (Wideband) Code Division Multiple Access, EV-DO: Evolution Data-Optimized, HSDPA: High-Speed Downlink Packet Access, HSUPA: High-Speed Uplink Packet Access, TD-SCDMA: Time Division Synchronous Code Division Multiple Access, LTE: Long Term Evolution, FBB: Fixed Broadband

Cellular Spectrum (50 MHz)



30 kHz AMPS (1G) Channels

416 FDD Channels:

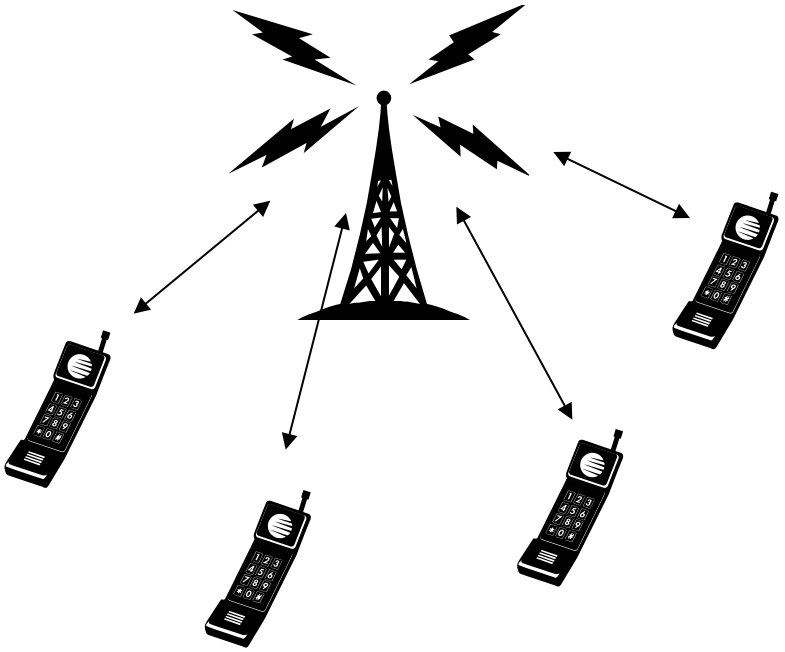
- 395 FDD voice channels
- 21 FDD control channels

Problems With First Generation (1G) Cellular

Cellular	Cordless
• Limited capacity • Limited roaming (big problem in Europe due to patchwork of different systems) • Voice only	• Limited range • Susceptible to interference • Poor security • Not interoperable

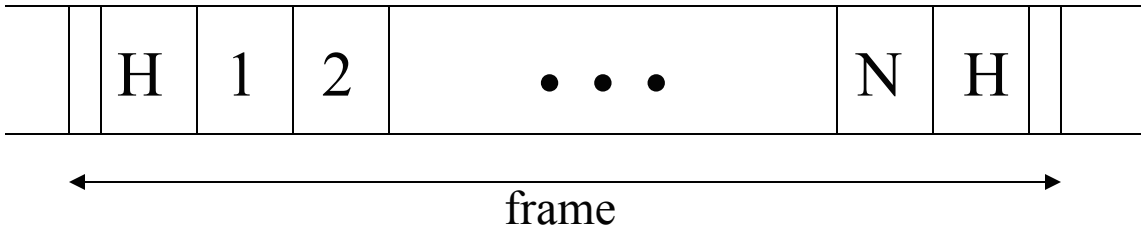
The Multiple Access Problem

How can multiple mobiles access (communicate with) the same base station?



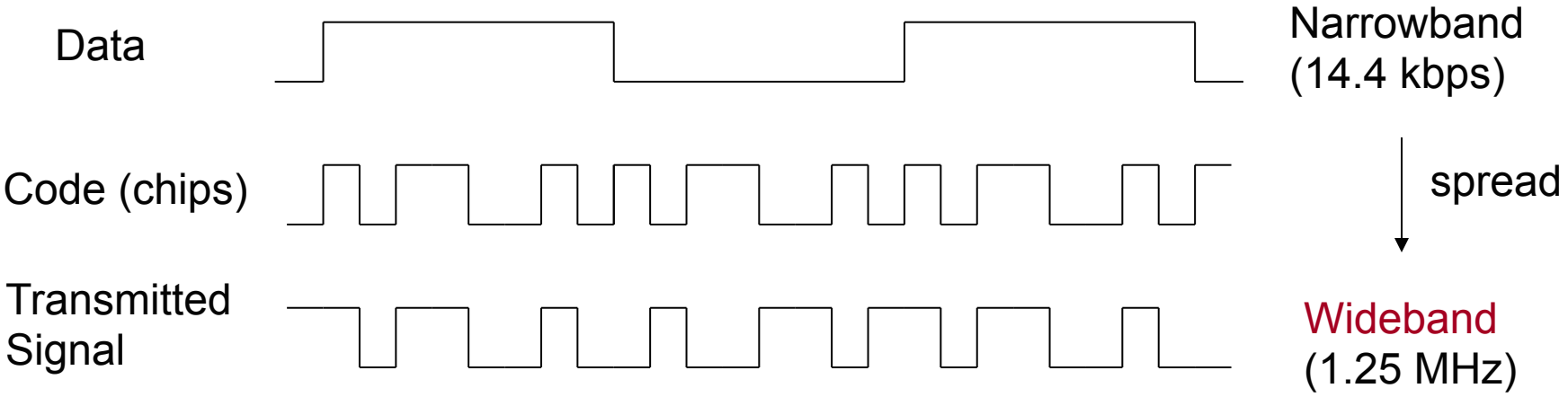
- Frequency-Division (AMPS)
- Time-Division (IS-136, GSM)
- Code-Division (IS-95, 3G)
- Orthogonal Frequency-Division Multiple Access (OFDMA, 4G)

Time-Division Multiple Access (TDMA)



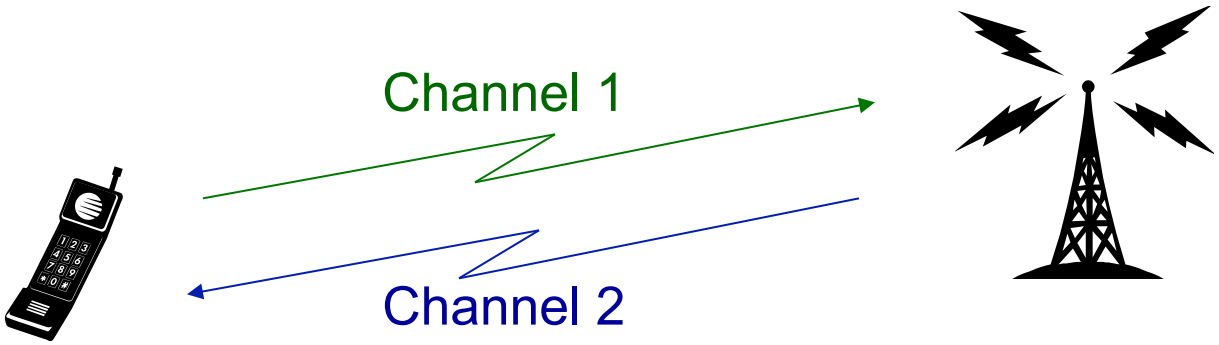
N time slots
H: Frame Header

Direct-Sequence (DS) Code-Division Multiple Access (CDMA)

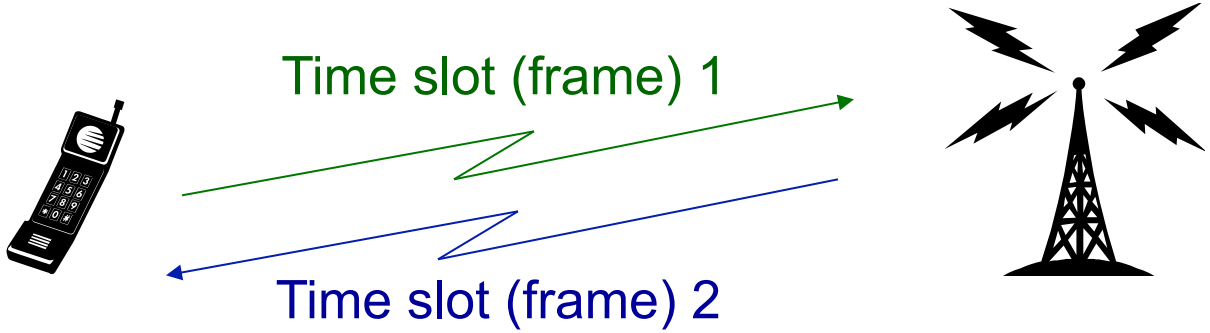


Duplexing (Two-way calls)

Frequency-Division Duplex (FDD)



Time-Division Duplex (TDD)



Second Generation (2G) Cellular: TDMA Standards

GSM

- Global System for Mobile Communications
- Originated in Europe
- Incompatible with 1G systems
- More than an air-interface standard: specifies wireline interfaces/functions

- TDMA/FDMA, FDD
- Dynamic frequency assignment
- 50 MHz allocated (890-960 MHz)
- 200 kHz channels
- 270.833 kbps

IS-136

- North Americal Digital Cellular (NADC)
- Fits into existing AMPS standard
- Air-interface *only*
- Another standard, IS-41, specifies networking functions

- TDMA/FDMA, TDD
- Fixed frequency assignment
- 50 MHz allocated (824-894 MHz)
- 30 kHz channels
- 48.6 kbps

Second Generation (2G) Cellular: TDMA Standards

GSM

- Global System for Mobile Communications
- Originated in Europe
- Incompatible with 1G systems
- More than an air-interface standard: specifies wireline interfaces/functions

- TDMA/FDMA, FDD
- Dynamic frequency assignment
- 50 MHz allocated (890-960 MHz)
- 200 kHz channels
- 270.833 kbps

IS-136

- North Americal Digital Cellular (NADC)
- Fits into existing AMPS standard
- Air-interface *only*
- Another standard, IS-41, specifies networking functions

- TDMA/FDMA, TDD
- Fixed frequency assignment
- 50 MHz allocated (824-894 MHz)
- 30 kHz channels
- 48.6 kbps

2G CDMA: IS-95 or cdmaOne

- Introduced by Qualcomm (San Diego)
- Direct-Sequence Spread Spectrum signaling
- FDD
- **Wideband channels (1.25 MHz)**
- Tight, closed-loop power control
- Sophisticated error control coding
- Multipath combining to exploit path diversity
- Noncoherent detection
- Soft handoff
- High capacity
- Air-interface only: uses IS-41

Problems with Second Generation Cellular

- Data services
  - limited to voice rate
  - circuit-switched
- Interoperability
  - GSM, IS-136, CDMA are incompatible standards
  - Solution: multi-mode phones!

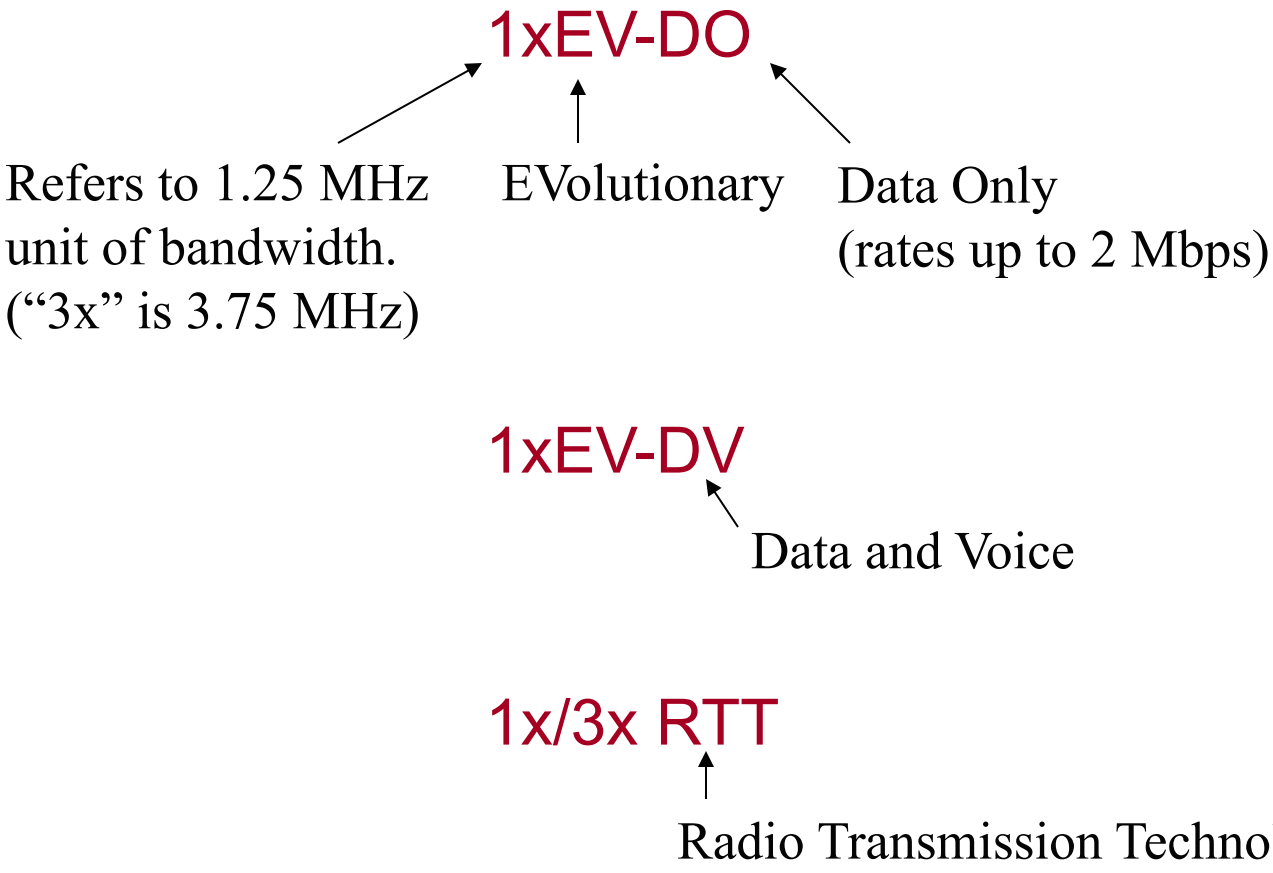
Third Generation Cellular: Objectives

- Data (internet) services as well as voice
- Higher data rates than 2G, depending on mobility
  - *144 kbps for users in motor vehicles (high-tier mobility)*
  - *384 kbps for pedestrians (low-tier mobility)*
  - *2 Mbps for office use*
- Support for both circuit- and packet-switched data services
- Global roaming
- Operation in all radio environments
  - *urban, suburban, hilly, mountainous, etc*.

Some 3G Terminology

- CDMA 2000
  - 3G standard developed for deployment in the U.S.
  - 1.25 MHz bandwidth
- WCDMA (Wideband CDMA)
  - 3G standard developed for deployment in Europe, but also deployed in the U.S.
  - also called UMTS (Universal Mobile Telecommunications System)
  - 5 MHz bandwidth
- Third Generation Partnership Project (3GPP)
  - International effort to harmonize the evolution of 3G systems

"1x/3x" Technologies



Third Generation Standards: Some Important Acronyms

- **ITU:** International Telecommunications Union
  - *Standards body for the United Nations headquartered in Geneva*
- **IMT-2000:** International Mobile Telecommunications-2000
  - *Initiative for 3G mobile systems within the ITU*
- **TIA:** Telecommunications Industry Association (U.S.)
- **ETSI:** European Telecommunications Standards Institute
- **UMTS:** Universal Mobile Telecommunication System
  - *European version of IMT-2000*
- **UTRA:** UMTS Terrestrial Radio Access
  - *UMTS without the satellite component*
- **ARIB:** Association of Radio Industries and Businesses (Japan)
- **3GPP:** Third Generation Partnership Project (www.3gpp.com)
  - *International effort to harmonize various air interface proposals*

3G Air Interfaces

cdma2000

- 1X Radio Transmission Technology (RTT): 1.25 MHz bandwidth (1 carrier)
  - *Supports 307 kbps instantaneous data rate in packet mode*
  - *Expected throughput up to 144 kbps*
- 1xEV (Evolutionary): High Data Rate standard introduced by Qualcomm
  - *1xEV-DO: data only, 1xEV-DV: data and voice*
  - *Radio channels assigned to single users (not CDMA!)*
  - *2.4 Mbps possible, expected throughputs are a few hundred kbps*
  - *1xEV-DV has twice as many voice channels as IS-95B*

Wideband (W)-CDMA

- Also referred to as Universal Mobile Telecommunications System (UMTS)
- European proposal to ITU (1998)
- Backwards compatibility with 2G GSM
- Network and frame structure of GSM
- Supports packet data rates up to 2 Mbps
- Requires minimum *5* MHz bandwidth, FDD, coherent demodulation
- 6 times spectral efficiency of GSM

2.5G Technologies: Evolution to 3G

- HCSCD: High Speed Circuit Switched Data
  - *Enhancement to GSM which allows multiple time slots/user*
- GPRS: General Packet Radio Service
  - *Provides a packet network on dedicated GSM or IS-136 radio channels.*
  - *"always on"*
  - *Peak data rate of 21.4 kbps per dedicated time slot*
  - *Can assign multiple time slots*
  - *No new Radio Frequency (RF) hardware needed!*
- EDGE: Enhanced Data rates for GSM (or Global) Evolution
  - *More advanced upgrade to GSM*
  - *Adaptively selects modulation and coding scheme (MCS)*
  - *Higher-order modulation (8-PSK) achieves up to 384 kbps*
- IS-95B: (2.5G CDMA standard)
  - *Allows multiple codes per user*
  - *Practical throughput of 64 kbps*

3G Enhancement (3.5 G): High Speed Packet Access (HSPA)

- Set of protocols for enhancing the performance of UMTS
- HSDPA: High Speed Downlink Packet Access
  - *Existing deployments provide rates up to 7.2 Mbps with planned upgrades for rates up to 14.4 Mbit/s.*
  - *Introduces dynamic scheduling of users and adaptive rate control through adaptive modulation and spreading.*
- HSUPA: High Speed Uplink Packet Access
  - *Rates up to 5.7 Mbps*

Service Providers and Technologies

Verizon	Cellular & PCS (850 & 1900 MHz)	CDMA 2000; 1 x EV-DO; LTE	8-128 Kbps up to 2.5 Mbps
ATT/Cingular	Cellular (850 & 1900 MHz)	GSM/GPRS/EDGE UMTS/HSPA	up to 512 kbps
Sprint; Clearwire	PCS (1900 MHz)	CDMA2000; 1 x EV-DO; WiMax	8-128 Kbps up to 2.5 Mbps
T-Mobile	PCS (1900 MHz)	GSM/GPRS/EDGE HSPA	8-350 Kbps
NexTel[1]	Public service band (800 MHz)	iDEN (TDMA) & WiDEN[2]	25-64 kbps near 100 kpbs
U. S. Cellular	Cellular & PCS (850 & 1900 MHz)	1 x EV-DO	up to 2.5 Mbps

[1]Merged with Sprint.

[2]Wideband version of iDEN.

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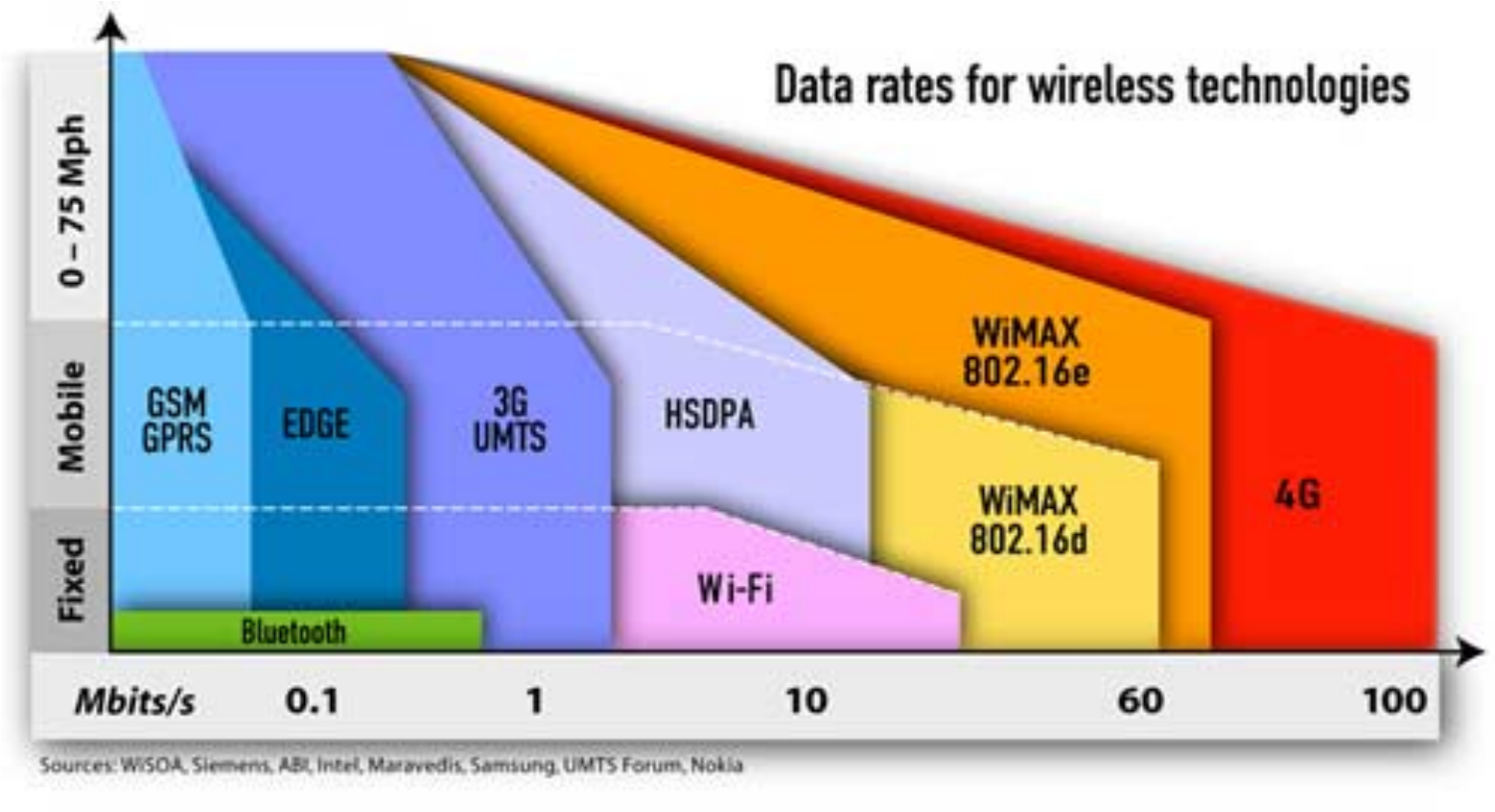
All are transitioning to 4G/Long Term Evolution (LTE): LTE deployments

[1]Merged with Sprint.

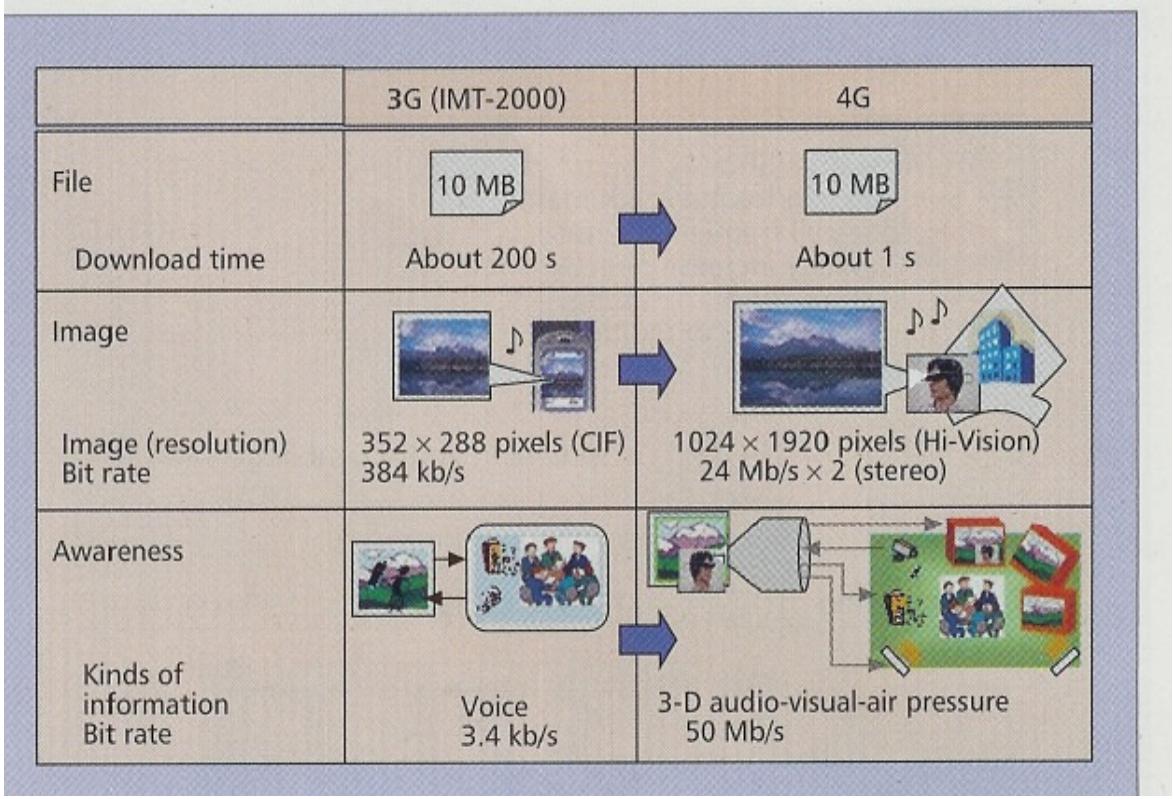
[2]Wideband version of iDEN.

Evolution to 4G



Fourth Generation Drivers (pre-2007)

- Higher data rate services:
  - Enhanced video, multimedia
- Ubiquity
  - Seamless mobility between WLAN, cellular



Enter the Smartphone

Demand is Increasing

InternetNews.com >> Mobility

AT&T Faces 5,000 Percent Surge in Traffic

The nation's No. 2 carrier moves to address huge gains in data traffic, mirroring an industry-wide trend in wireless.

October 8, 2009
By Michelle Megna: *More stories by this author:*

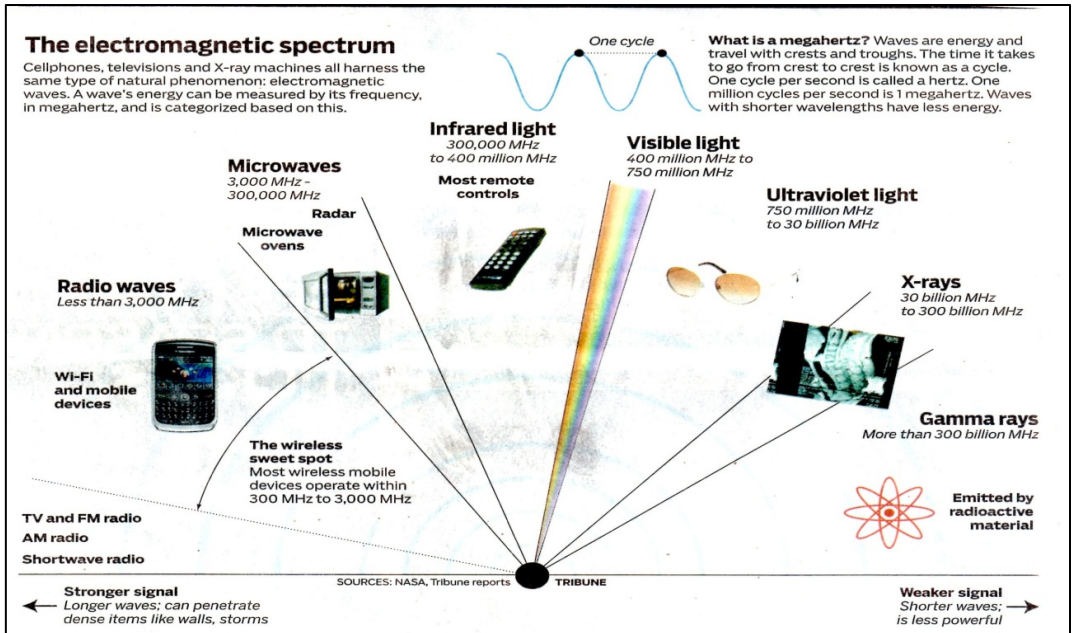
AT&T's chief technology officer today highlighted how the recently maligned carrier is addressing skyrocketing demand for mobile data as it experiences a 5,000 percent surge in mobile data traffic.

As AT&T (NYSE: T), the exclusive carrier for the Apple (NASDAQ: AAPL) iPhone, has embraced smartphones and their applications as well as other devices including netbooks and e-readers, mobile data traffic has grown nearly 5,000 percent on the AT&T network over just the past three years, said AT&T CTO John Donovan, who was speaking at the CTIA IT & Entertainment conference.

Donovan outlined how AT&T is addressing this unprecedented challenge by investing $38 billion over two years on its wireless and wired networks. "AT&T is focused on delivering an ideal combination of more mobile data capacity and faster 3G speeds, with these capabilities being deployed over a very short timeframe to maximize customer benefit," said Donovan.

AT&T is 90 percent complete in its deployment of high-quality 850 MHz spectrum for 3G, which adds overall network capacity as well as improved in-building coverage.

High Profile Issue



Wireless carriers try to scrounge up spectrum

By Victor Godinez
MCCLATCHY/TRIBUNE NEWS

Almost every wireless gadget on the planet, from the lock button on your car keys to the iPhone in your pocket to the Wi-Fi in your favorite coffee shop, runs over the electromagnetic spectrum.

And those invisible signals are worth tens of billions of dollars to companies such

"We need to tackle the looming spectrum crunch."

— Julius Genachowski, FCC chairman

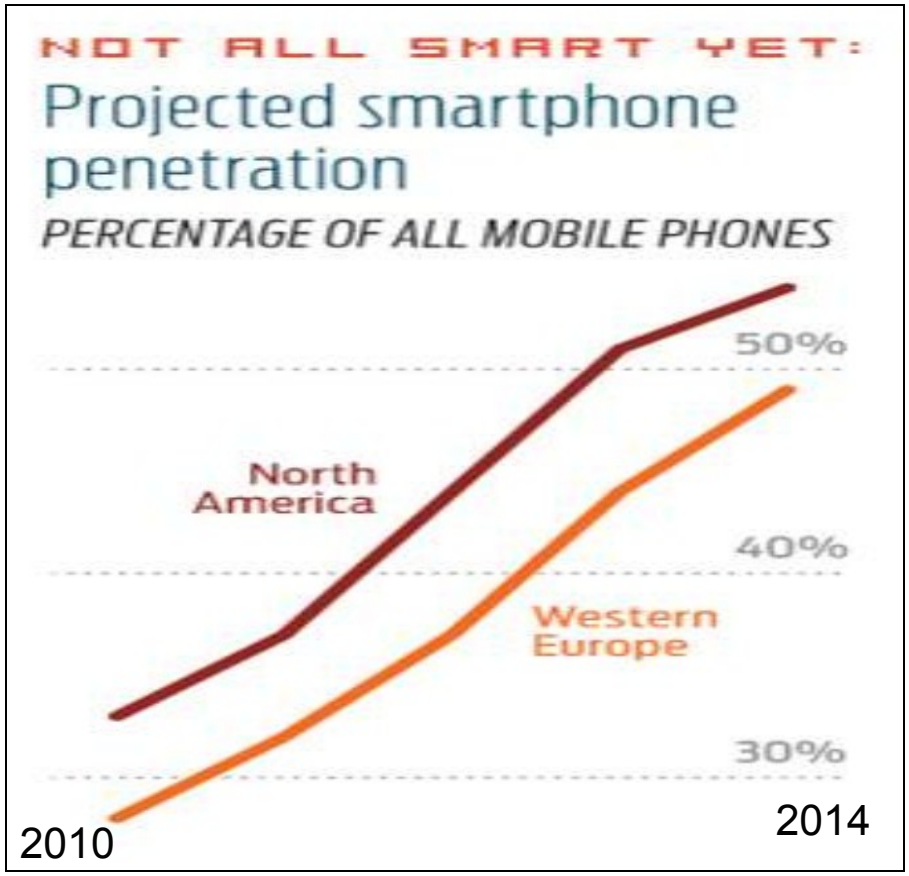
paperwork about the planned merger with the Federal Communications Commission by the end of next week. The request for a

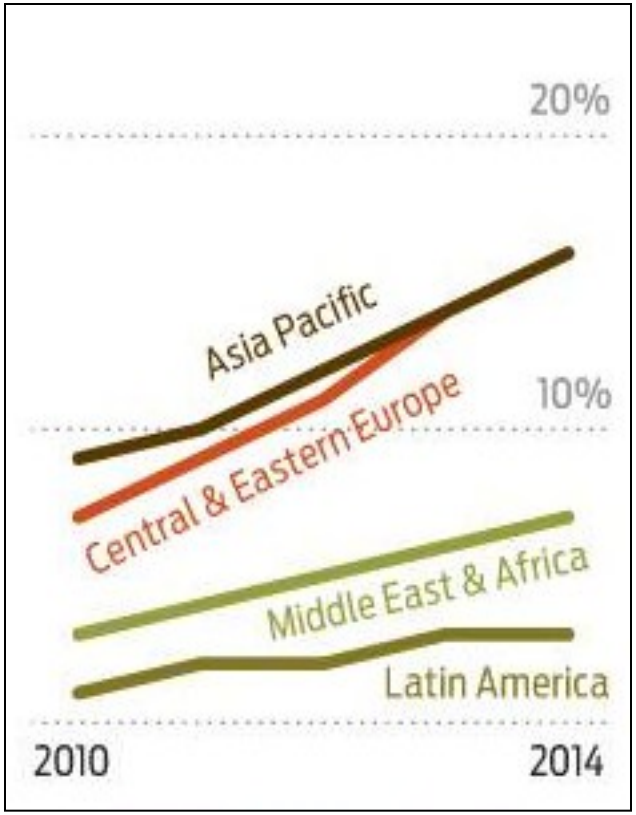
growth by improving quality and expanding wireless service to 95 percent of Americans. AT&T predicts that by 2015, it will transmit as much data over its wireless network every six weeks as it did in all of 2010.

"There's just going to be a constant need for additional spectrum," AT&T Chief Executive Randall Stephenson said during a presentation after the deal was an-

Chicago Tribune
April 15, 2011

Smartphone Penetration



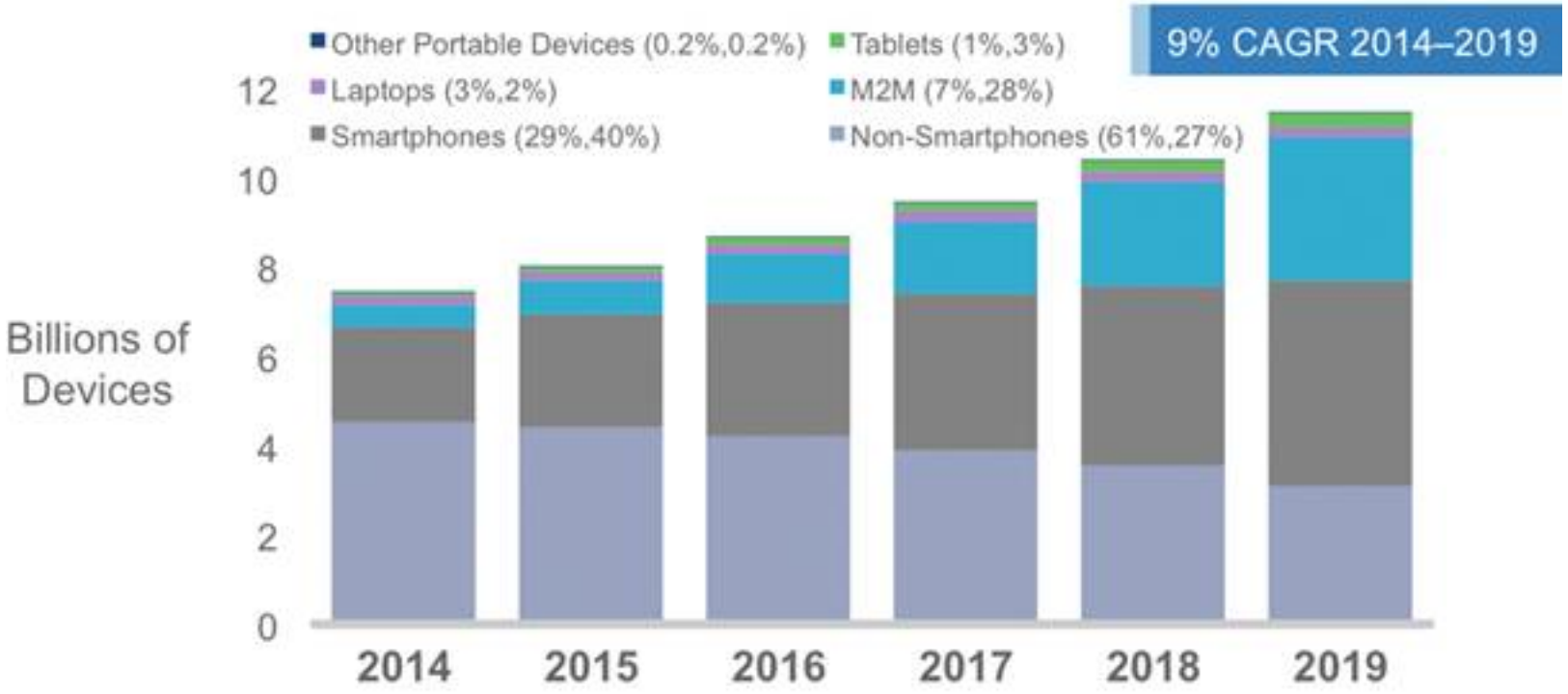


Mobile Data Forecast

Exa: 10^{18}

Source: Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update 2014–2019 White Paper

Mobile Devices Forecast



Source: Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update 2014–2019 White Paper

Mobile Data Statistics (Cisco)

- Global mobile data traffic grew 69 percent in 2014.
- Last year's mobile data traffic was nearly 30 times the size of the entire global Internet in 2000.
- Mobile video traffic exceeded 50 percent of total mobile data traffic for the first time in 2012.

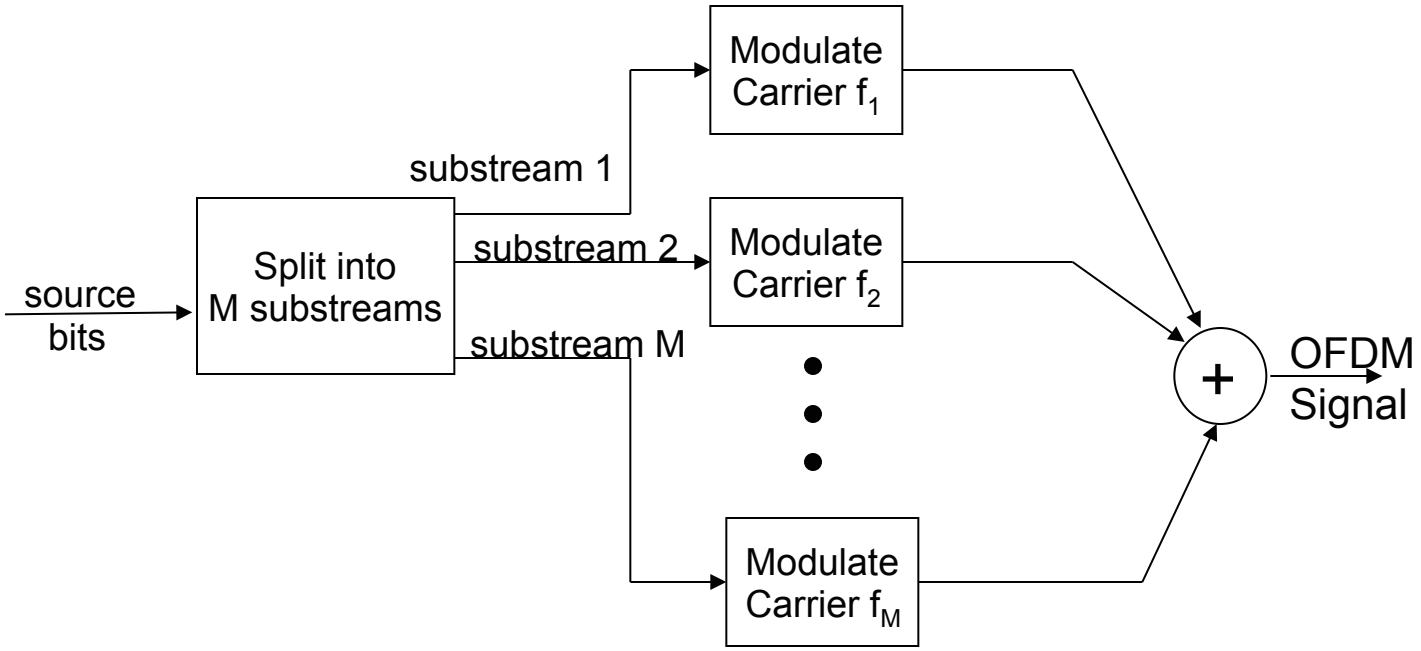
Mobile Data Forecast (Cisco)

- Global mobile data traffic will increase nearly tenfold between 2014 and 2019.
- By the end of 2014, the number of mobile-connected devices will exceed the number of people on earth, and by 2019 there will be nearly 1.5 mobile devices per capita.
- Mobile network connection speeds will increase more than twofold by 2019.
  - The average mobile network connection speed (1.7 Mbps in 2014) will reach nearly 4.0 megabits per second (Mbps) by 2019.

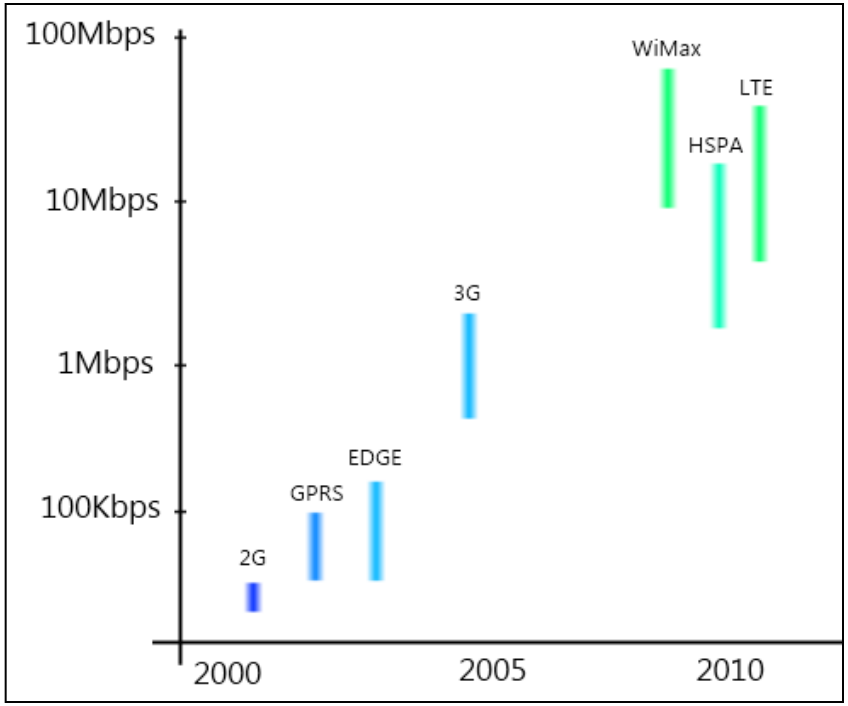
Long-Term Evolution (LTE)

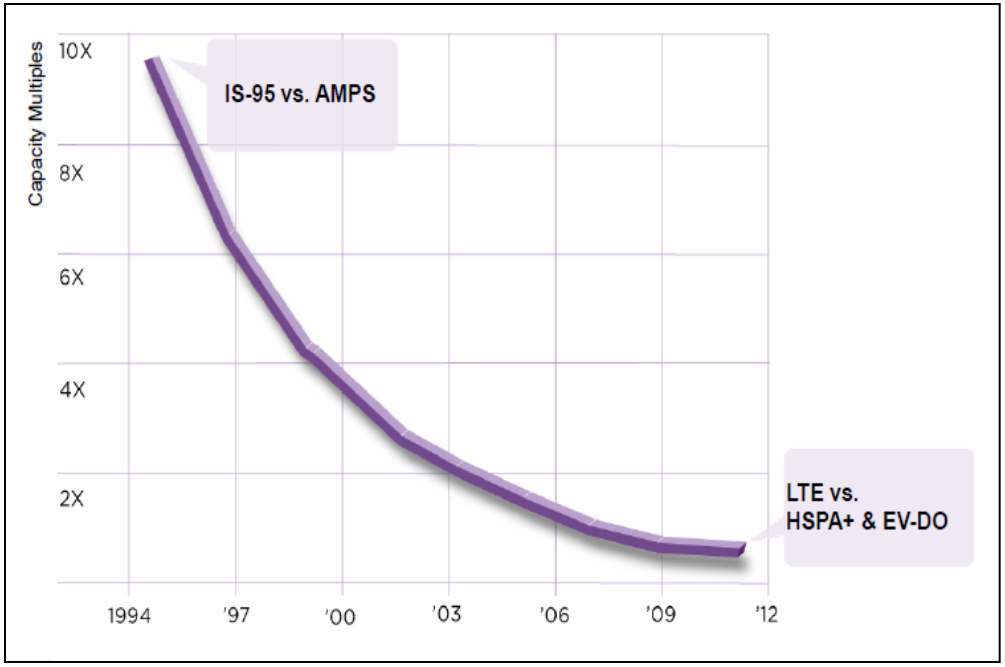
- Project within 3GPP to improve UMTS
  - Not a new standard, but a plan for extending and modifying UMTS
- Goals:
  - IP based
  - Download rates of 100 Mbit/s,
    Upload rates of 50 Mbit/s for every 20 MHz of spectrum
  - Increased spectrum flexibility, “carrier aggregation”
    (the ability to use spectrum slices from 1.25 to 20 MHz)
  - At least 200 active users in every 5 MHz cell.
  - Low latency (< 5 ms) for small IP packets
  - Cell sizes up to 100 km cell with acceptable performance
  - Co-existence with legacy standards (e.g., GSM, W-CDMA)
- Based on Orthogonal Frequency Division Multiplexing (OFDM)

Orthogonal Frequency Division Multiplexing (OFDM)

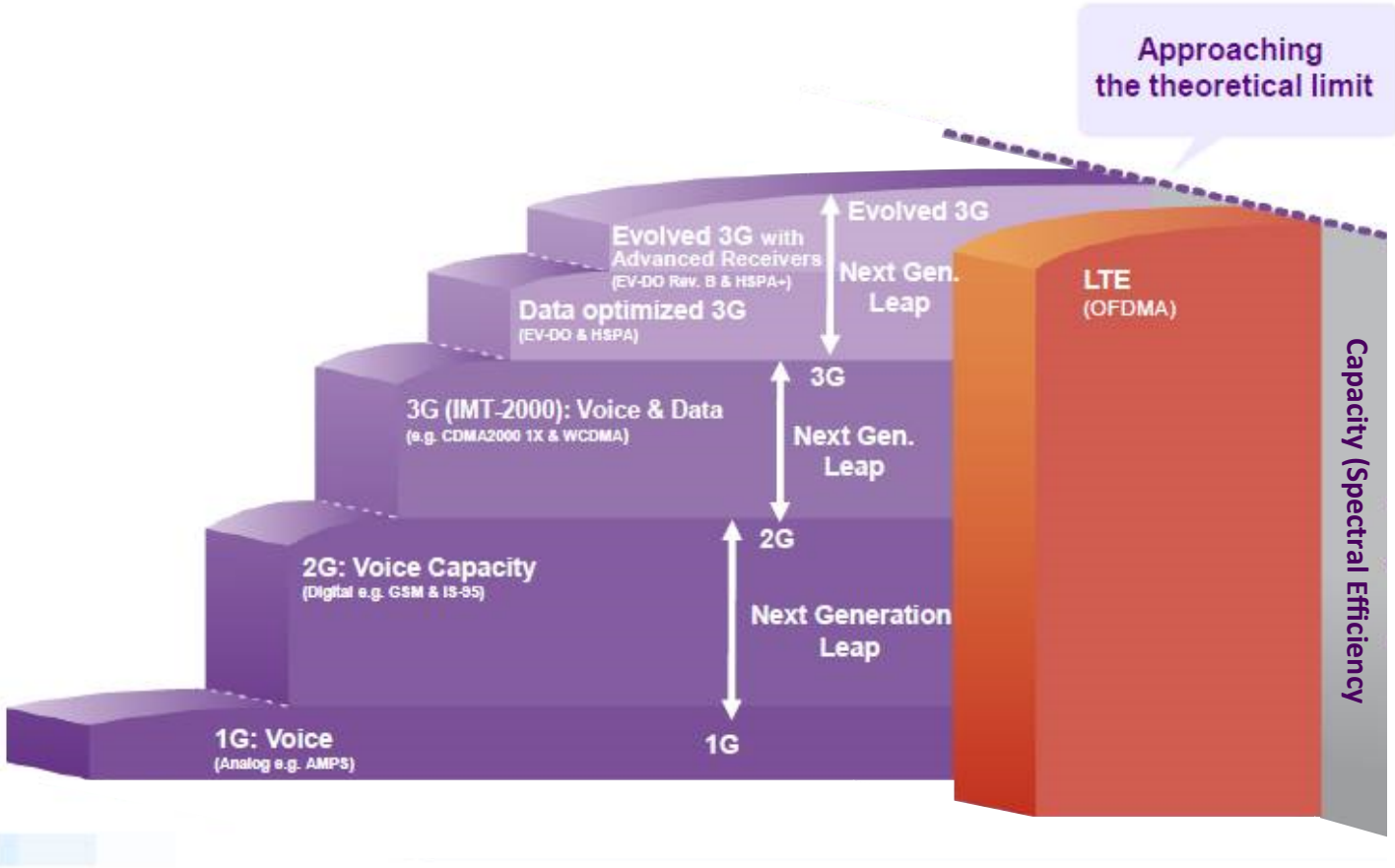


Will 4G Satisfy Projected Demand?



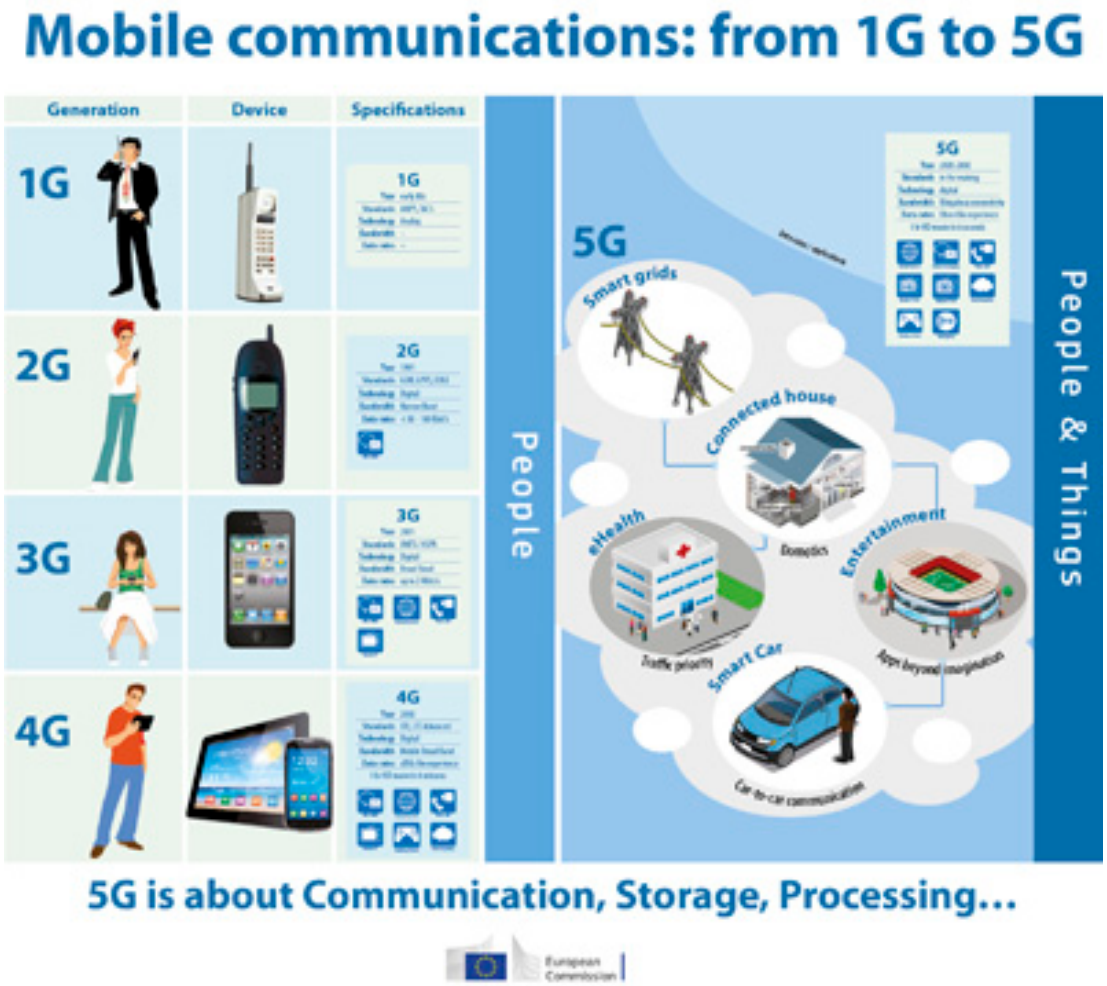


Increases in Cellular Capacity



What About 5G?

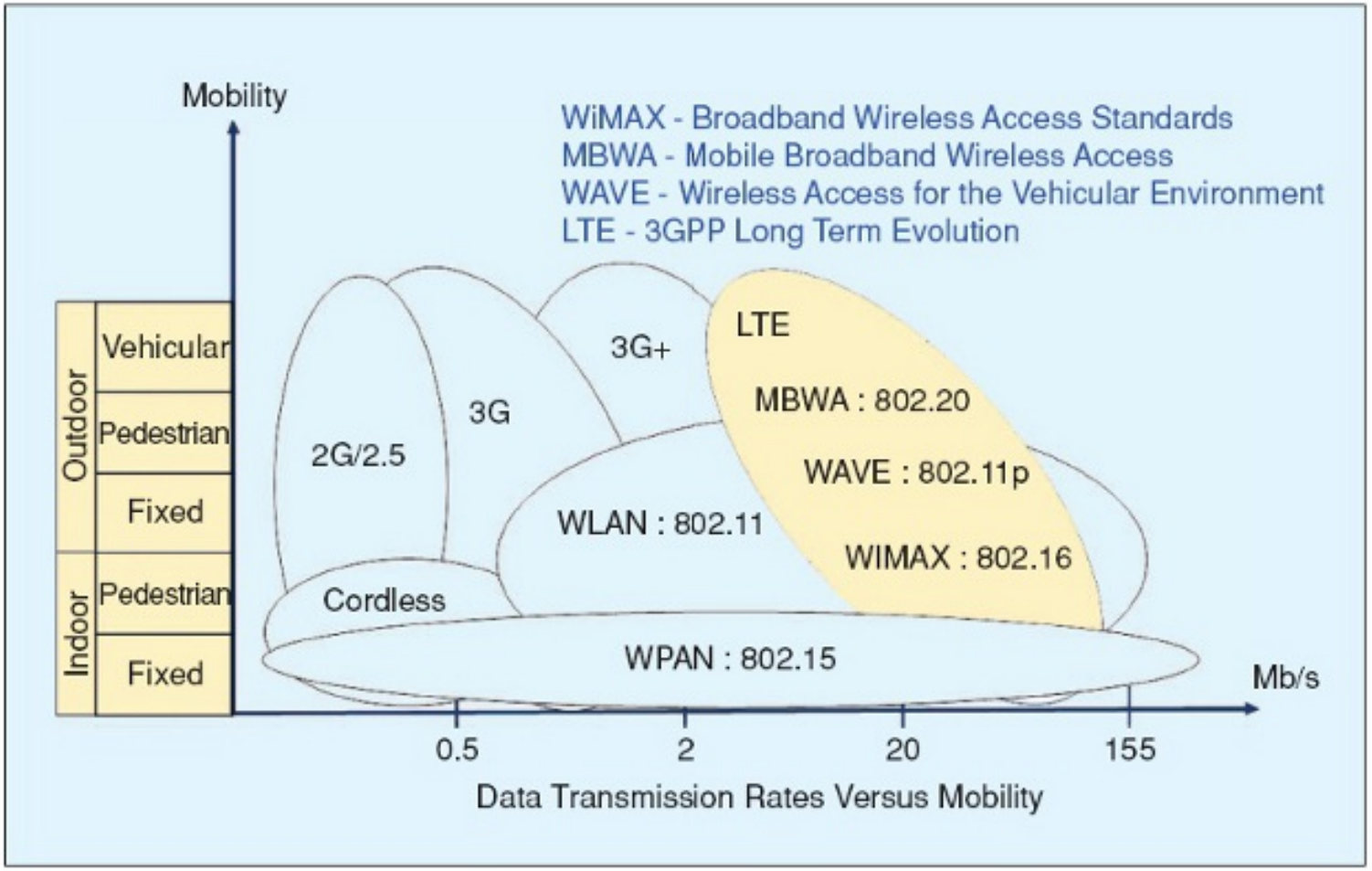
- No standard or specifications yet. Most likely will be a mix of technologies that integrate:
  - Small cells with lots of antennas
  - Higher frequencies (including millimeter wave, meaning above 28 GHz)
  - Licensed and unlicensed spectrum
- With 4G rates eventually projected to be 1 Gbps what additional value can 5G offer?
- Wikipedia site


Mobile communications: from 1G to 5G
Generation
Device
Specifications
1G
2G
3G
4G
People
5G
Smart grids
Connected house
eHealth
Entertainment
Smart Car
People & Things
5G is about Communication, Storage, Processing...
European Commission

Classification of Wireless Systems

- Cellular
- Wireless Local Area Networks (WLANs)
- Wireless Personal Area Networks (WPANs)
- Sensor Networks

Comparison of Wireless Systems



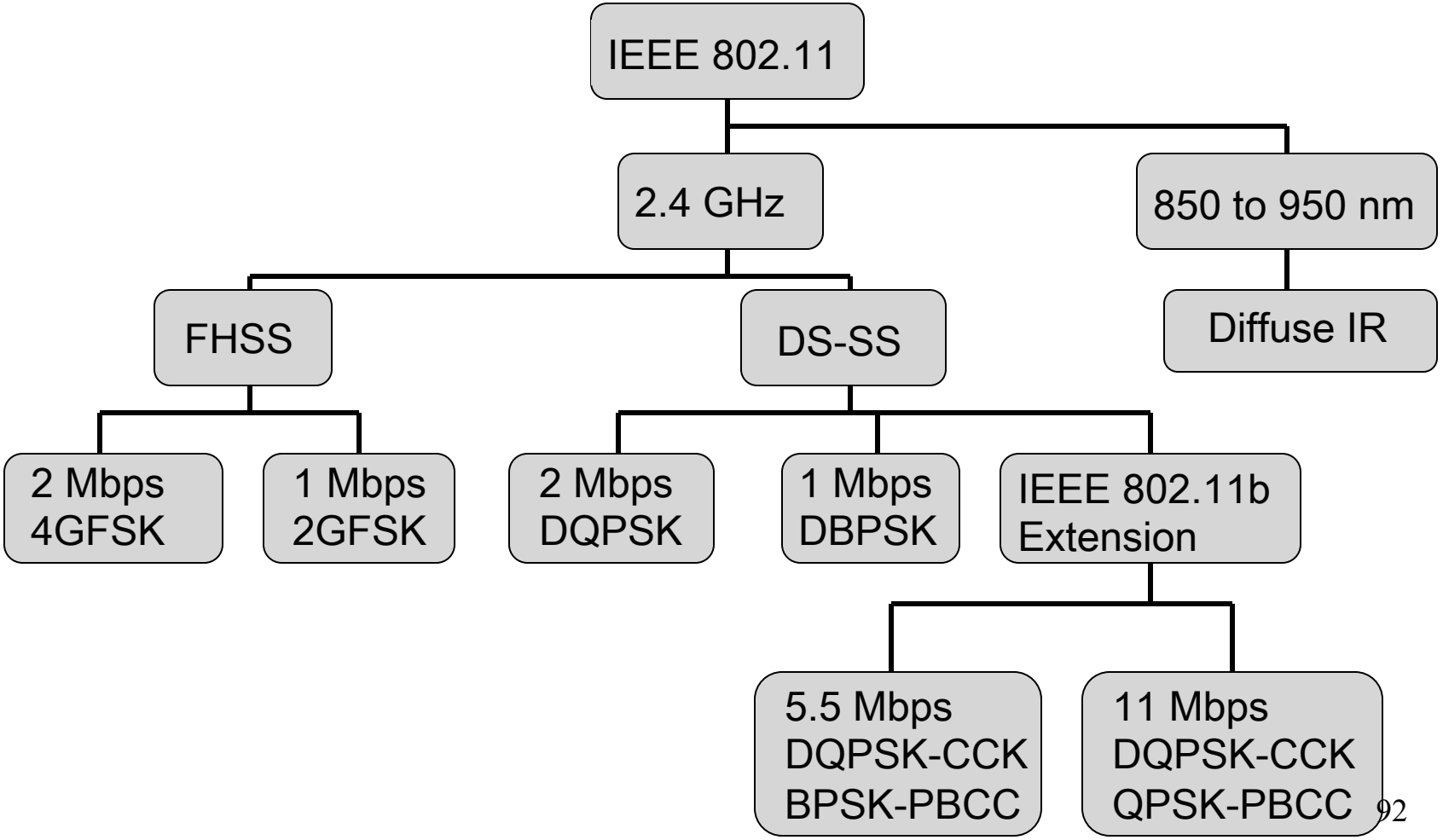
Wireless Local Area Networks (WLANs)

- Very high data rates (up to 600 Mbps!)
- Low mobility within confined region (building or campus)
- Unlicensed bands
  - *Industrial, Scientific, Medical (ISM): 2.4 GHz*
  - *National Information Infrastructure (UNII): 5 GHz*
- Must accept interference, therefore uses spread spectrum signaling, or random access with collision avoidance.
- Family of standards (IEEE 802.11)

WLANs Take Off (late 90's)

- Routers, access points, WLAN cards are inexpensive.
- 802.11 standards enable a public LAN (publan)
  - *Wireless Internet Service Provider (WISP) (MobileStar, Wayport)*
  - *Product interoperability (Wireless Ethernet Compatibility Alliance)*
  - *Always-on internet access with a public service fee*
- Advantages for the enterprise
  - *Enables mobility*
  - *Easy to maintain (no wiring)*
- Advantages for the residence
  - *Provides broadband services*
  - *Home media gateway appliance*
    - *802.11a/g from gateway to home electronics/devices*
- Spectrum sharing model works for wireless data.
- Concerns
  - *Security, interference*

Overview of 802.11 Standard



WLAN Family of Standards: 802.11

- 802.11:
  2 Mbps (with fallback to 1 Mbps), 1997 & 1999
- 802.11b:
  provides additional 5.5 and 11 Mbps rates in the 2.4 GHz band
- 802.11a:
  provides up to 54 Mbps in the 5 GHz band
- 802.11g:
  Supports roaming, higher rate, backward compatible with 802.11b
- 802.11n:
  High throughput amendment using multiple antennas
  (Multi-Input Multi-Output (MIMO))
- 802.11ac:
  High throughput in 5 GHz band (> 1 Gbps) using wider bandwidth, multi-user MIMO

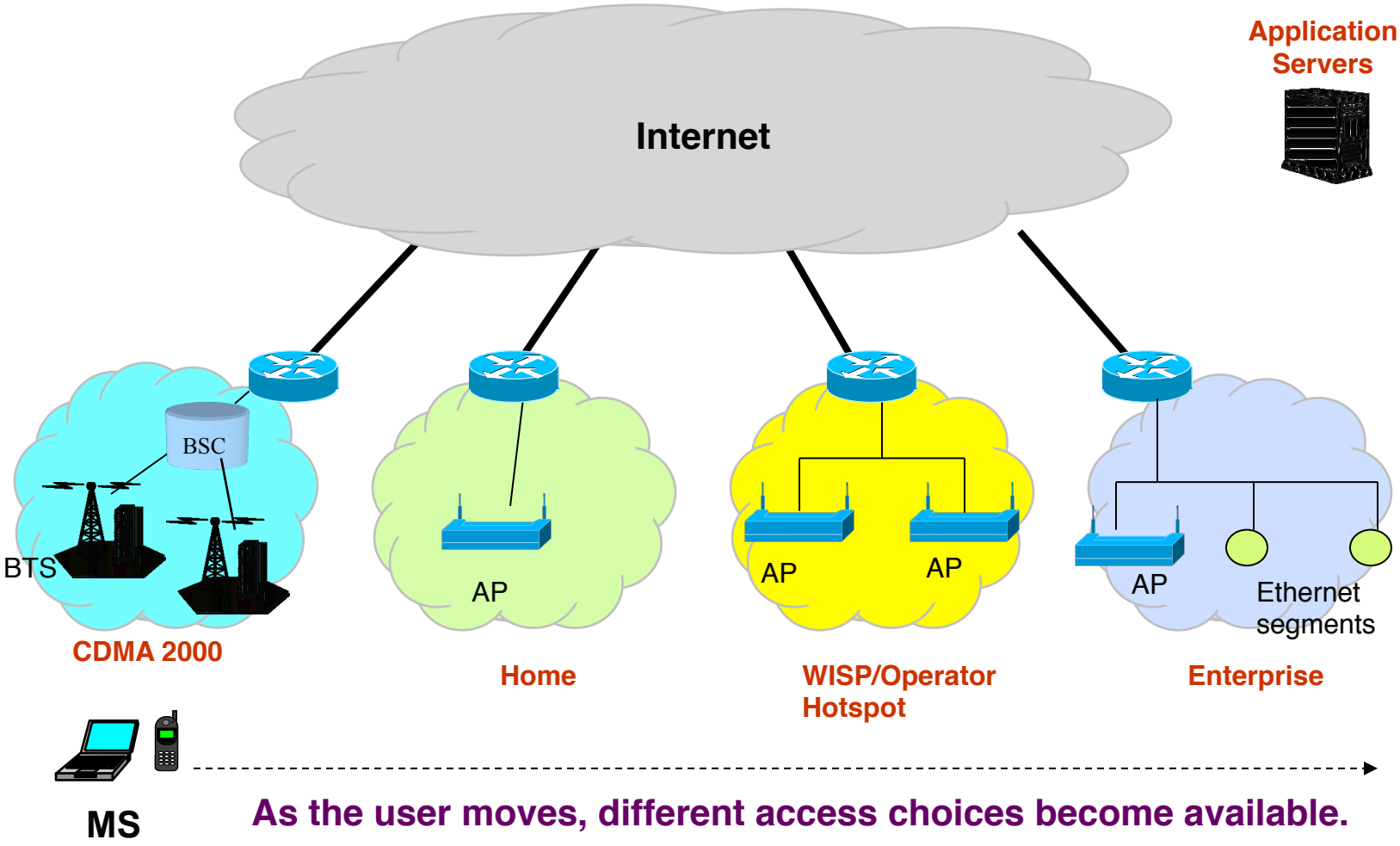
Additional 802.11 Standards

- 802.11ad (WiGig): up to 7 Gbps in 60 GHz band
- 802.11e: QoS & Security Enhancements
- 802.11f: Inter Access Point Protocol (IAPP)
- 802.11h: Power Management for 5 GHz in Europe
- 802.11i: Security enhancements
- 802.11j: Enhancements to 802.11a for operation in Japan.
- 802.11k: Radio resource management
- 802.11m: Technical corrections and clarifications
- 802.11u: Interfacing with external networks
- 802.11v: Upper layer interface for managing 802.11 equipment

802.11 Comparison

Comparison table

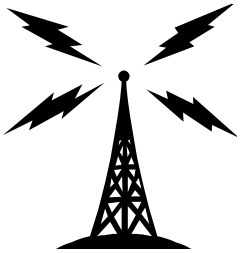
Integrated WLAN-Cellular Network



802.11 Extension to Cellular

Handoff to 802.11

Cellular (LTE) connection



Integrated WLAN/Cellular Network

- High data rates at hot spots covered by WLANs.
- Lower data rates elsewhere provided by cellular.
- Single account; single bill
- Roaming
- Session mobility
- Common applications and services
- Cellular traffic → WiFi offload

Classification of Wireless Systems

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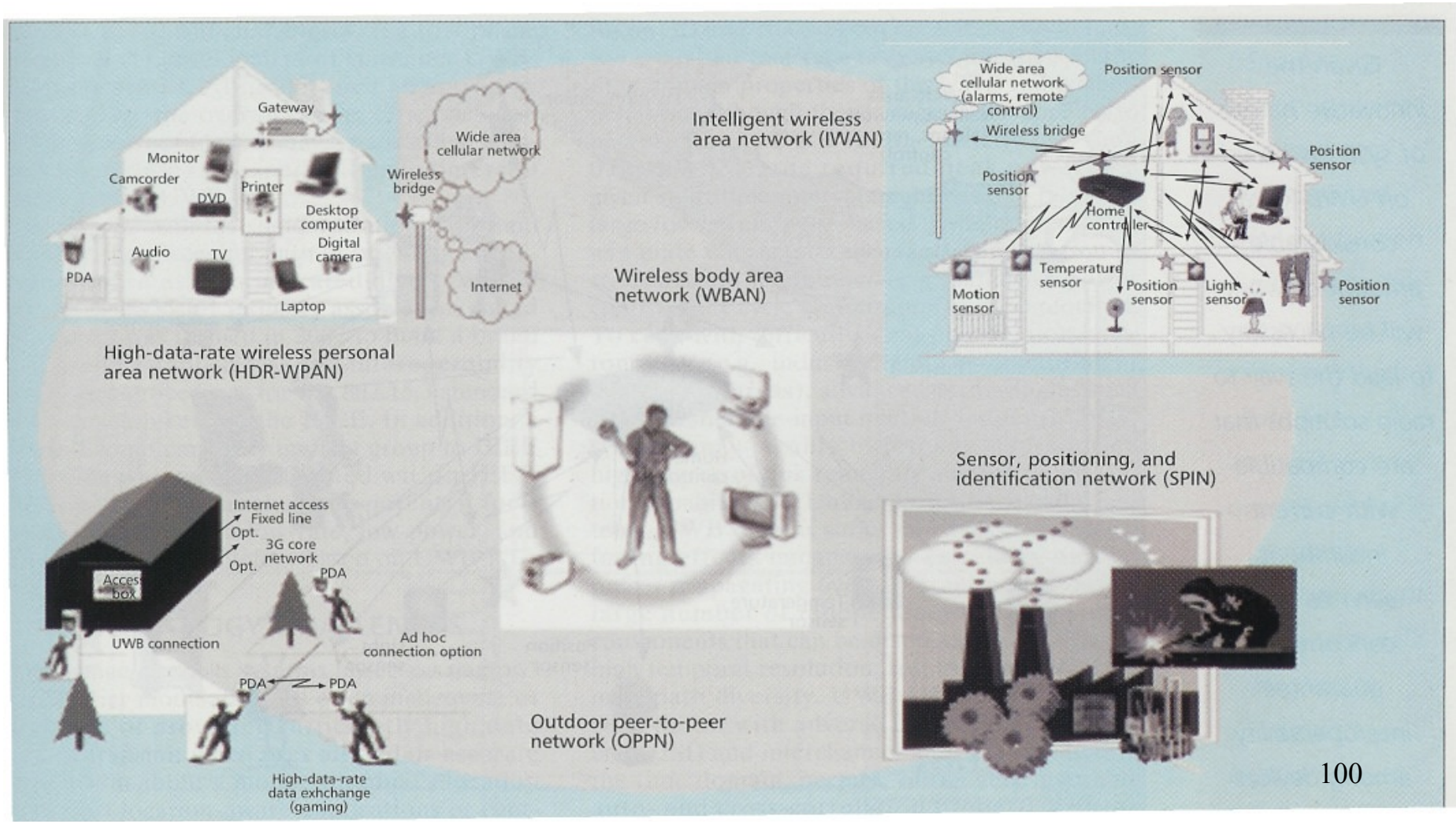
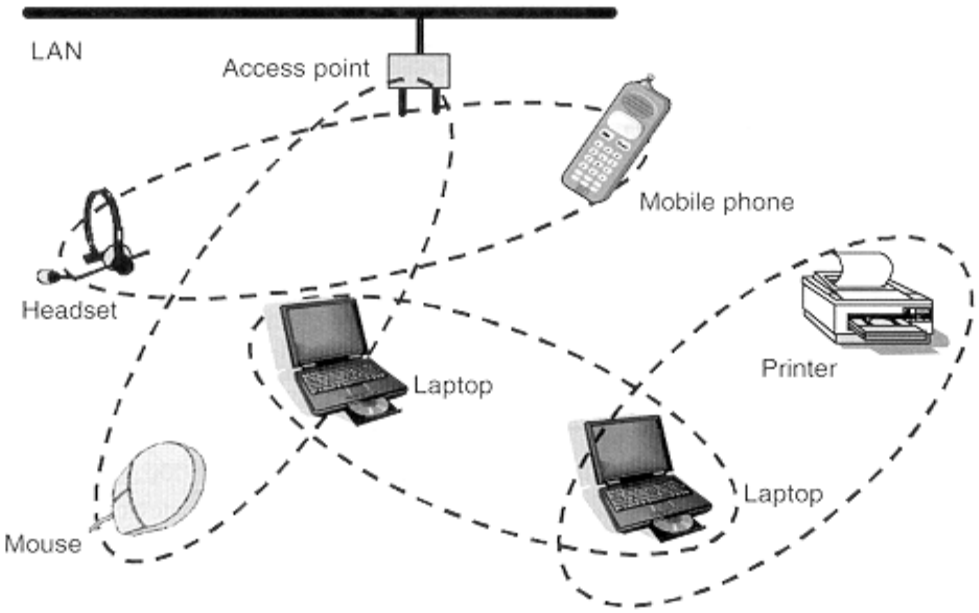
- Wireless Personal Area Networks (WPANs)
- Sensor Networks

Personal Area Networks (PANs)



Bluetooth: A Global Specification for Wireless Connectivity



- Wireless Personal Area Network (WPAN).
- Provides wireless voice and data over short-range radio links via low-cost, low-power radios (“wireless” cable).
- Initiated by a consortium of companies (IBM, Ericsson, Nokia, Intel)
- IEEE standard: 802.15.1

Bluetooth Specifications

- Allows small portable devices to communicate together in an ad-hoc “piconet” (up to eight connected devices).
- Frequency-hopped spread-spectrum in the 2.4 GHz ISM band.
- Range set at 10m.
- Interferes with 802.11 b/g/n
- Second generation (Bluetooth 2.0+) supports rates up to 3 Mbps.

Wireless Challenges