Introduction to Wireless Communications

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Outline

- What is Wireless Communications?
- History of Wireless Communications
- The advantages
- The challenges
- The types
- The Indian factor
- Existing Wireless Systems
- Emerging Wireless Systems

What is Wireless Communication?

- Transmitting/receiving voice and data using electromagnetic waves in open space
  - The information from sender to receiver is carrier over a ***well-defined*** frequency band (*channel*)
  - Each channel has a ***fixed*** frequency *bandwidth* and *Capacity* (bit-rate)
  - Different channels can be used to transmit information in ***parallel*** and independently.

Example

- Assume a spectrum of 120 KHz is allocated over a base frequency for communication between stations A and B
- Each channel occupies 40 KHz

<table>
<tr><td rowspan="3">Station A</td><td>Channel 1 (b - b+40)</td><td rowspan="3">Station B</td></tr>
<tr><td>Channel 2 (b+40 - b+80)</td></tr>
<tr><td>Channel 3 (b+80 - b+120)</td></tr>
</table>

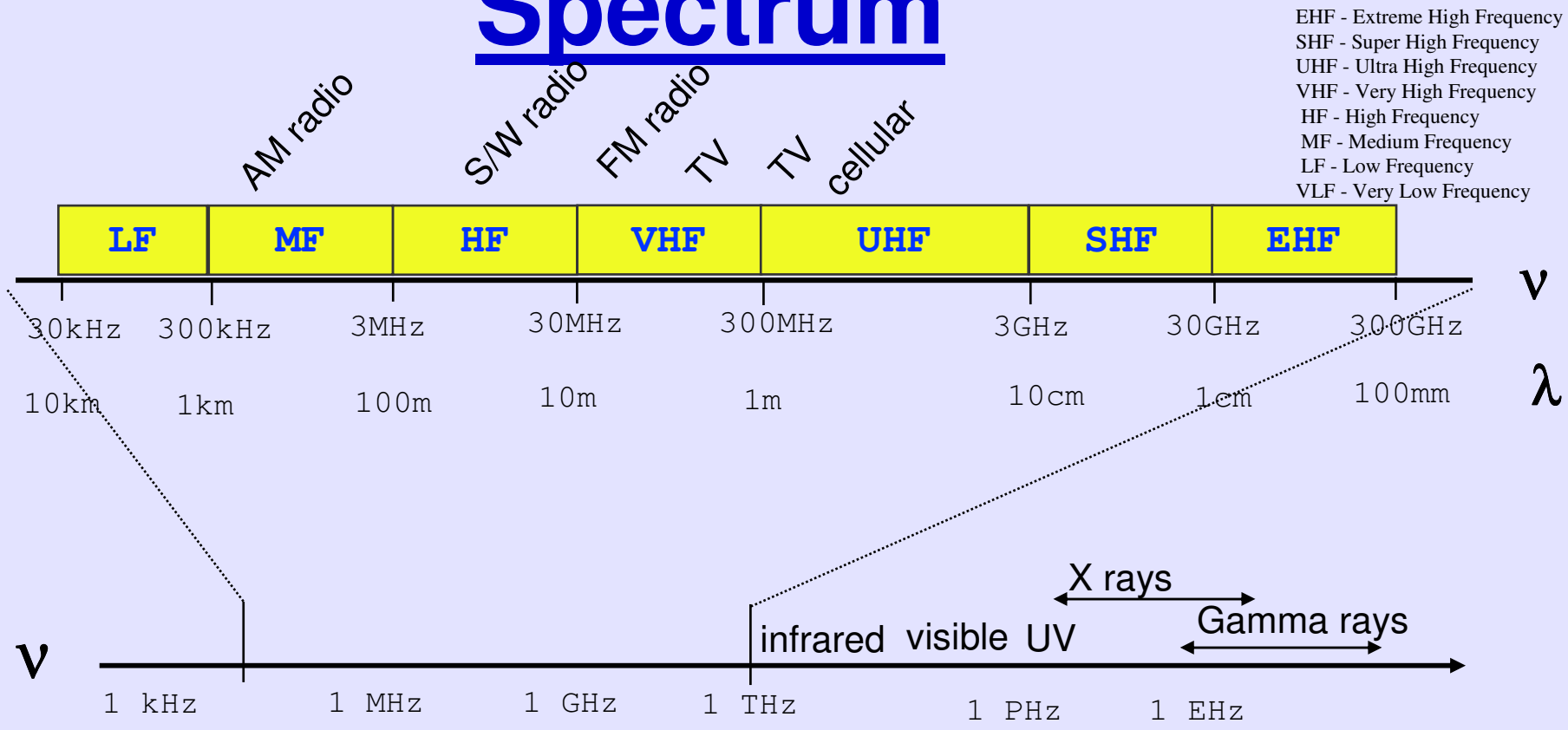
Types of Wireless Communication

- **Mobile**
  - Cellular Phones (GSM / cdma2000.1x)
- **Portable**
  - IEEE 802.11b (WiFi),
  - IEEE 802.15.3 (UWB)
- **Fixed**
  - IEEE 802.16 (WirelessMAN)

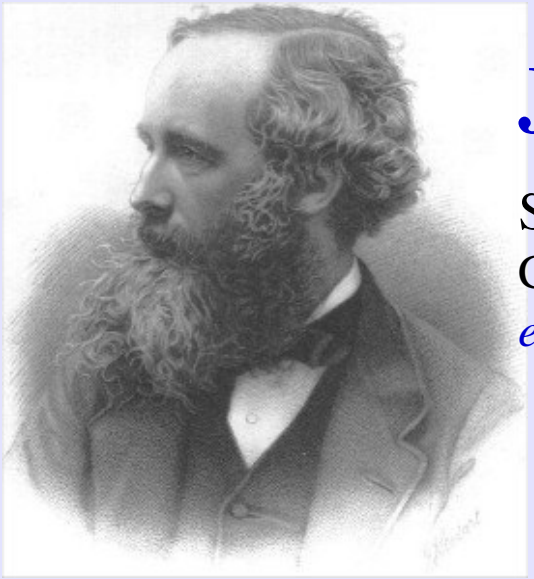
Typical Frequencies

- FM Radio ~ 88 MHz
- TV Broadcast ~ 200 MHz
- GSM Phones ~ 900 MHz
- GPS ~ 1.2 GHz
- PCS Phones ~ 1.8 GHz
- Bluetooth ~ 2.4 GHz
- WiFi ~ 2.4 GHz

The Electromagnetic Spectrum



Propagation characteristics are different in each frequency band



James Clerk Maxwell (1831–1879)

Scottish, Professor of physics, King's College (London) and Cambridge University. *Formulated the theory of electromagnetism from 1865 to 1873.*

$$\nabla \times \bar{E} = -\frac{\partial \bar{B}}{\partial t}$$

$$\nabla \times \bar{H} = \bar{J} + \frac{\partial \bar{D}}{\partial t}$$

$$\nabla \cdot \bar{D} = \rho$$

$$\nabla \cdot \bar{B} = 0$$

His work established the theoretical foundation for the development of wireless communications.

"From a very long view of the history of mankind - seen from, say, ten thousand years from now - there can be little doubt that the most significant event of the 19th century will be judged as Maxwell's discovery of the laws of electrodynamics. The American Civil War will fade into provincial insignificance in comparison with this important scientific event of the same decade."

Richard Feynman, Lectures on Physics, Vol. II

Timeline of Wireless Communications Development . . .

Prof. H. Hertz (1857-1894) experimental validation of Maxwell 1886-1888 at Karlsruhe

Guglielmo Marconi (1874-1937) development of wireless telegraphy trans-Atlantic 1901

Martin Cooper, Motorola, develops first handheld cellular phone in 1973

Dave interviews at Bell Labs for Mobile Phone project – "This thing isn't going anywhere."

2003 - US cellular subscribers exceed 150M

1860 1880 1900 1920 1940 1960 1980 2000

Prof. J. Maxwell (1831-1879) theory of electromagnetism developed in 1865

KDKA Radio -1920

First television broadcast - 1928

Two-way mobile radio services 1960s – 1970s

1983 - Cellular AMPS service in Chicago

2008 - Indian cellular subscribers exceed 300M

Why Wireless Communication? (1)

- **Freedom from wires**
  - No cost of installing wires or rewiring
  - No bunches of wires running here and there
  - "*Auto magical*" instantaneous communications without physical connection setup, e.g., Bluetooth, WiFi
- **Global Coverage**
  - Communications can reach where wiring is infeasible or costly, e.g., rural areas, old buildings, battlefield, vehicles, outer space (through Communication Satellites)

Why Wireless Communication? (2)

- **Stay Connected**
  - Roaming allows flexibility to stay connected anywhere and any time
  - Rapidly growing market attests to public need for mobility and uninterrupted access
- **Flexibility**
  - Services reach you wherever you go (Mobility). E.g, you don't have to go to your lab to check your mail
  - Connect to multiple devices simultaneously (no physical connection required)

Why Wireless Communication? (3)

- Increasing dependence on telecommunication services for business and personal reasons
- Consumers and businesses are willing to pay for it

- **Basic Mantra: Stay connected – anywhere, anytime.**

Challenges (1)

- **Efficient Hardware**
  - ***Low power*** Transmitters, Receivers
  - ***Low Power*** Signal Processing Tools
- **Efficient use of *finite* radio spectrum**
  - Cellular frequency reuse, medium access control protocols,...
- **Integrated services**
  - voice, data, ***multimedia*** over a single network
  - service differentiation, priorities, resource sharing,...

Multimedia Requirements

	Voice	Data	Video
Delay	<100ms	-	<100ms
Packet Loss	<1%	0	<1%
BER	10^{-3}	10^{-6}	10^{-6}
Data Rate	8-32 Kbps	1-100 Mbps	1-20 Mbps
Traffic	Continuous	Bursty	Continuous

One-size-fits-all protocols and design do not work well

Wired networks use this approach, with poor results

Challenges (2)

- Network support for **user mobility** (mobile scenarios)
  - location identification, handover,...
- Maintaining **quality of service** over unreliable links
- Connectivity and coverage (**internetworking**)
- **Cost** efficiency

Challenges (3)

- Fading
- Multipath
- Higher probability of data corruption
  - Hence, need for stronger channel codes
- Need for stronger Security mechanisms
  - privacy, authentication,…

Wireless vs Mobile

- *NOTE* : Wireless does not necessarily mean mobile
- Wireless Systems may be
  - **Fixed** (e.g., Metropolitan Area Network)
  - **Portable** (e.g., wireless interaction between TV and VCR)
  - **Mobile** (e.g., mobile phone)

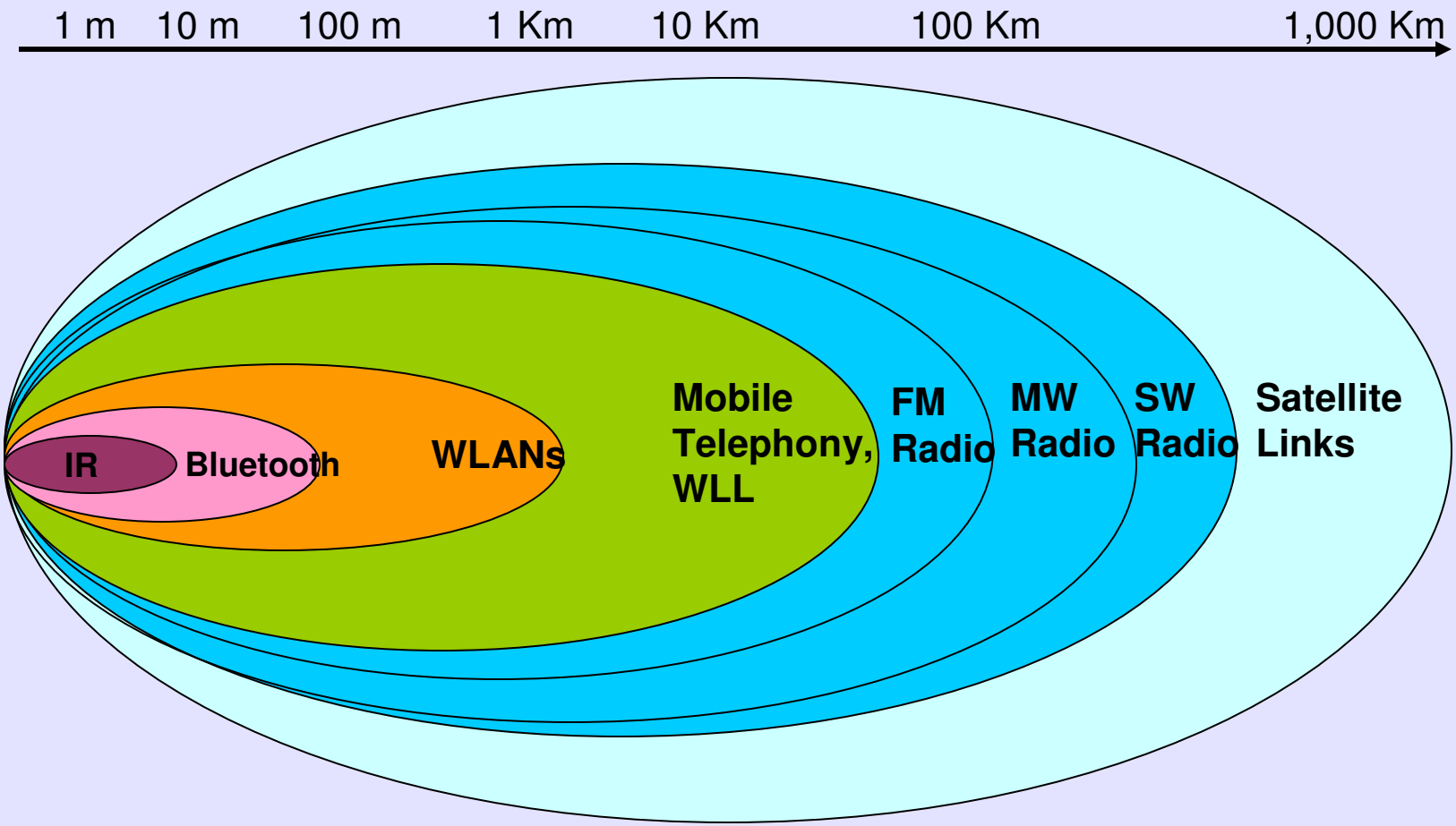
Types of Wireless Communication (1)

- **Radio Transmission**
  - Easily generated, omni-directionally travel long distances, easily penetrate buildings
  - Problems:
    - frequency-dependent
    - relative low bandwidth for data communication
    - tightly licensed by the governments
- **Microwave Transmission**
  - Widely used for long distance communication
  - Gives a high S/N ratio, relatively inexpensive
  - Problems:
    - don't pass through buildings well
    - weather and frequency-dependent

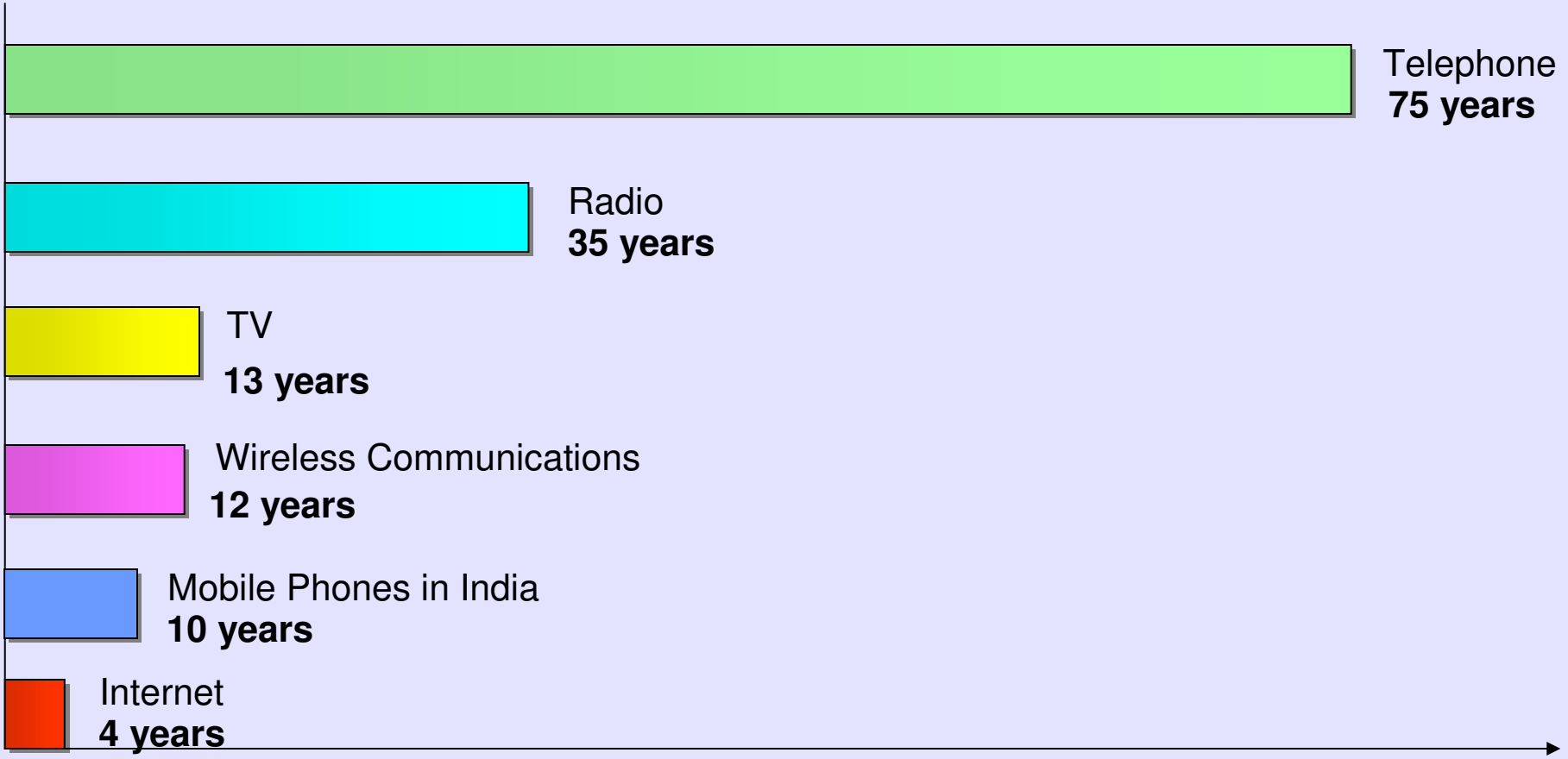
Types of Wireless Communication (2)

- **Infrared and Millimeter Waves**
  - Widely used for short-range communication
  - Unable to pass through solid objects
  - Used for indoor wireless LANs, not for outdoors
- **Lightwave Transmission**
  - Unguided optical signal, such as laser
  - Connect two LANs in two buildings via laser mounted on their roof
  - Unidirectional, easy to install, don't require license
  - Problems:
    - unable to penetrate rain or thick fog
    - laser beam can be easily diverted by turbulent air

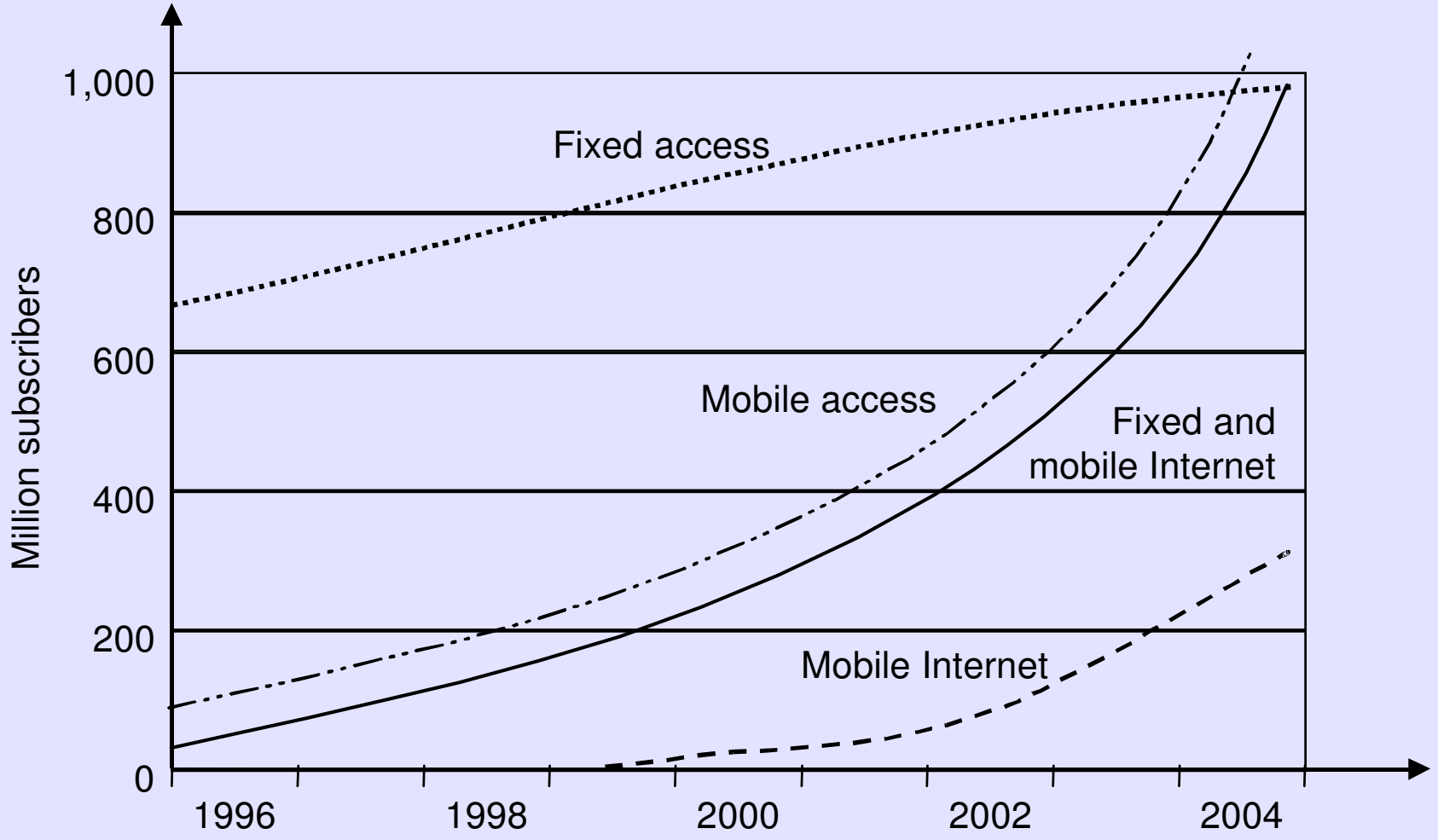
Wireless Systems : Range Comparison



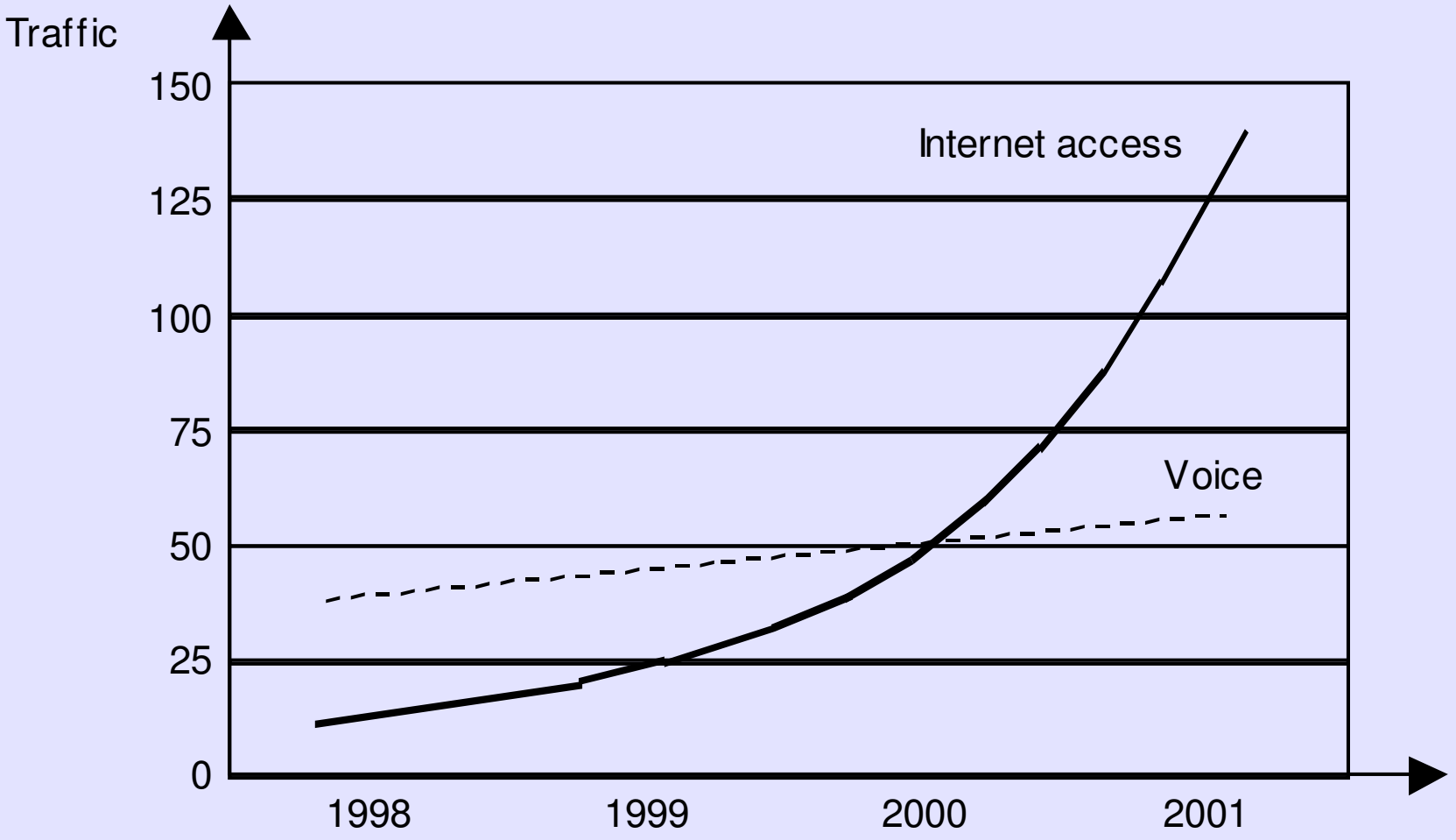
Growth : Technology take-up time to 50M users



User Growth


1,000
800
600
400
200
0
Million subscribers
Fixed access
Mobile access
Fixed and
mobile Internet
Mobile Internet
1996
1998
2000
2002
2004

Traffic Growth



Mobile Phones by Numbers!

Rank	Country/Region	Number of mobile phones	Population	% of Population	Date of Information
—	World	3,665,000,000	6,671,266,000	32.5	Jun 2008
1	China	601,000,000	1,323,758,000	45.5	Jun 2008
—	European Union	466,000,000	497,198,740	93.7	2005
2	India	305,240,000	1,129,866,154	27.0	Aug 2008
3	United States	260,000,000	303,403,000	85.7	March 2008
4	Russia	172,000,000	141,947,000	121.2	Dec 2007
5	Brazil	135,290,000	186,163,000	73	July 2008
6	Indonesia	115,600,000	231,627,000	49.9	2008
7	Japan	102,980,000	127,790,000	79.6	April 2008
8	Germany	101,500,000	82,210,000	123.5	2008
9	Pakistan	90,204,284	162,474,000	55.90	Sept 2008
10	United Kingdom	80,000,000	60,975,000	116.0	2007

The Indian Affordability factor (1)

- India has > 1.1 billion people and 200 million households
- Today, India has more mobile phones (~ 310 million) than fixed line phones (~ 65 million)
- Landline Phones:
  - Cost Rs 30,000 to install per line
  - Monthly revenue should be Rs. 1,000 for economic viability.

- Not affordable by more than 3% of the households unless we have a cheap solution!
- **Need to go wireless in order to increase tele-density.**

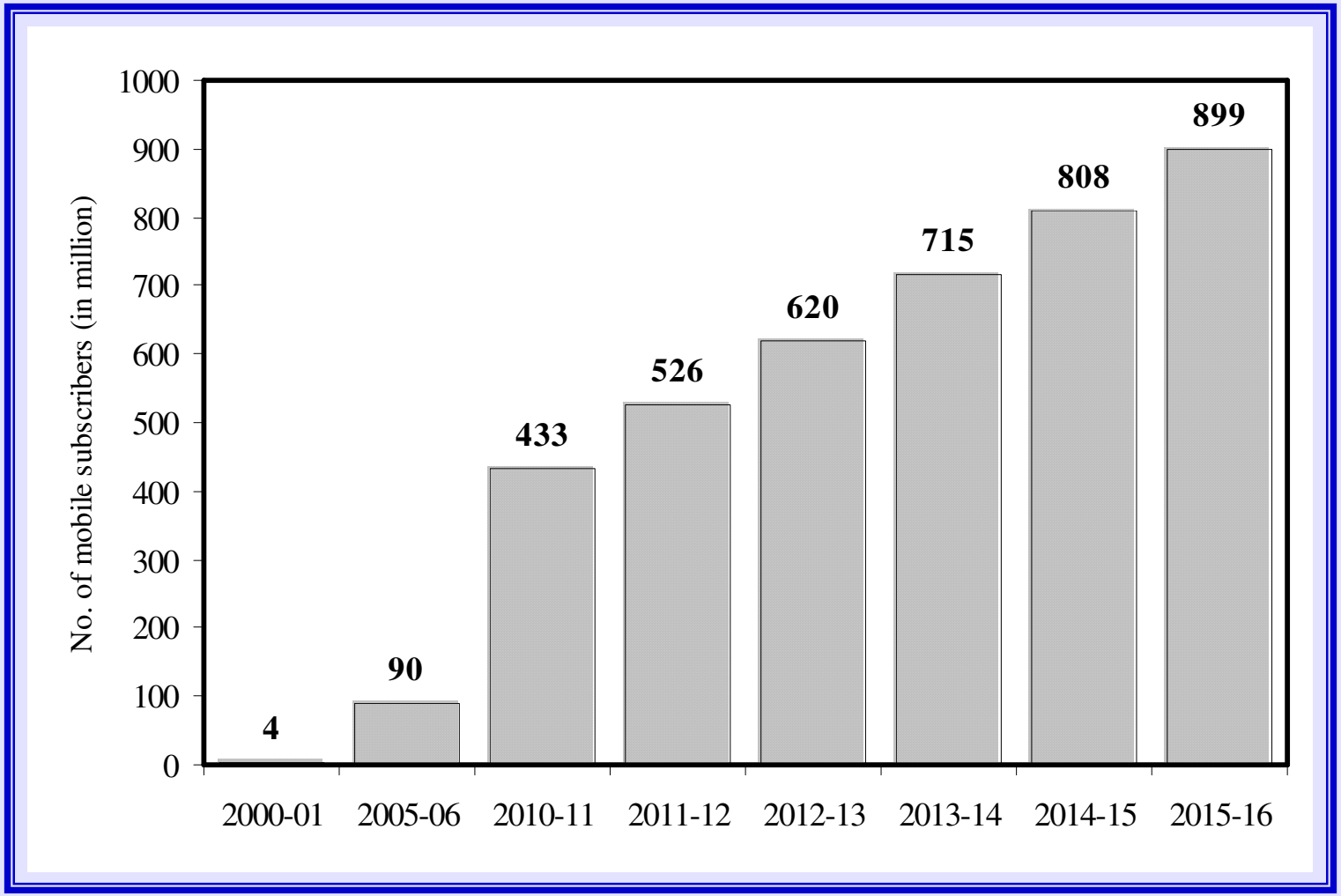
The Indian Affordability factor (2)

- India's mobile-phone industry is adding about 10 million new users a month (mostly in the cities).
- The Telecom Regulatory Authority of India (TRAI) predicts that there will be 150 million mobile subscribers by 2007.
- Declining prices for mobile-phone handsets will likely keep sales rising into the future.
- Mobile handset costs could drop to less than Rs. 1,000 from Rs. 2,500, if local companies start to manufacture the handsets.

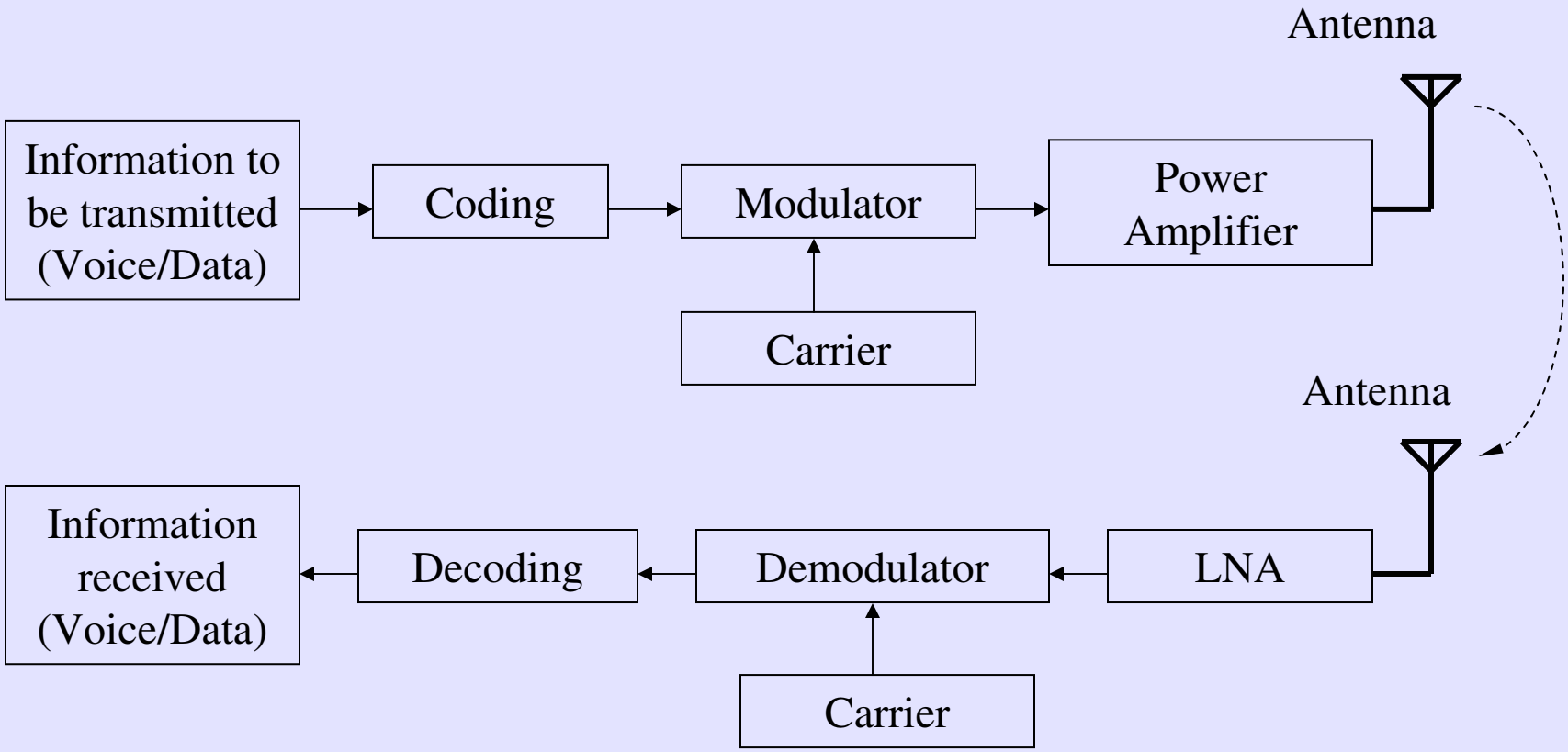
The Indian Affordability factor (3)

- Because of India's large geography, wireless is the fastest and cheapest way to expand telecom networks.
- A large cellular subscriber base will give telecom carriers the economies of scale to run sustainable businesses.
- The next big milestone in the Indian telecommunications industry is the broadband connectivity.
- According to TRAI, India's broadband penetration rate today is a negligible 0.02%.
- The government aims to have 3 million broadband users by 2005.

The future of mobiles in India !



A Simplified Wireless Communication System Representation



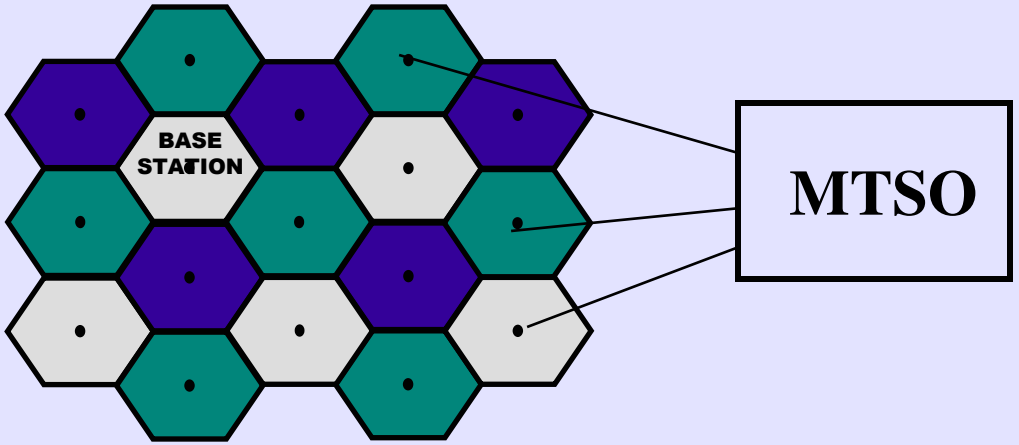
Current Wireless Systems

- Cellular Systems
- Wireless LANs
- Satellite Systems
- Wireless PANs (bluetooth, UWB)

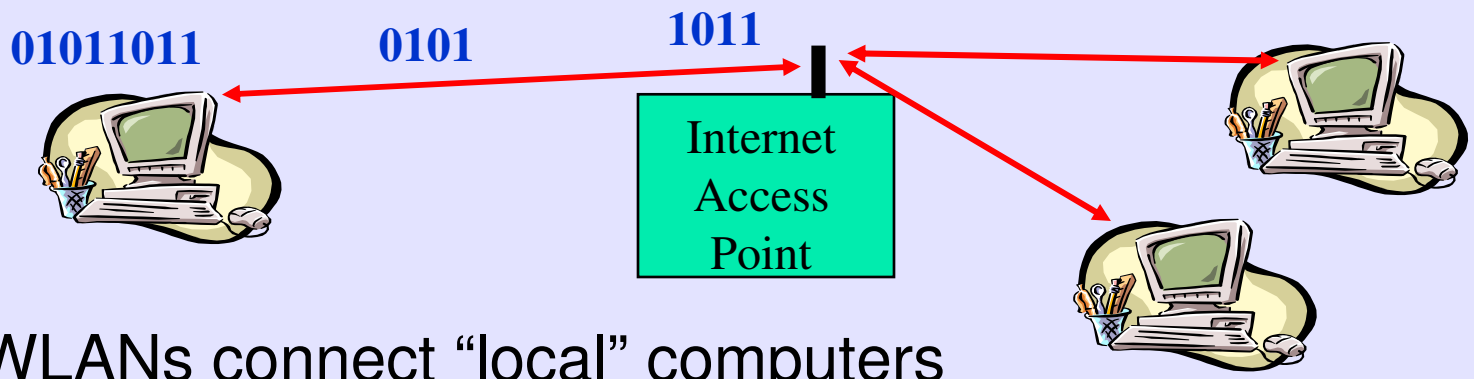
1. Cellular Systems

Reuse channels to maximize capacity

- Geographic region divided into cells
- Frequencies/timeslots/codes reused at spatially-separated locations
- Base stations/Mobile Telephone Switching Offices (MTSOs) coordinate handoff and control functions



2. Wireless Local Area Networks (WLANs)

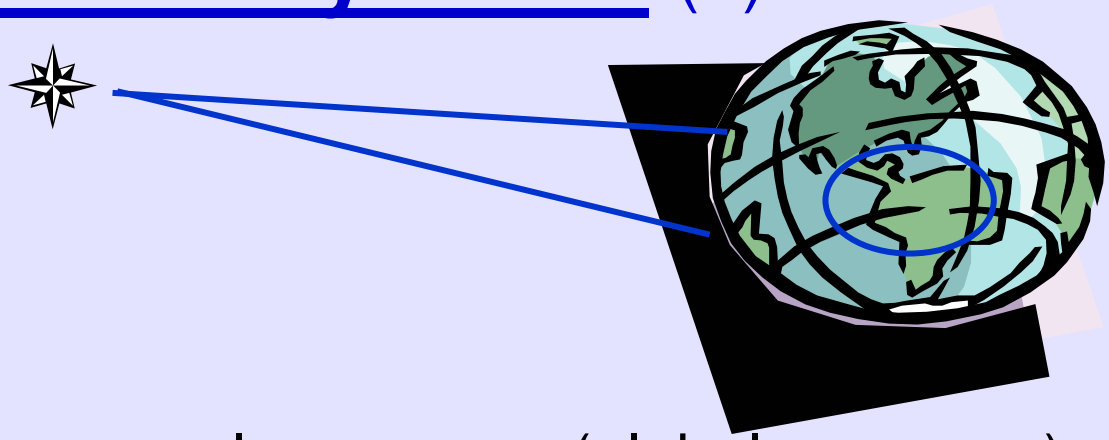


- WLANs connect “local” computers
  (100m range => confined regions)
- Breaks data into packets
- Channel access is shared (random access)
- Backbone Internet provides best-effort service
- Poor performance in some applications (e.g. video)
- Low mobility

Wireless LAN Standards

	Bitrate	Frequency Band	Range
IEEE 802.11b	5.5 – 11Mbps	2.4 GHz	~100m
IEEE 802.11a	54 Mbps	5 Ghz	~100m
HiperLAN (Europe)	20Mbps	5 GHz	~50m
HiperLAN/2	54 Mbps	5 GHz	~50m

3. Satellite Systems (1)



- Cover very large areas (global coverage)
  - Very useful in sparsely populated areas: rural areas, sea, mountains, etc.
- Different orbit heights
  - GEOs (39000 Km) versus LEOs (2000 Km)
- Optimized for one-way transmission
  - Radio (XM, DAB) and movie (SatTV) broadcasting
- Expensive base stations (satellites)

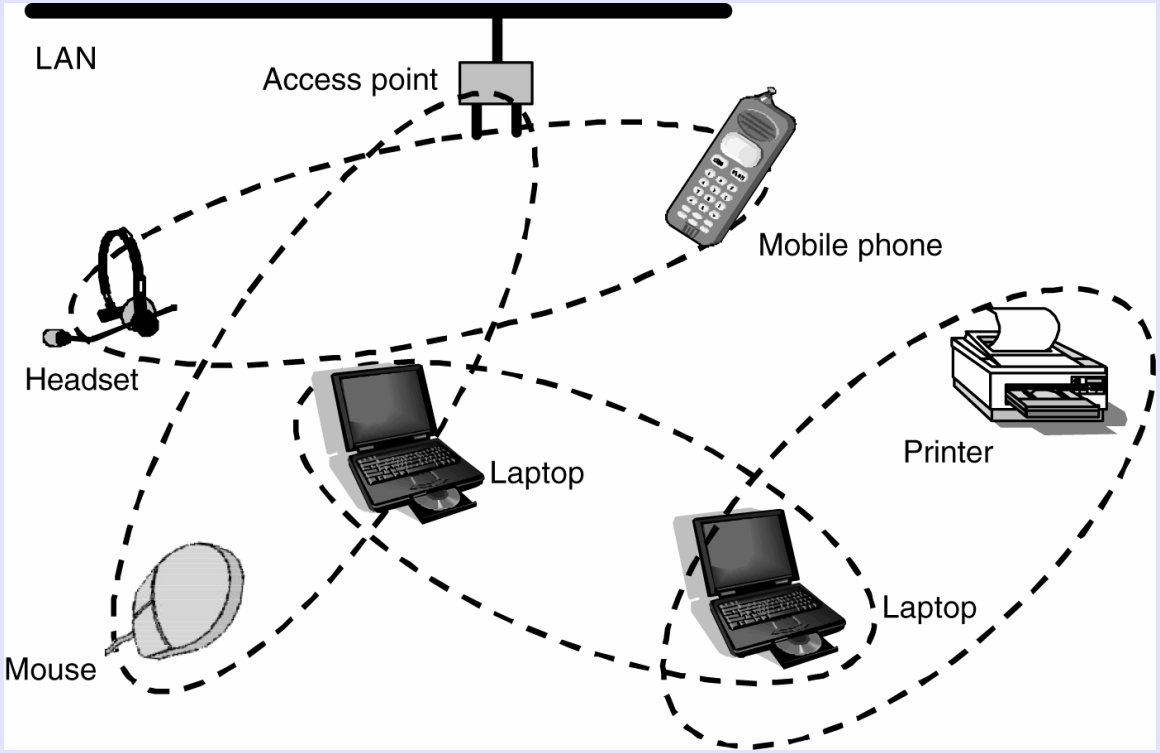
3. Satellite Systems (2)

- Limited-quality voice/data transmission
- Traditional Applications
  - Weather satellite
  - Radio and TV broadcasting
  - Military satellites
- Telecommunication Applications
  - Global telephone connections
  - Backbone for global network
  - GPS
- Iridium, Globalstar, Teledesic, Inmarsat are some example systems

4. Personal Area Networks (PANs)

- **Bluetooth**
  - Cable replacement RF technology (low cost)
  - Short range (10m, extendable to 100m)
  - 2.4 GHz band (crowded)
  - 1 Data (700 Kbps) and 3 voice channels
  - 1 Mbps data rate shared between 7 devices
  - TDD duplex scheme
  - Polling based multiple access
  - Widely supported by telecommunications, PC, and consumer electronics companies

4. PANs (2)



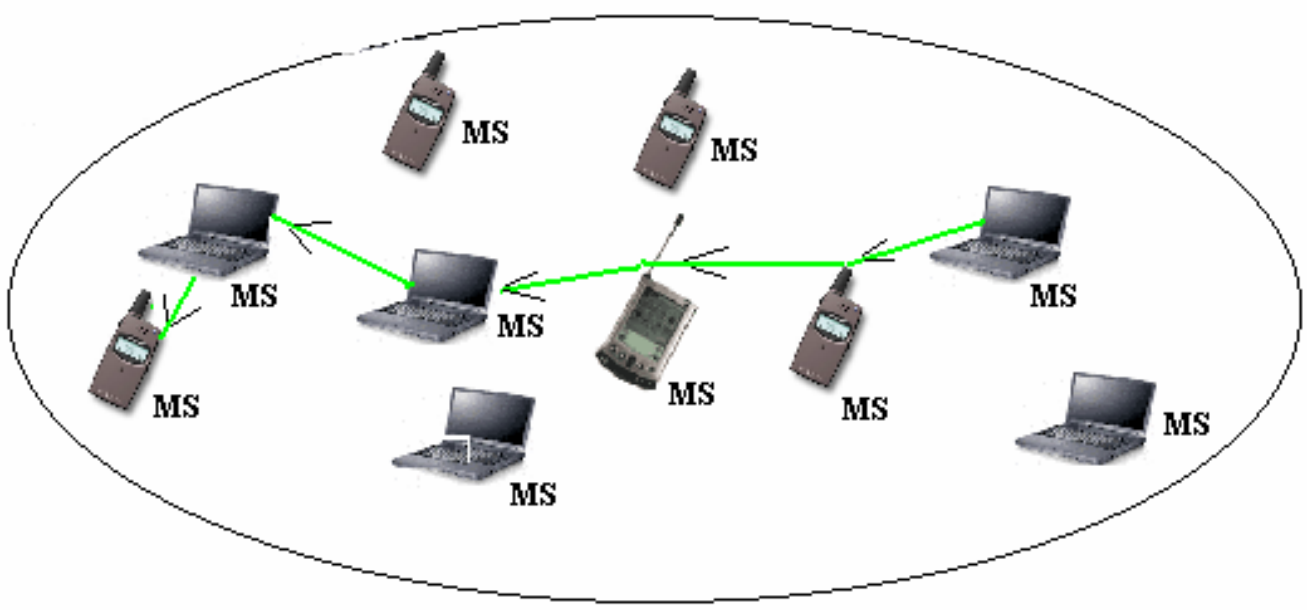
Example of a PAN as provided by the Bluetooth standard.

(Source : T. S. Rappaport, Figure 2.17)

Emerging Wireless Systems

- Ad hoc wireless networks
- Sensor networks
- Distributed control networks
- Ultra Wideband (UWB) Systems

1. Ad-Hoc Networks (1)



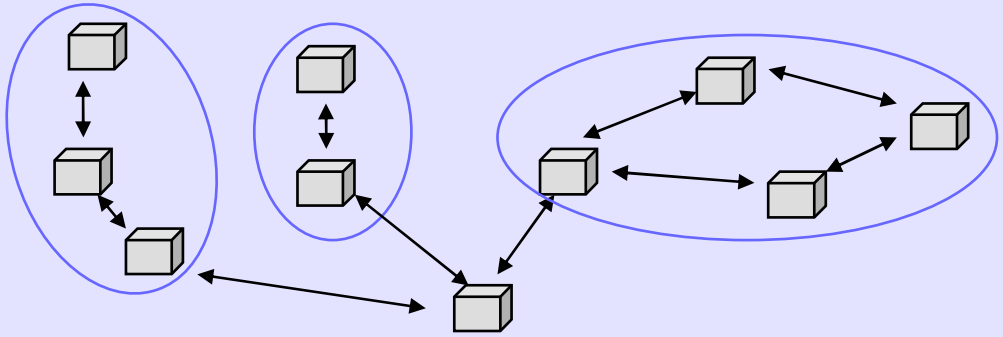
- Peer-to-peer communications.
- No backbone infrastructure.
- Routing can be multihop.
- Topology is dynamic.
- Fully connected with different link SINRs

1. Ad-Hoc Networks (2)

- Ad-hoc networks provide a flexible network infrastructure for many emerging applications.
- The capacity of such networks is generally unknown.
- Transmission, access, and routing strategies for these networks are generally ad-hoc.
- Energy constraints impose interesting design tradeoffs for communication and networking.

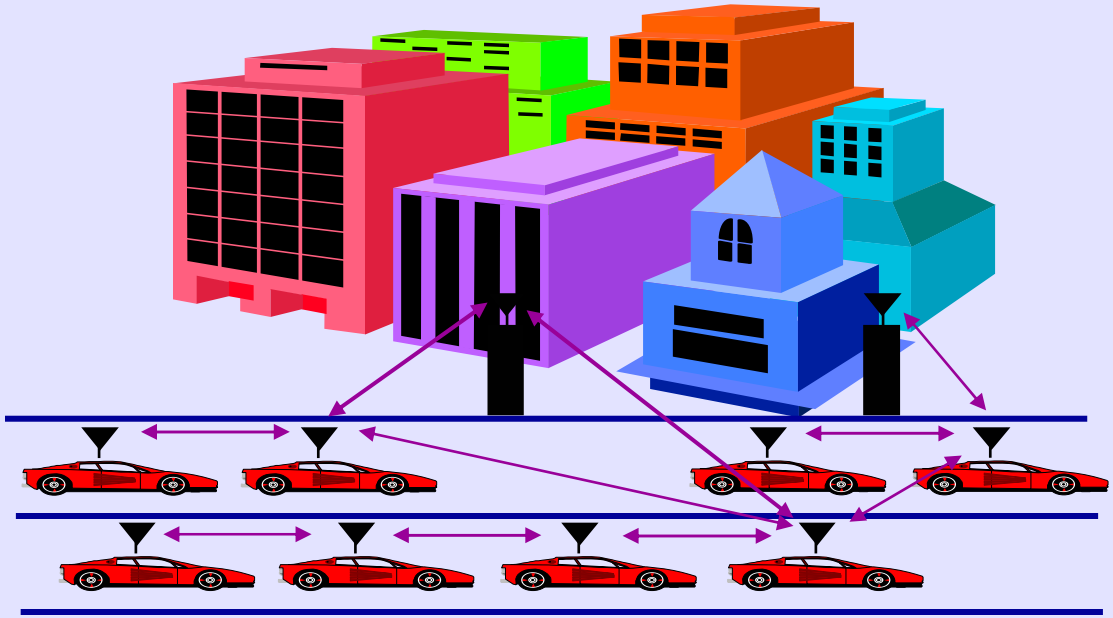
2. Sensor Networks

Energy is the driving constraint



- Nodes powered by non-rechargeable batteries
- Data flows to centralized location.
- Low per-node rates but up to 100,000 nodes.
- Data highly correlated in time and space.
- Nodes can cooperate in transmission, reception, compression, and signal processing.

3. Distributed Control over Wireless Links



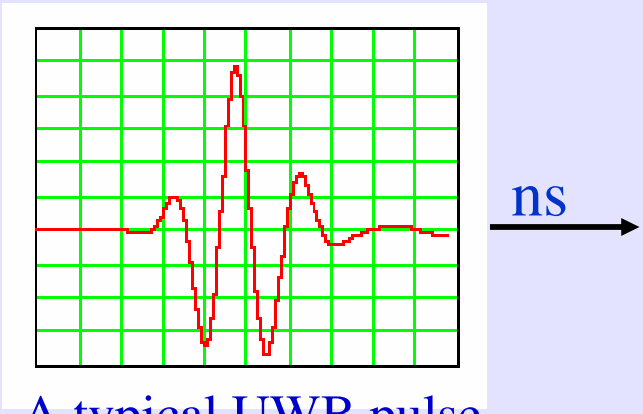
Automated Vehicles

- **Cars**
- **UAVs**
  (Unmanned Aerial Vehicle)
- **Insect flyers**

- Packet loss and/or delays impacts controller performance.
- Controller design should be robust to network faults.
- Joint application and communication network design.

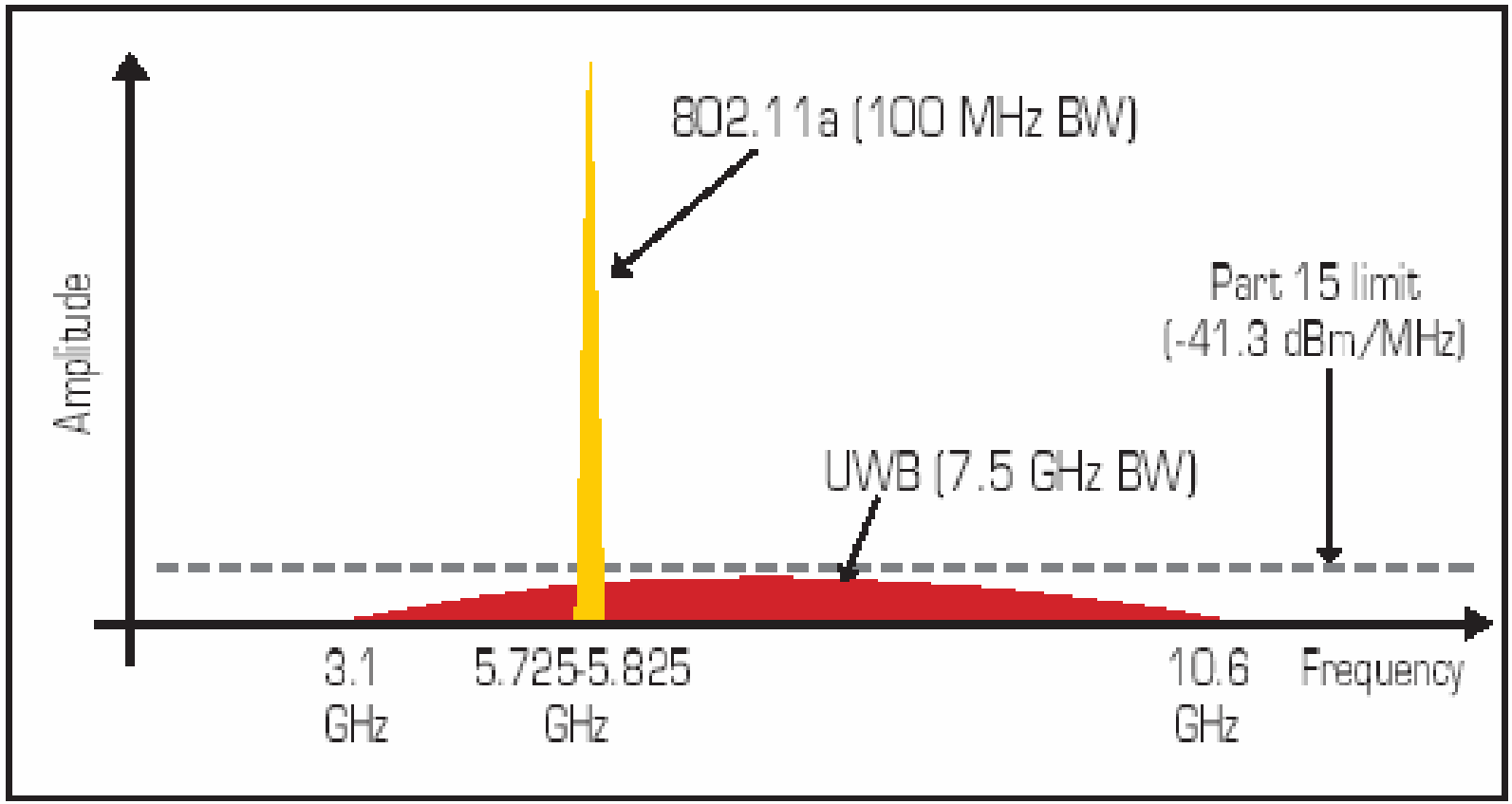
4. Ultra Wide Band Systems (1)

- **U**ltra **W**ide **B**and (UWB) is an emerging wireless communications technology that can transmit data at around **100 Mb/s (up to 1000 Mb/s)**.
- UWB transmits ultra-low power radio signals with very **narrow pulses** (nanosecond).
- Because of its low power requirements, UWB is very **difficult to detect** (hence secure).



A typical UWB pulse

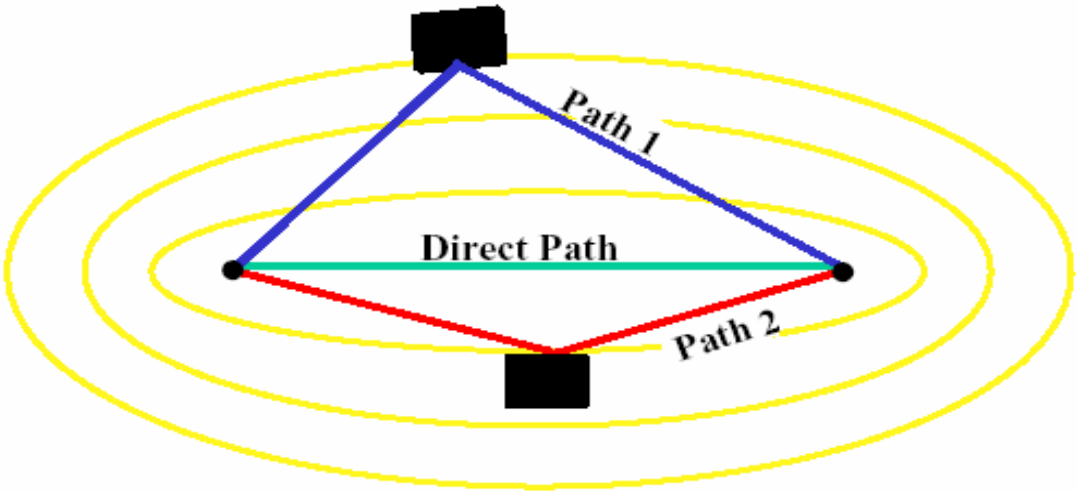
4. Ultra Wide Band Systems (2)

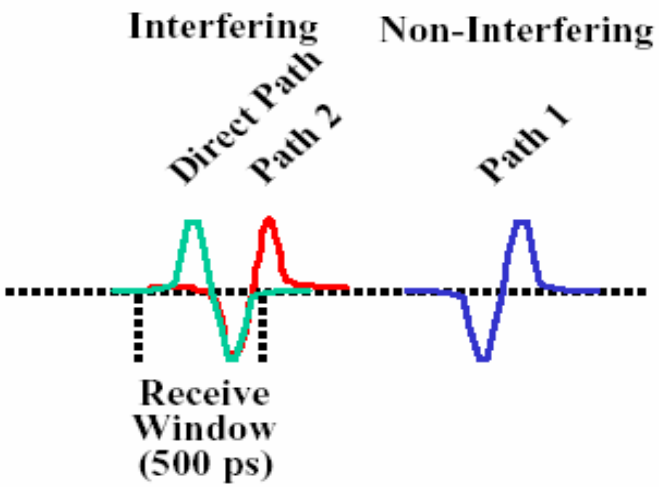


4. Ultra Wide Band Systems (3)

Why UWB?

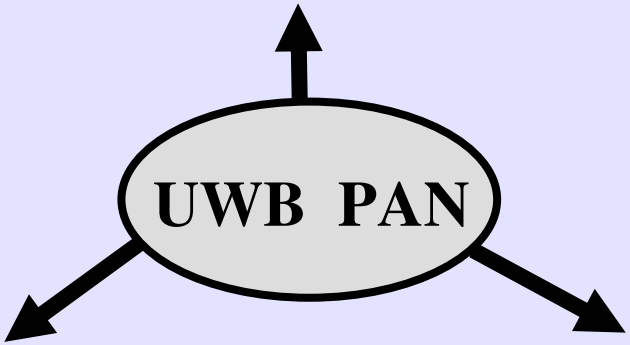
- **Exceptional multi-path immunity**
- **Low power consumption**
- **Large bandwidth**
- **Secure Communications**
- **Low interference**
- **No need for a license to operate**
- **Next generation communication system**



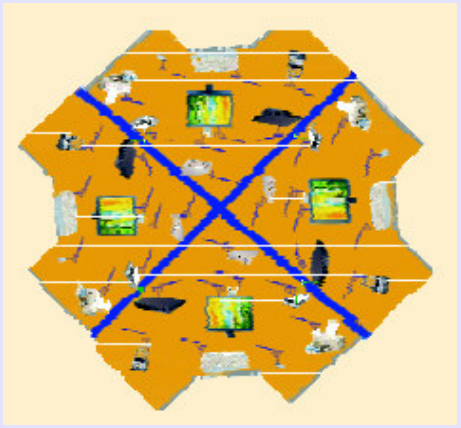


4. Ultra Wide Band Systems (4)

Home entertainment



Wearable computing



Wireless desktop

Spectrum Regulation

- Worldwide spectrum controlled by ITU-R
- ITU auctions spectral blocks for set applications.
- Some spectrum set aside for universal use.

Spectral allocation/regulation heavily impacts the evolution of wireless technology

Standard Bodies

- CCIR(Consultative Committee on International Radio)
  - study groups for radio spectrum usage and interworking of wireless systems
- Radio Communications Sector ITU-R (formerly CCIR and IFRB)
  - world conferences, radio regulations
- Telecommunication Standardization Sector ITU-T (formerly CCITT)
  - all worldwide wireline and wireless standards
  - IEEE standards often accepted

Suggested Reading

1. T.S. Rappaport, Wireless Communications, 2nd Edition, Pearson Education. 2002.
2. W.C.Y. Lee, Mobile Cellular Telecommunications, 2nd Edition, McGraw Hill, 1995.
3. Kamilo Feher, Wireless Digital Communications: Modulation and Spread Spectrum Applications, Prentice Hall, 2002.

Thank you for your attention !