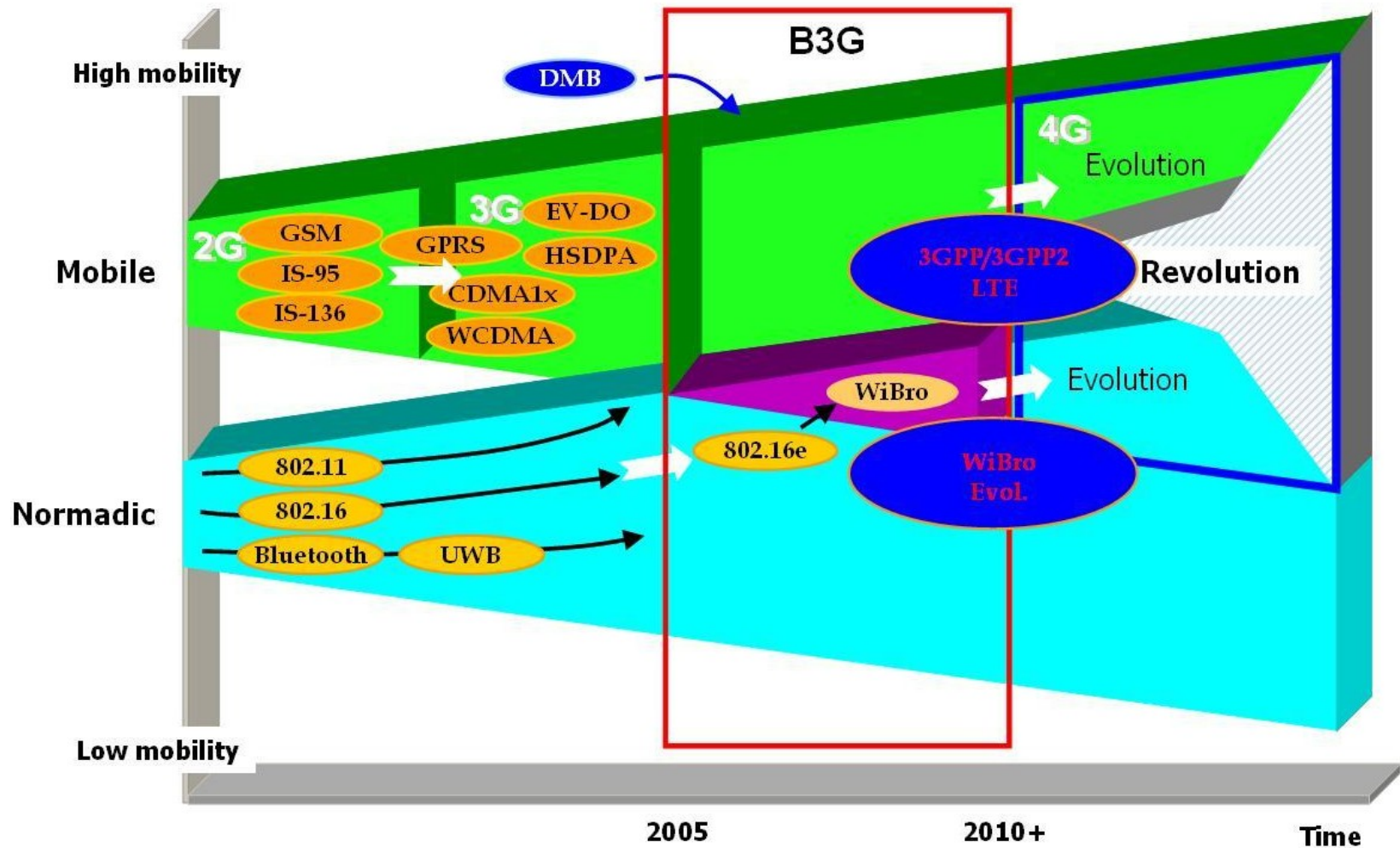


# Wireless Communications

## Overview of Wireless Systems



# Outline

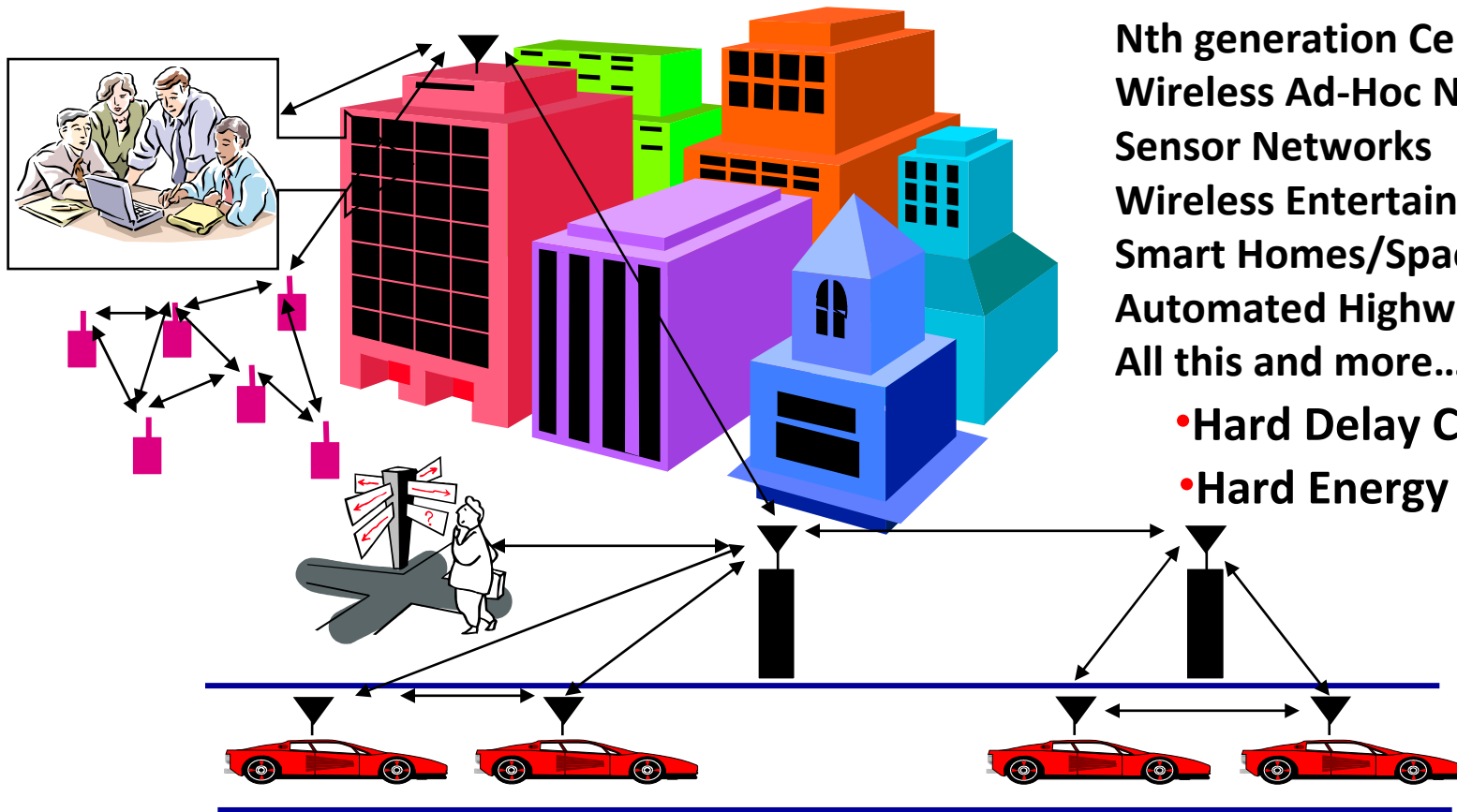
- The Wireless Vision
- Technical Challenges
- Current Wireless Systems
- Emerging Wireless Systems
- Spectrum Regulation
- Standards

# Wireless History

- **Ancient Systems: Smoke Signals, Carrier Pigeons, ...**
  - **Radio invented in the 1880s by Marconi**
- **Many sophisticated military radio systems were developed during and after WW2**
- **Cellular has enjoyed exponential growth since 1988, with almost 3 billion users worldwide today**
  - **Ignited the wireless revolution**
  - **Voice, data, and multimedia becoming ubiquitous**
  - **Use in third world countries growing rapidly**
- **WiFi also enjoying tremendous success and growth**
  - **Wide area networks (e.g. Wimax) and short-range systems other than Bluetooth (e.g. UWB) less successful**

# Future Wireless Communication

## *Ubiquitous Communication Among People and Devices*



Wireless Internet access  
Nth generation Cellular  
Wireless Ad-Hoc Networks  
Sensor Networks  
Wireless Entertainment  
Smart Homes/Spaces  
Automated Highways  
All this and more...

- Hard Delay Constraints
- Hard Energy Constraints

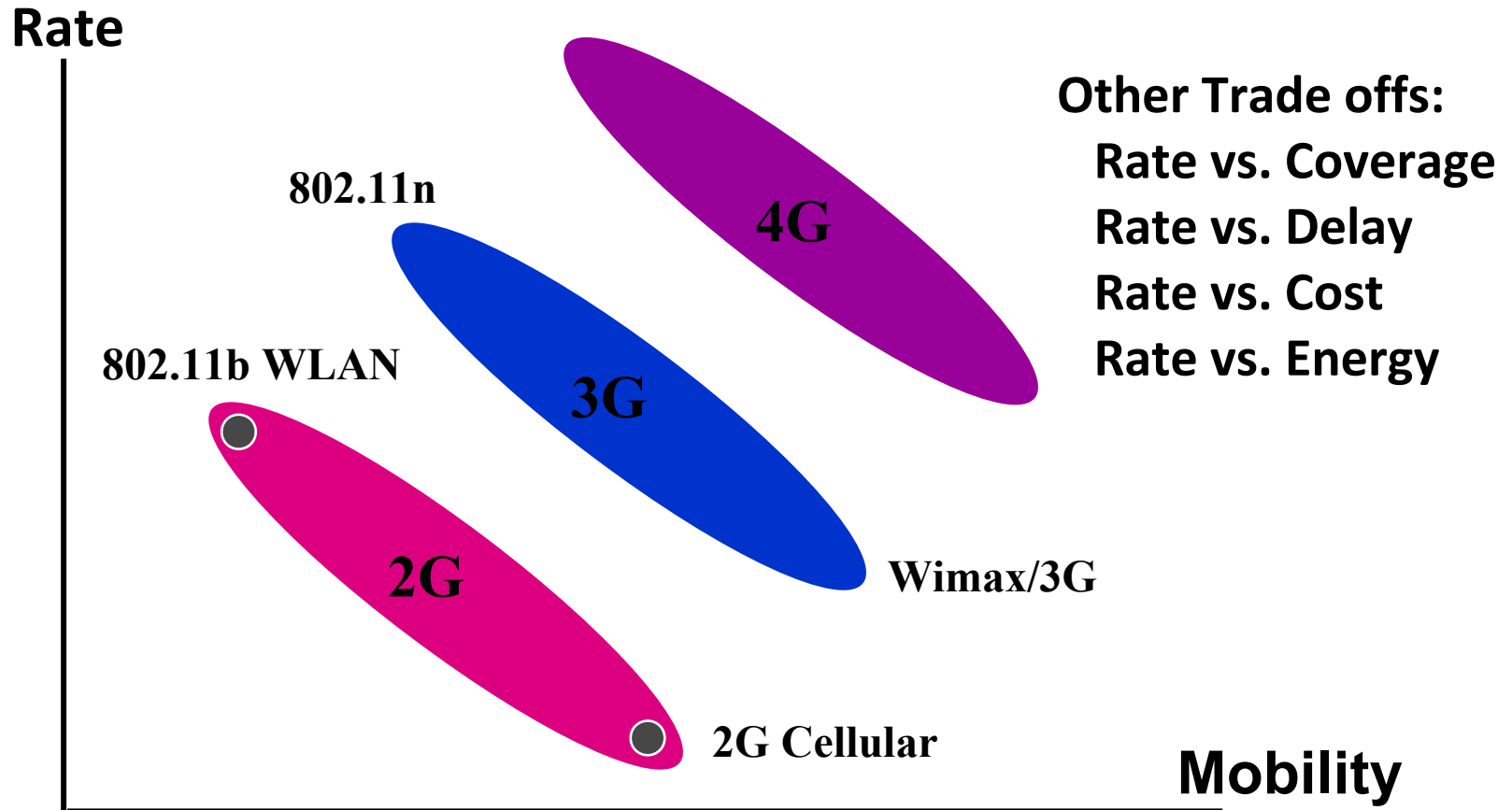
# Design Challenges

- Wireless channels are a difficult and capacity-limited broadcast communications medium
- Traffic patterns, user locations, and network conditions are constantly changing
- Applications are heterogeneous with hard constraints that must be met by the network
- Energy and delay constraints change design principles across all layers of the protocol stack

# Evolution of the Current Systems

- Wireless systems today
  - 3G Cellular: ~200-300 Kbps.
  - WLANs: ~450 Mbps (and growing).
- Next Generation is in the works
  - 4G Cellular: Likely OFDM/MIMO
  - 4G WLANs: Wide open, 3G just being finalized.
- Technology Enhancements
  - Hardware: Better batteries, circuits and processors.
  - Link: Antennas, modulation, coding, adaptivity, DSP, BW.
  - Network: Not much: more efficient algorithms & ACK
  - Application: Soft and adaptive QoS.

# Future Generations



**Fundamental Design Breakthroughs Needed**

# 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**

# Quality of Service (QoS)

- QoS refers to the requirements associated with a given application, typically rate and delay requirements.
- It is hard to make a one-size-fits all network that supports requirements of different applications.
- Wired networks often use this approach with poor results, and they have much higher data rates and better reliability than wireless.
- QoS for all applications requires a cross-layer design approach.

# Cross-Layer Design

- Application
- Network
- Access
- Link
- Hardware



**Delay Constraints**  
**Rate Constraints**  
**Energy Constraints**

*Adapt across design layers*  
*Reduce uncertainty through scheduling*  
*Provide robustness via diversity*

# Cross-Layer Techniques

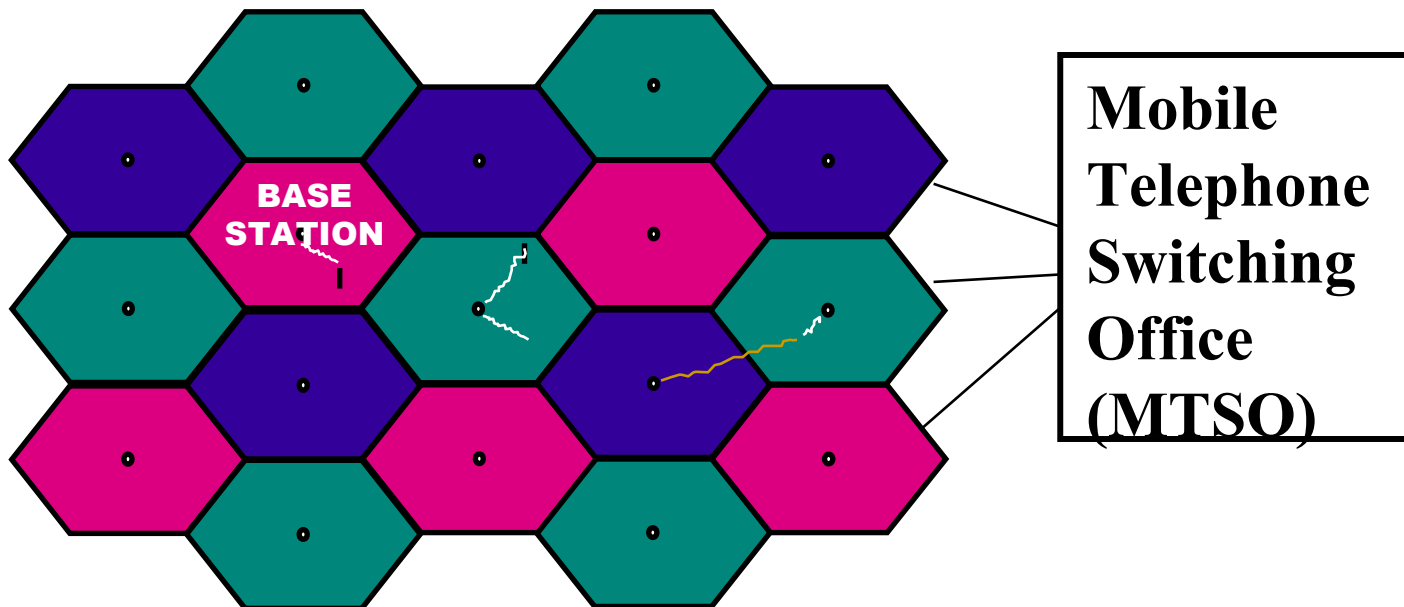
- Adaptive techniques
  - Link, MAC, network, and application adaptation
  - Resource management and allocation (power control)
- Diversity techniques
  - Link diversity (antennas, channels, etc.)
  - Access diversity/ Route diversity
  - Application diversity
  - Content location/server diversity
- Scheduling
  - Application scheduling/data prioritization
  - Resource reservation
  - Access scheduling

# Current Wireless Systems

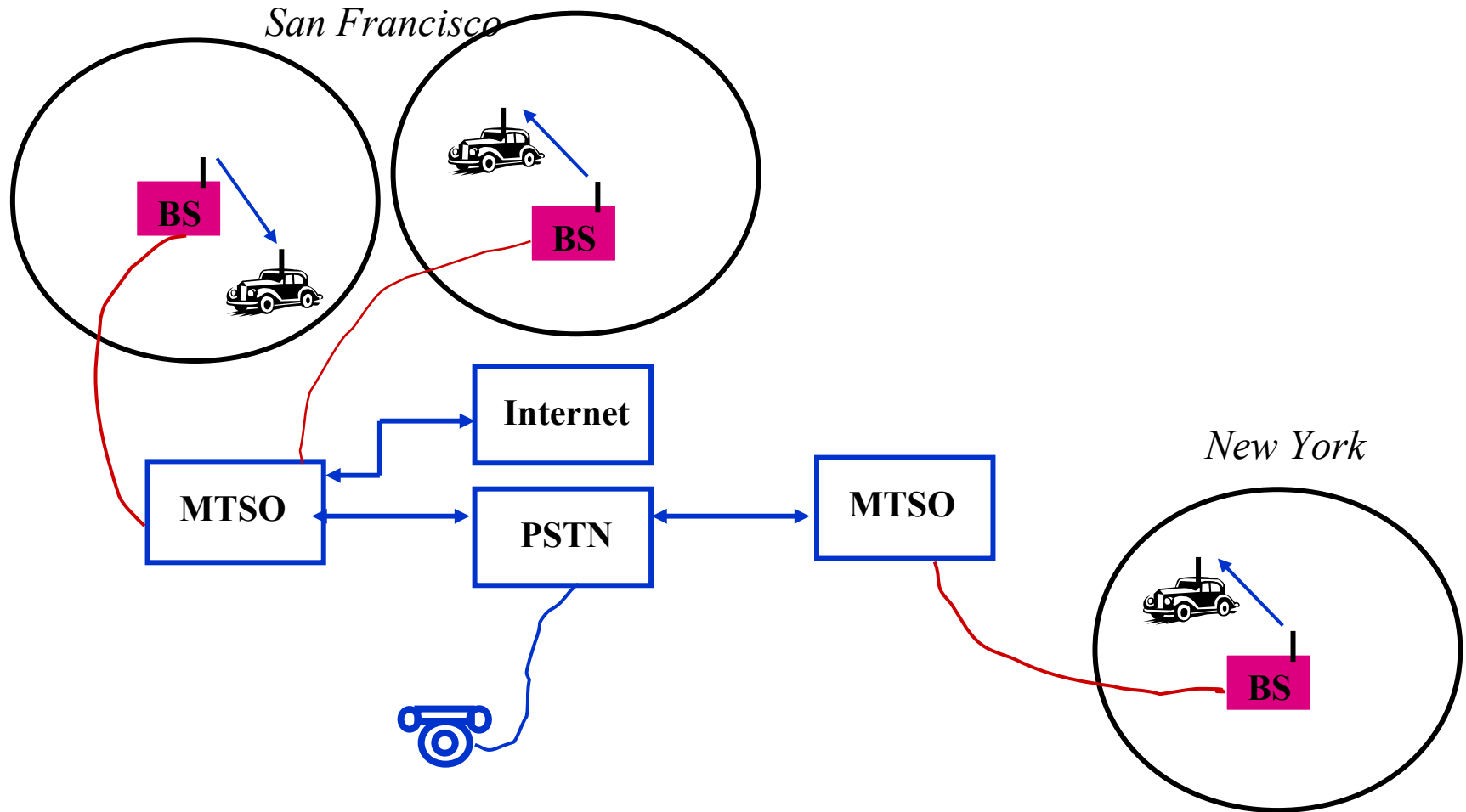
- Cellular Systems
- Wireless LANs
- WiMAX
- Satellite Systems
- Paging Systems
- Bluetooth
- Ultra-WideBand radios
- Zigbee radios

# Cellular System

- Geographic region divided into cells
- Frequency/time slots/codes/ reused at spatially-separated locations.
- Co-channel interference between same colour cells.
- Base stations/MTSOs coordinate hand-off and control functions
- Shrinking cell size increases capacity, as well as networking burden



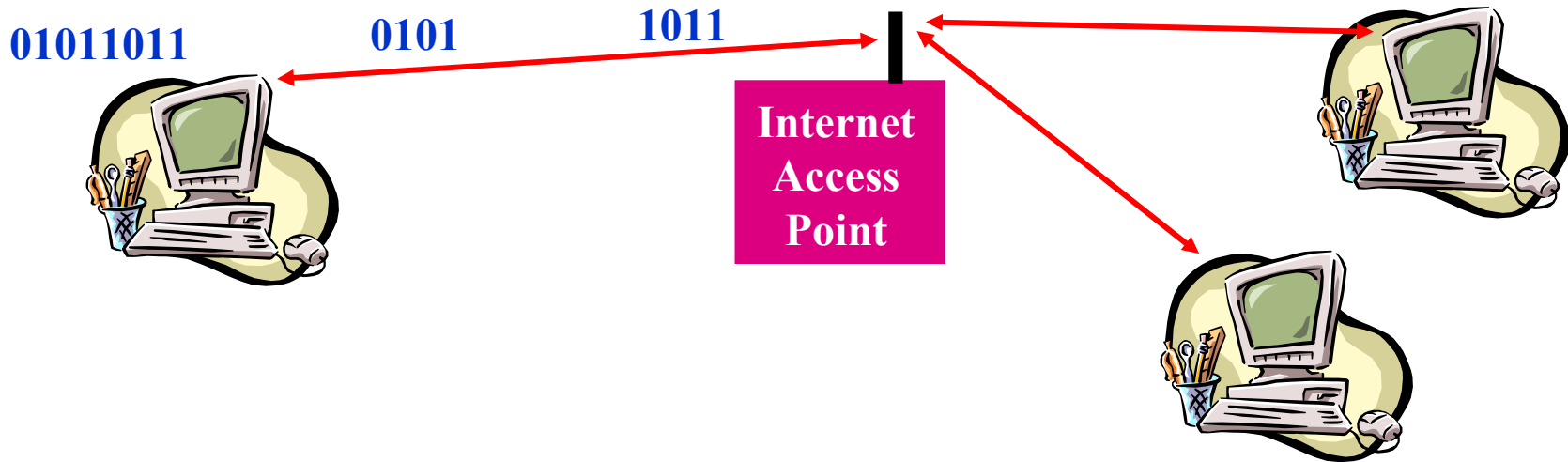
# Cellular Phone Networks



# 3G Cellular Design

- Data is bursty, whereas voice is continuous
  - Typically require different access and routing strategies
- 3G “widens the data pipe”:
  - 384 Kbps (802.11n has 100s of Mbps).
  - Standard based on Wideband CDMA
  - Packet-based switching for both voice and data
- 3G cellular popular in Asia and Europe
- Evolution of existing systems in US (2.5G++)
  - GSM+EDGE, IS-95(CDMA)+HDR
  - 100 Kbps may be enough
  - Dual phone (2/3G+Wifi) use growing (iPhone, etc)
- *What is beyond 3G?*

# Wireless Local Network



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

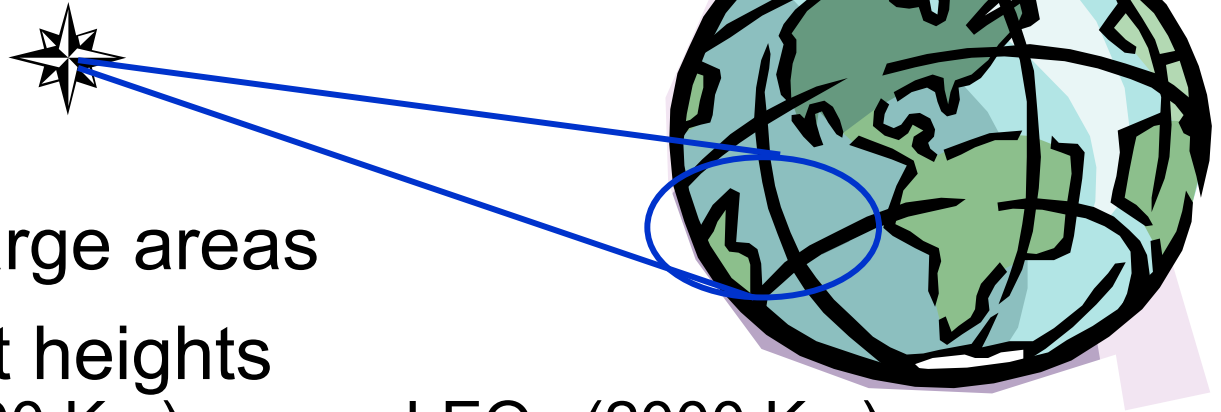
# WLAN Standards

- 802.11b (Old – 1990s)
  - Standard for 2.4GHz ISM band (80 MHz)
  - Direct sequence spread spectrum (DSSS)
  - Speeds of 11 Mbps, approx. 500 ft range
- 802.11a/g (Middle Age– mid-late 1990s) } Many WLAN cards have all 3 (a/b/g)
  - Standard for 5GHz NII band (300 MHz)
  - OFDM in 20 MHz with adaptive rate/codes
  - Speeds of 54 Mbps, approx. 100-200 ft range
- 802.11n (Hot stuff, standard close to finalization)
  - Standard in 2.4 GHz and 5 GHz band
  - Adaptive OFDM /MIMO in 20/40 MHz (2-4 antennas)
  - Speeds up to 600Mbps, approx. 200 ft range
  - Other advances in packetization, antenna use, etc.

# WiMAX (802.16)

- Wide area wireless network standard
  - System architecture similar to cellular
  - Hopes to compete with cellular
- OFDM/MIMO is core link technology
- Operates in 2.5 and 3.5 MHz bands
  - Different for different countries, 5.8 also used.
  - Bandwidth is 3.5-10 MHz
- Fixed (802.16d) vs. Mobile (802.16e) Wimax
  - Fixed: 75 Mbps max, up to 50 mile cell radius
  - Mobile: 15 Mbps max, up to 1-2 mile cell radius

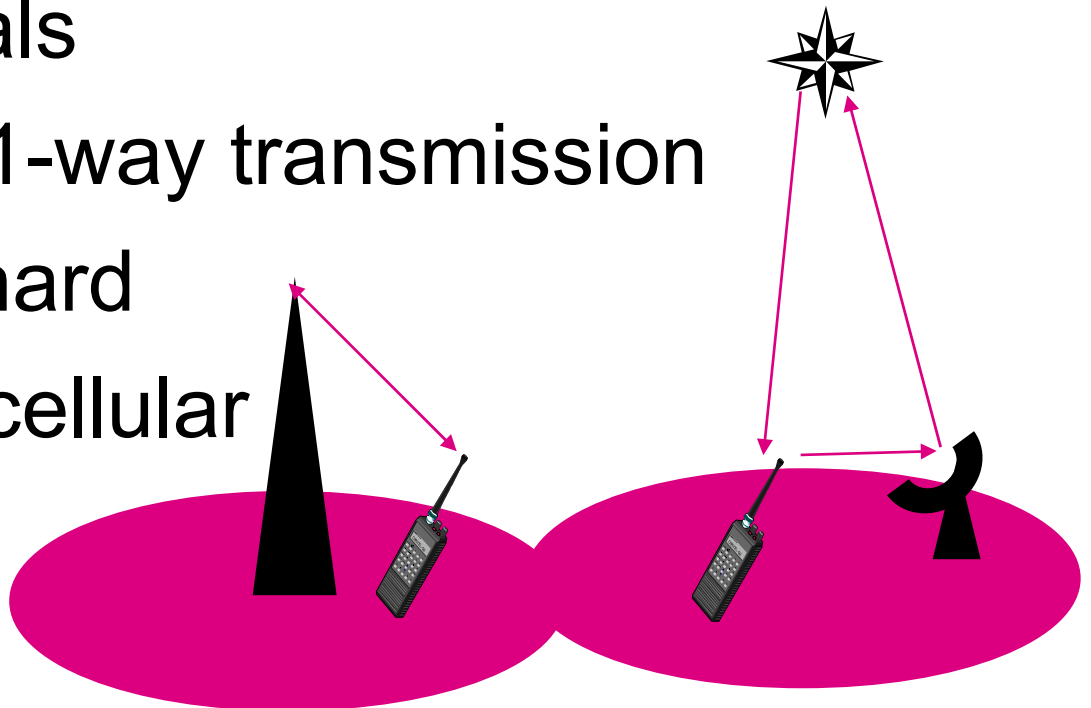
# Satellite Systems



- Cover very large areas
- Different orbit heights
  - GEOs (39000 Km) versus LEOs (2000 Km)
- Optimized for one-way transmission
  - Radio and movie (SatTV, DVB/S) broadcasts
  - Most two-way systems struggling or bankrupt
- Global Positioning System (GPS) use growing
  - Satellite signals used to pinpoint location
  - Popular in cell phones, PDAs, and navigation devices

# Paging Systems

- Broad coverage for short messaging
- Message broadcast from all base stations
- Simple terminals
- Optimized for 1-way transmission
- Answer-back hard
- Overtaken by cellular



# 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, up to 3 Mbps
- Widely supported by telecommunications, PC, and consumer electronics companies
- Few applications beyond cable replacement

# Ultra-Wide Band Radio (UWB)

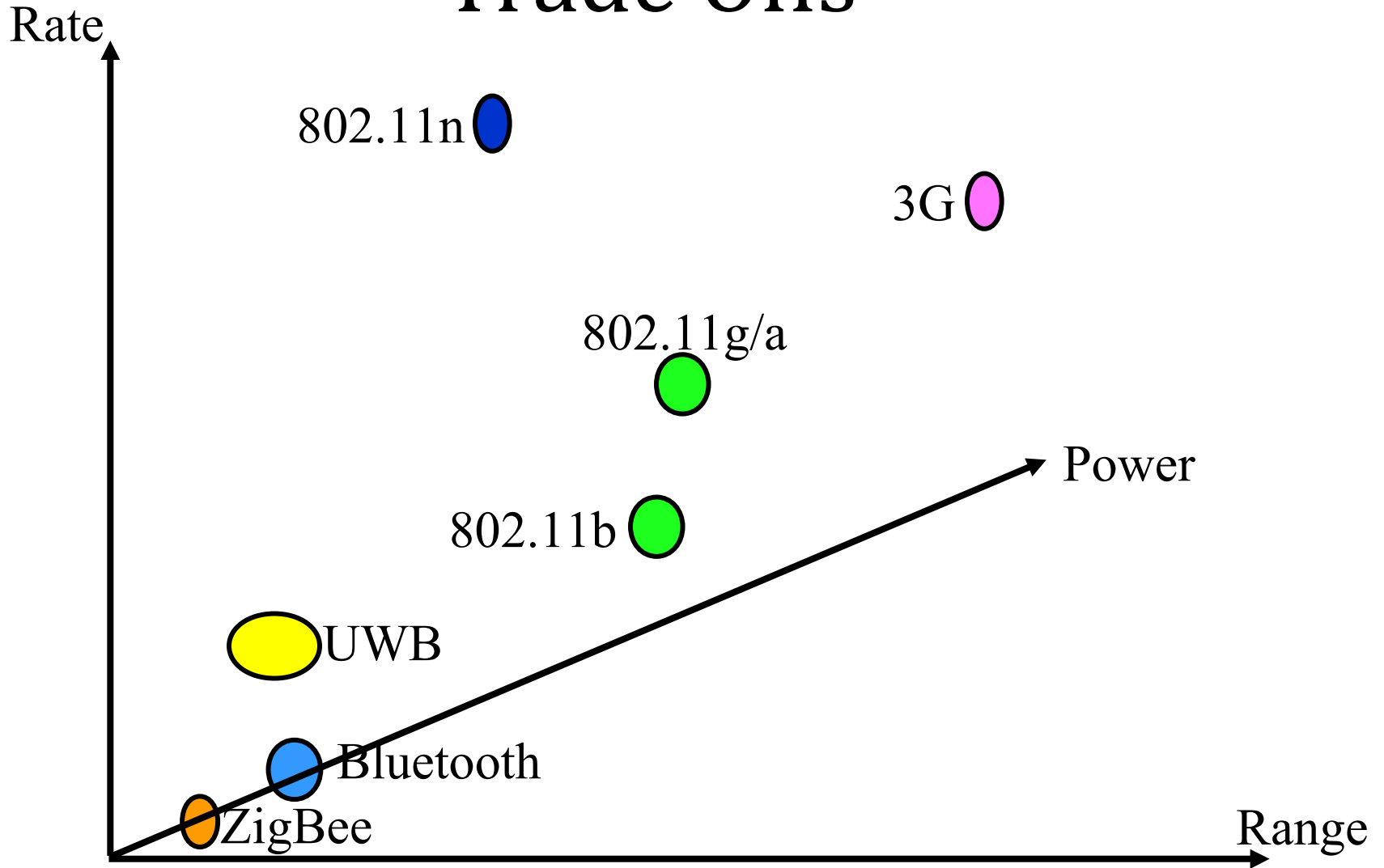
- UWB is an impulse radio: sends pulses of tens of picoseconds ( $10^{-12}$ ) to nanoseconds ( $10^{-9}$ )
  - Duty cycle of only a fraction of a percent
- A carrier is not necessarily needed
- Uses a lot of bandwidth (GHz)
- High data rates, up to 500 Mbps
- 7.5 GHz of “free spectrum” in the U.S.
- Multi-path highly resolvable: good and bad
- Limited commercial success to date

# IEEE 802.15.4 /Zigbee

- Low-Rate WPAN
- Data rates of 20, 40, 250 Kbps
- Support for large mesh networking or star clusters
- Support for low latency devices
- CSMA-CA channel access
- Very low power consumption
- Frequency of operation in ISM bands

*Focus is primarily on low power sensor networks*

# Trade Offs

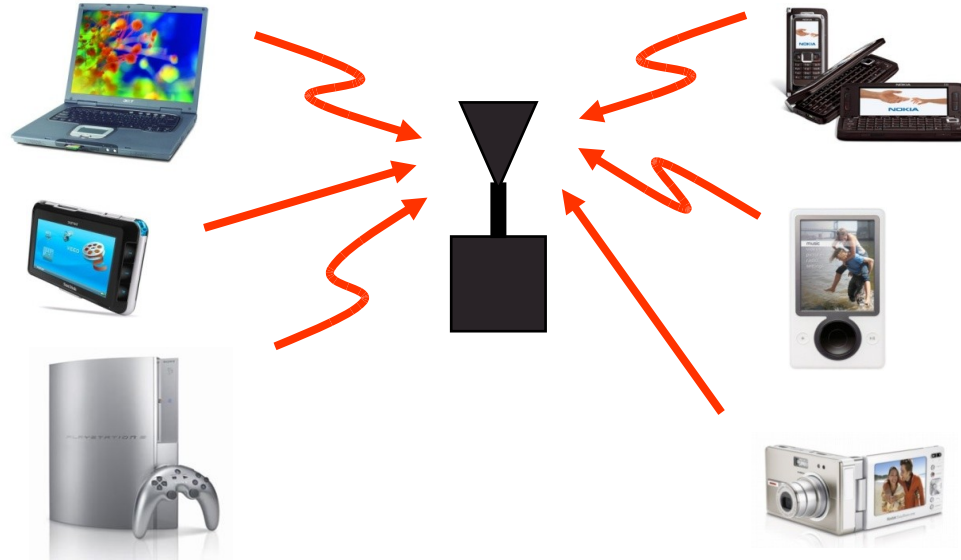


# Spectrum Regulation

- Spectral Allocation in US controlled by FCC (commercial) or OSM (defence)
- FCC auctions spectral blocks for set applications.
- Some spectrum set aside for universal use
- Worldwide spectrum controlled by ITU-R
- Regulation is a necessary evil.

# Coexistence Challenge:

*Many devices use the same radio band*



- Technical Solutions:
  - Interference Cancellation
  - Smart/Cognitive Radios

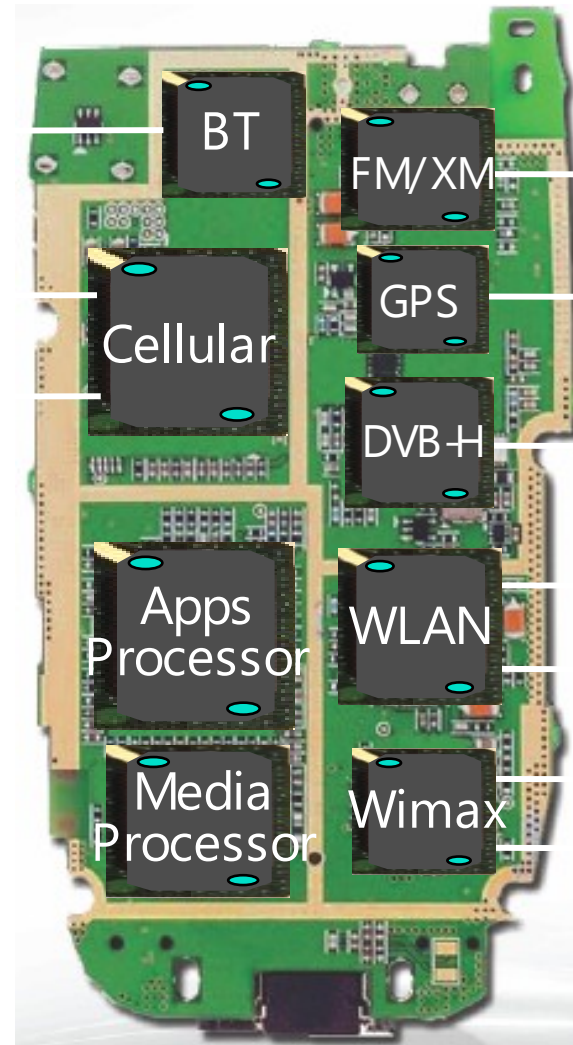
# Next-Generation Devices

*Everything Wireless in One Device*



# Multi Radio Integration Challenge

- RF Interference
- Where to put antennas
- Size
- Power Consumption



# Standards

- Interacting systems require standardization
- Companies want their systems adopted as standard
  - Alternatively try for de-facto standards
- Standards determined by TIA/CTIA in US
  - IEEE standards often adopted
  - Process fraught with inefficiencies and conflicts
- Worldwide standards determined by ITU-T
  - In Europe, ETSI is equivalent of IEEE

# Emerging Systems

- 4<sup>th</sup> generation cellular (4G)
  - OFDMA will be PHY layer (like Wimax)
  - Other new features and bandwidth still in flux
- Ad hoc/mesh wireless networks
- Cognitive radios
- Sensor networks
- Distributed control networks

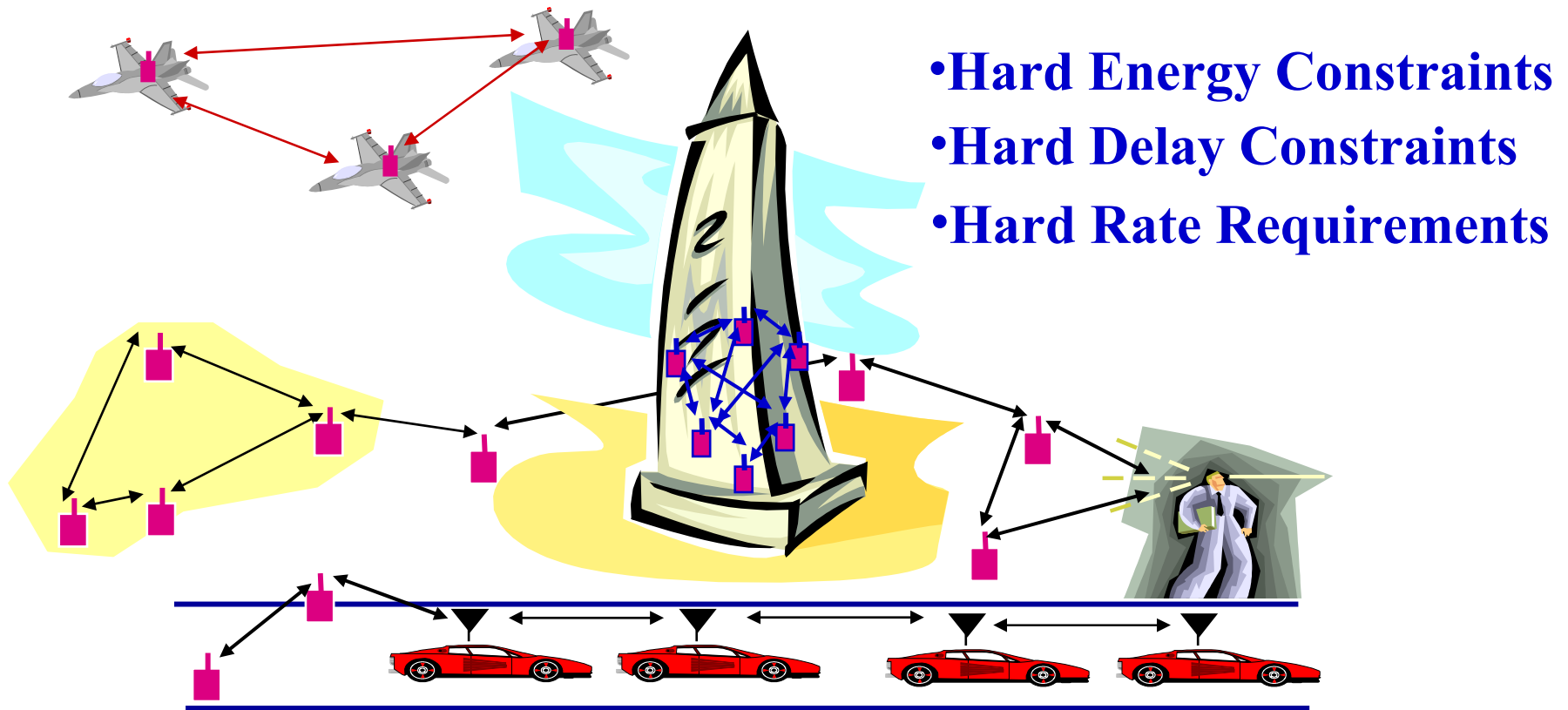


# Design Issues

- 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 ad-hoc networks are generally ad-hoc.
- Cross-layer design critical and very challenging.
- Energy constraints impose interesting design trade-offs for communication and networking.

# Wireless Sensor Networks

## *Data Collection and Distributed Control*

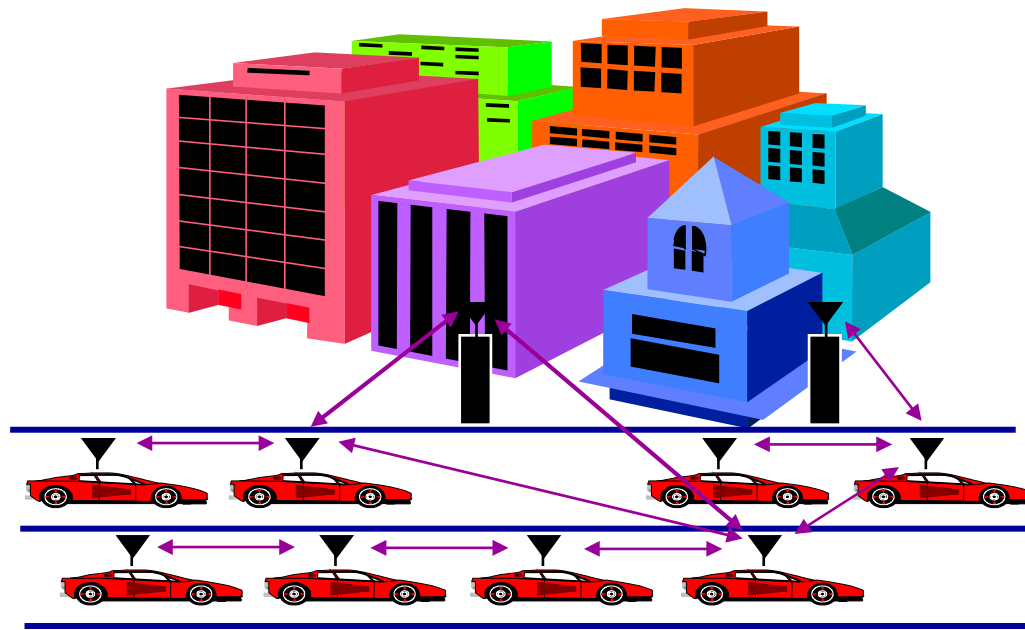


**Nodes can cooperate in transmission, reception, compression, and signal processing.**

# Energy- Constrained Nodes

- Each node can only send a finite number of bits.
  - Transmit energy minimized by maximizing bit time
  - Circuit energy consumption increases with bit time
  - Introduces a delay versus energy trade-off for each bit
- Short-range networks must consider transmit, circuit, and processing energy.
  - Sophisticated techniques not necessarily energy-efficient.
  - Sleep modes save energy but complicate networking.
- Changes **everything** about the network design:
  - Bit allocation must be optimized across **all** protocols.
  - Delay vs. throughput vs. node/network lifetime trade-offs.
  - Optimization of node cooperation.

# Distributed Control Over Wireless Links



## Automated Vehicles

- Cars
- UAVs
- Insect flyers

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

# Main Points

- The wireless vision encompasses many exciting systems and applications
- Technical challenges transcend across all layers of the system design.
- Cross-layer design emerging as a key theme in wireless.
- Existing and emerging systems provide excellent quality for certain applications but poor interoperability.
- Standards and spectral allocation heavily impact the evolution of wireless technology