Wireless Networks
(Reti Wireless)

Prof. Claudio Palazzi
cpalazzi@math.unipd.it

Office 426, Torre di Archimede

Presentation

- LANGUAGE:
  - English
- PREREQUISITE:
  - Having passed Computer Networks exam
- TEXT BOOK (NOT compulsory, only part of the class is based on it):
  - Wireless Communications & Networks (2nd Edition), William Stallings; Prentice Hall; 2005; 0131918354
- OTHER MATERIAL:
  - **slides and scientific papers**
- WEB SITE:
  - **http://www.math.unipd.it/~cpalazzi/retiwireless.html**

Program 1/2

- Introduction, wireless systems, protocols architecture, issues and measures
  - Physical Layer (just fundamentals and mobility effects)
  - Data Link Layer (duplexing, TDMA, FDMA, CDMA)
  - Network Layer (addressing with device mobility)
  - Transport Layer (Reliable communication and mobility impact on TCP)
  - Application Layer (Geolocalized services, DTN)

- Wireless Network Architectures: management and challenges
  - WLAN, Infrastructure and Hot-Spot Networks
  - Wireless Mesh Networks (WMN)
  - Sensor Networks (Sensor Networks)
  - Mobile Ad Hoc Networks (MANETs)
  - Vehicular Ad-Hoc Networks (VANETs)
  - Satellite systems, challenged networks and possible solutions

Program 2/2

- Consumer market technology; main standards; advanced issues:
  - IEEE 802.11b/g/a/e/n/s/p
  - IEEE 802.15.1 (Bluetooth)
  - IEEE 802.15.4 (ZigBee)
  - RFID

- Services:
  - Location-based services
  - Client/Server and alternative service paradigms
  - Wireless Internet
  - Pervasive wireless communication systems
  - Other fields where Wireless Networks apply: existing and visionary services

- Practical implementation or study of course-related scenarios
  - Performance evaluation of protocols in wireless scenarios
  - Development of applications for mobile environments (e.g., videogames or other applications for smartphones)

Exam 1/2

- Project development
  - To be decided with the Professor
  - Paper or Slide Presentation + oral discussion
- Oral discussion on class material (slides, etc.)
  - Material varies depending on the project
- TOTAL CREDITS: 6 (4 + 2)
  - Availability of more challenging projects as first step of a Thesis

Exam 2/2

- Project evaluation
  - Difficulty
  - Results
  - Autonomy
  - Possible topics:
    - Critical analysis of the state of the art, new solutions for wireless issues (protocols, algorithms), verification through simulations or real experiments, wireless systems implementation (e.g., games on mobile phones)

At the End of this Class …

- You'll understand or have some knowledge of
  - Physical layer (radios, rate, antennas, channels)
  - MAC protocols (who gets the chance to talk)
  - Routing (path selection algorithms and issues)
  - Reliability (wireless congestion control, rate control)

  - Applications (Device-to-Device networks)
  - Human sensing, Urban sensing
    - Localization (extracting the location of a device)
    - Mobility (how it helps and disrupts communication)
    - Interfaces (phones are more than communication devices)

  - Energy-awareness (how it percolates various network functions)
  - Emerging Topics (rural nets, DTN, molecular communications)
  - Capacity (what is feasible, what are performance bounds)

Examples of What You'll Learn

- What's the difference between 802.11 b/g/n/p/s/e..?
- Why is the bandwidth really available in wireless networks much smaller (about half) than the nominal one?
- Why do VoIP and Online games scatter when there is someone else in the WLAN browsing the Internet? What solutions have been proposed?
- How do current protocols perform if we use them in a network of drones?
- How can smartphones be used to improve our lives and society?

What this Class Does Not Cover

- Not a wireless communication class
- Does not cover
  - Modulation schemes
  - Transmitter/Receiver design
  - Signal processing and antenna design
  - Source coding / channel coding
  - Privacy / Security
  - Etc.

- This is class on
  - Design, analysis, and implementation of protocols and algorithms in (mobile) wireless network systems

Some other Thoughts

- Dilemma
  1. Teach very advanced stuff for the networking pro
  2. Teach from absolute scratch for the uninitiated

I will try to strike a balance

Please bear with me if materials are sometimes too easy/difficult for YOU

Credits

- Credits for various slides and figures used in this class material:
  - A. A. Abouzeid
  - J.J. Aceves
  - I. F. Akyildiz
  - B. Awerbuch
  - L. Bononi
  - C. Caini
  - R. R. Choudhury
  - Q. Fang
  - R. Firrincieli
  - J. Gao
  - M. Gerla
  - L. J. Guibas
  - A. Hande
  - J.F. Kurose
  - P. Kyasanur
  - J. Levy
  - A. Mishra
  - K. W. Ross
  - J. Schiller
  - Sudhir Tiwari
  - N. Vaidya
  - M. Zorzi

Thoughts on Reading Papers

- Know why you are reading the paper
  - Reading for absorbing concepts (class assignment)
    - Read fully, think, reread, ask, challenge
  - Reading for excitement (deciding project topic)
    - Read initial parts, don't try to understand everything, get a feel
  - Reading for problem identification
    - Read the **problem** **carefully**

Most Important

  - Reading to discriminate (before finalizing project)
    - Read solution, ensure your ideas different, analyze performance

Paper Projects

- Projects consist of 4 parts:
  - Problem identification
  - State of the art discussion
  - Solution design
  - Performance evaluation

- Each paper you read is someone's project
  - Many papers are actually student's class projects
  - Read them critically
  - Ask yourself
    - Is the problem really important? Should you care?
    - Is the solution sound? Under what assumptions?
    - Do you have other (better) ideas?
    - Is evaluation biased ? Are results shown only in good light?

More on Projects

- Discuss your thoughts, ideas with your Professor
  - They need not be cooked, and can have many flaws
- If you like an area / direction
  - Read many related papers
- Don’t try to come up with a quick solution
  - Ensure your problem is a new, real problem
  - Finding the solution is typically easy

More on Projects

- Protocol evaluation typically requires coding
  - Think what you would like to do
  - Options are:
    - Coding on real devices (sensors, smartphones, routers)
    - Coding in existing network simulators (ns2, Qualnet, etc.)
    - Coding your own simulator
    - Theoretical projects involve MATLAB, CPLEX, etc.
- Project ideas take time … think now and then
  - Spending 3 hours for 10 days better than 10 hours for 3 days

More on Projects

- Find a project partner early
  - Discuss reviews, papers, potential project themes
- Class project often bottlenecked by platform
  - Think of the evaluation platform during project selection
  - If you are not familiar with the Linux OS, it's a bad idea to do a project involving router-programming
- This class is about research
  - Be active, ask questions, debate, and disagree

Slide Presentation Projects

- Choose a topic of interest
- Find related scientific bibiliography
  - scholar.google.com
  - http://ieeexplore.ieee.org/
  - http://dl.acm.org/

- Prepare a 30min presentation and discussion on the topic
  - Read related papers critically
  - For each paper ask yourself
    - What is the problem? Is it really important? Why?
    - Is the solution sound? Under what assumptions? What kind of experiments/analysis were performed?
    - Are there common classes of solutions?
    - Do you have other (better) ideas?
    - Is evaluation biased? Are results shown only in good light?

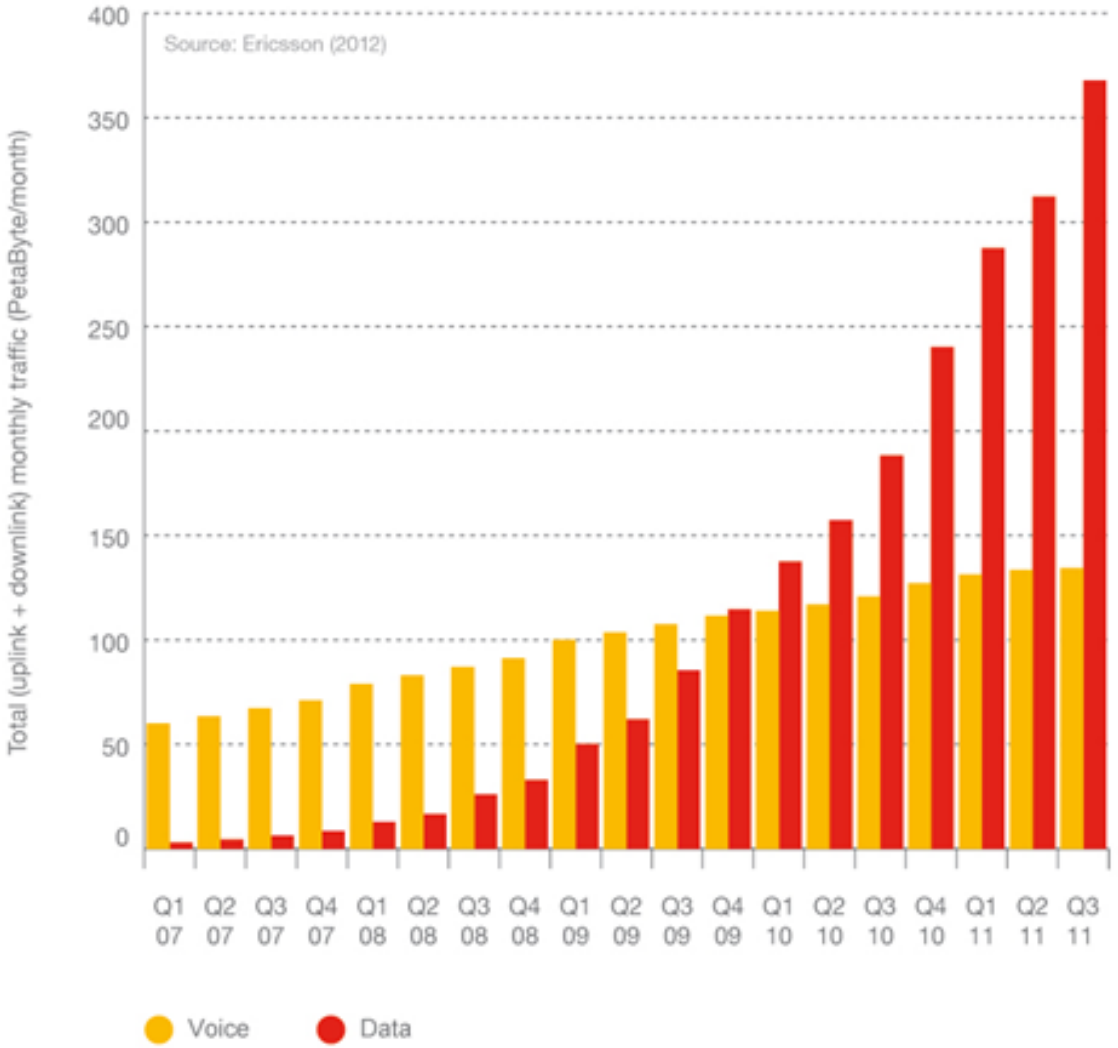
- These projects *should* be presented during class hours

Wireless Communication
Some 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**
  - Ignited the recent wireless revolution
  - **1 billion users in 2000, 4 billion users in 2012**
  - **6 billion mobile phones, 3 billion smartphones**
  - **3G (voice+data)**
  - **4G (LTE)**
  - **What is 5G ???**

Traffic and market data report
(source Eriksson, 2012)

Voice and data traffic on mobile network



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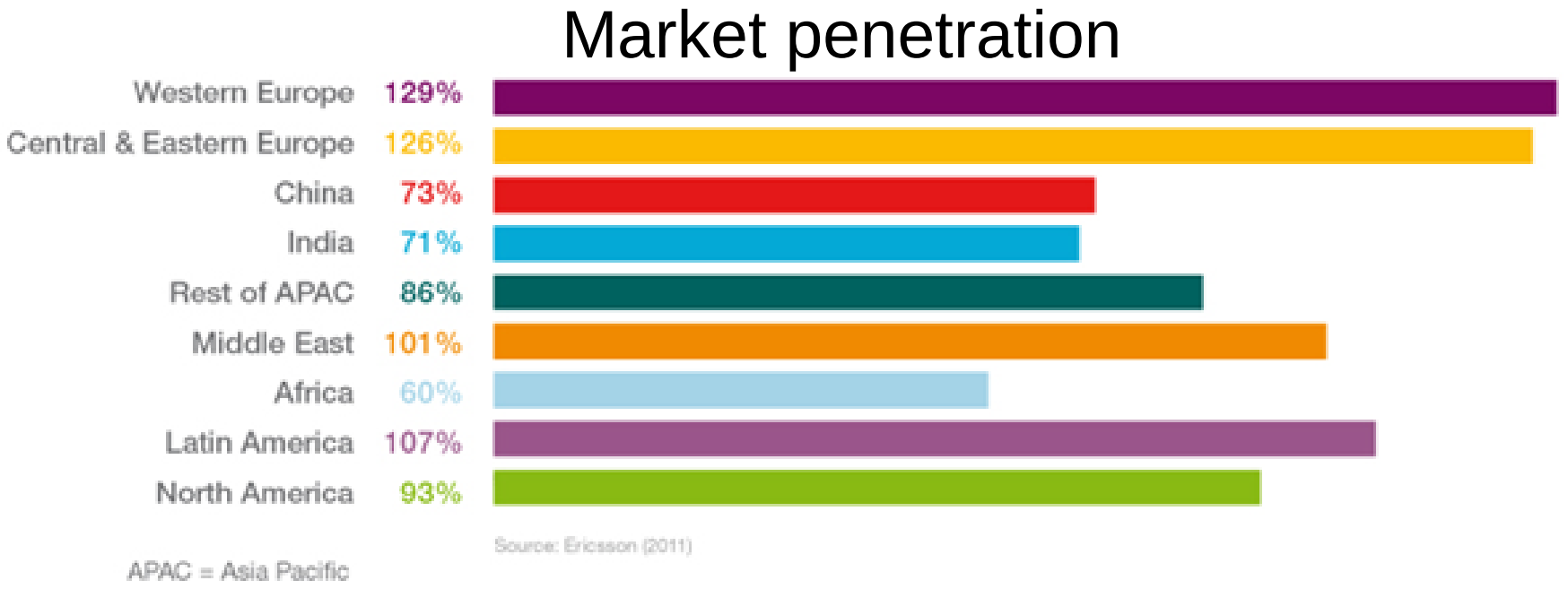
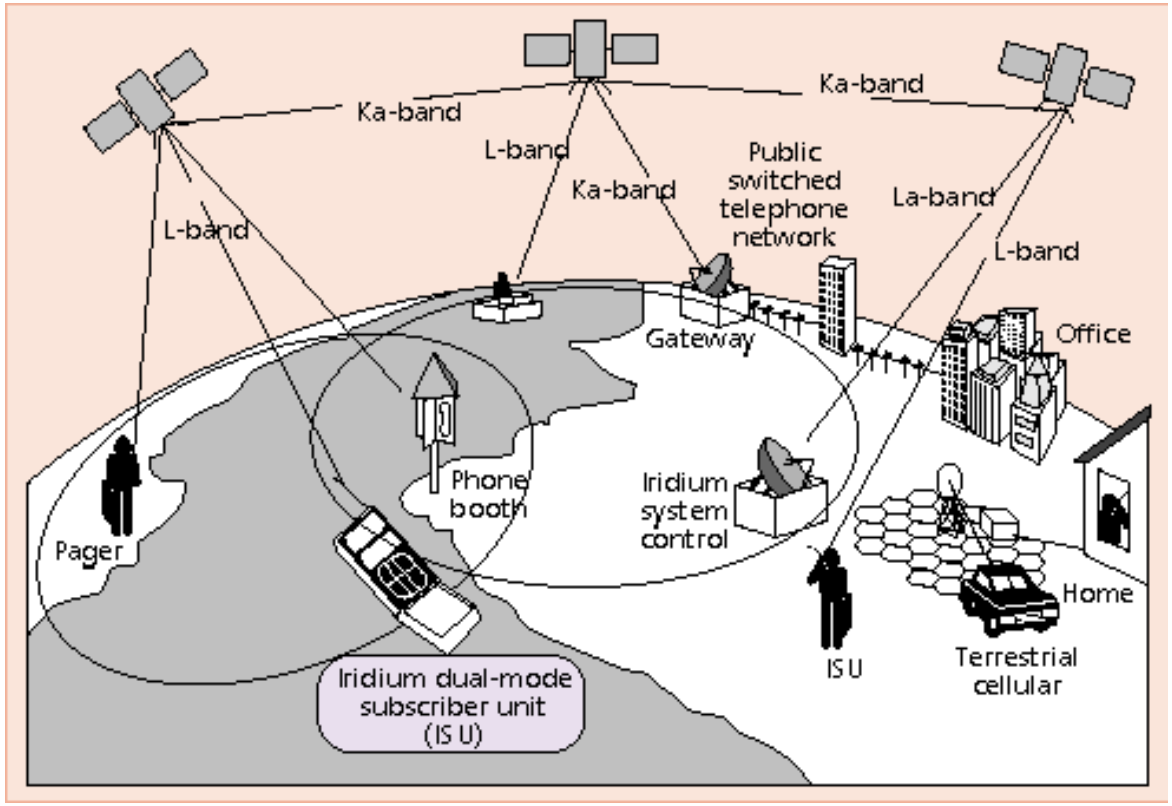


- 70% o world population has at least 1 mobile phone
- 13% of growth every year
- In 2011, 35% of new users where from China or India

Also Some Spectacular Failures

- **Iridium**
  - 77 LEO Satellites (2000 Km altitude)
  - Works everywhere (even middle of desert/ocean)
  - Tsunami Warning System

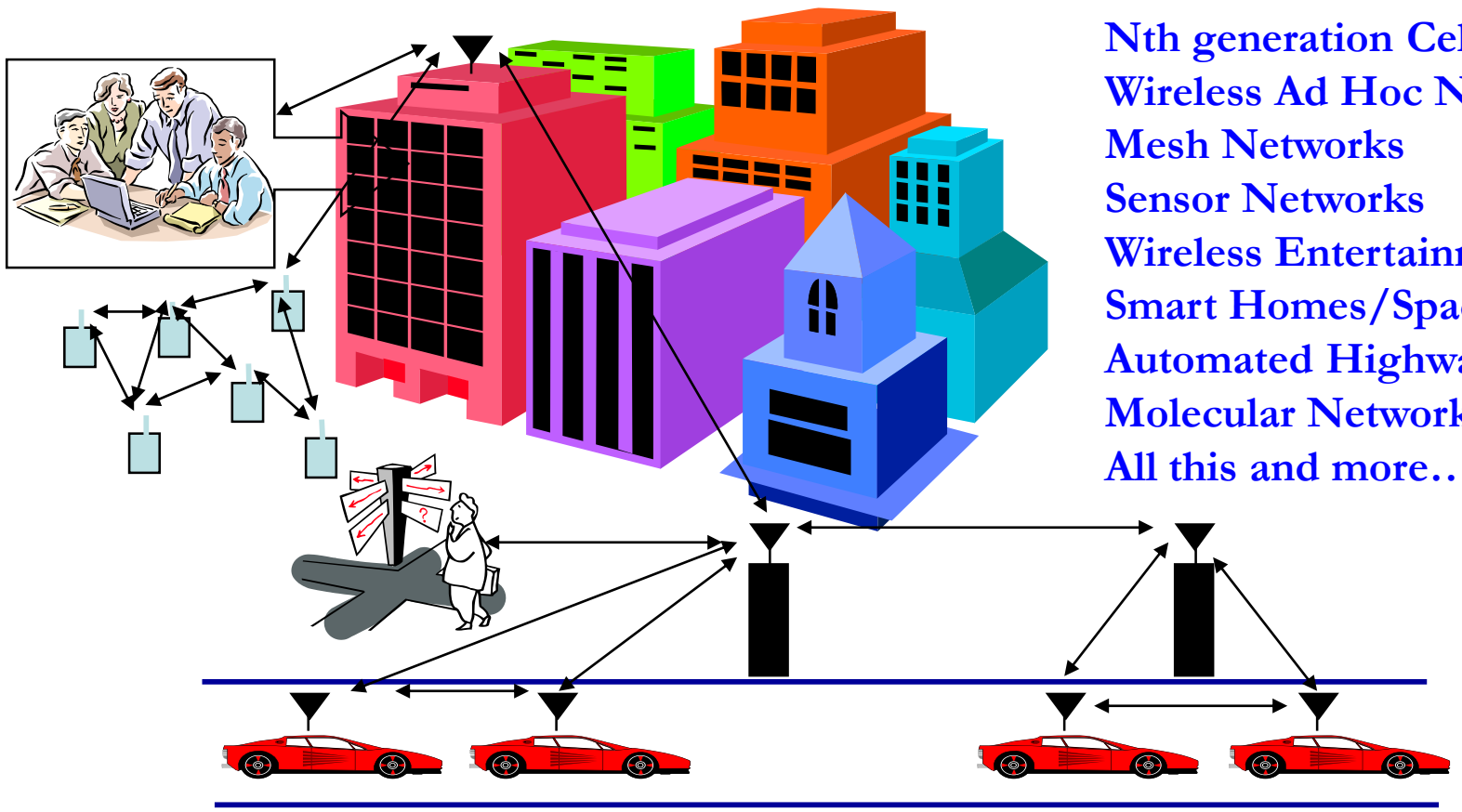


Current Wireless Development

- Internet and laptop use exploding
- Wi-Fi, 3G, LTE… are growing
- Both low and high rate data demand
- Military and security needs require wireless
- Emerging interdisciplinary applications
- Smartphones open new wireless scenarios
- Web Squared

Future(?) Wireless Networks

Ubiquitous Communication Among People and Devices



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

- **Constraints: Bandwidth, Delay, Energy, Connectivity**

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

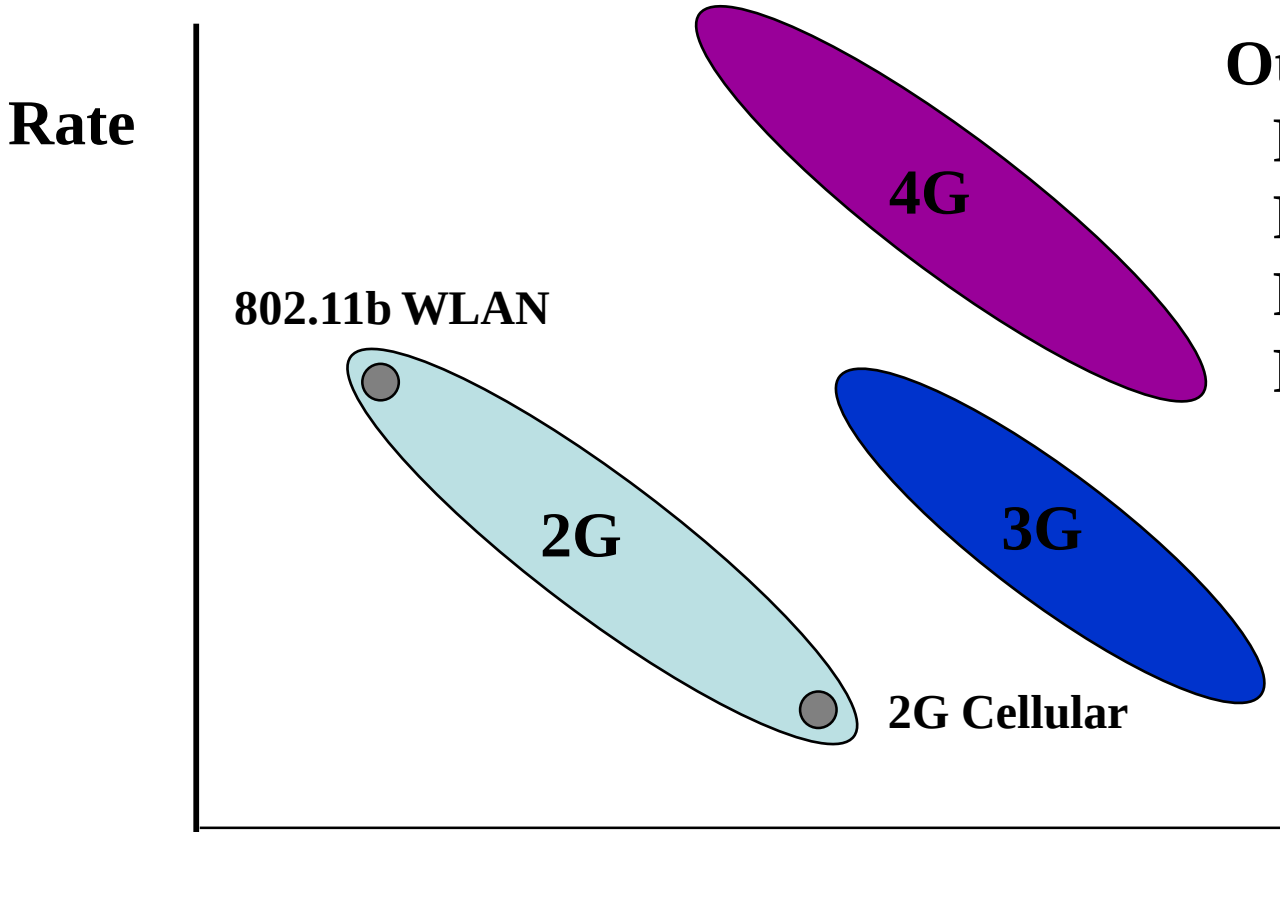
Multimedia Requirements

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

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

Wired networks use this approach, with poor results

Future Generations

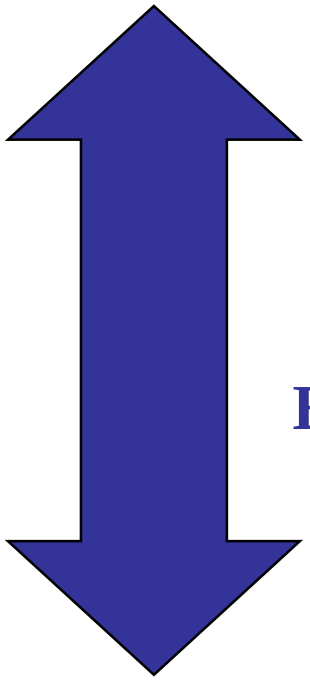


Other Tradeoffs:

- **Rate vs. Coverage**
- **Rate vs. Delay**
- **Rate vs. Cost**
- **Rate vs. Energy**

Crosslayer Design

- Hardware
- Link
- Access
- Network
- Application



Delay Constraints
Rate Constraints
Energy Constraints

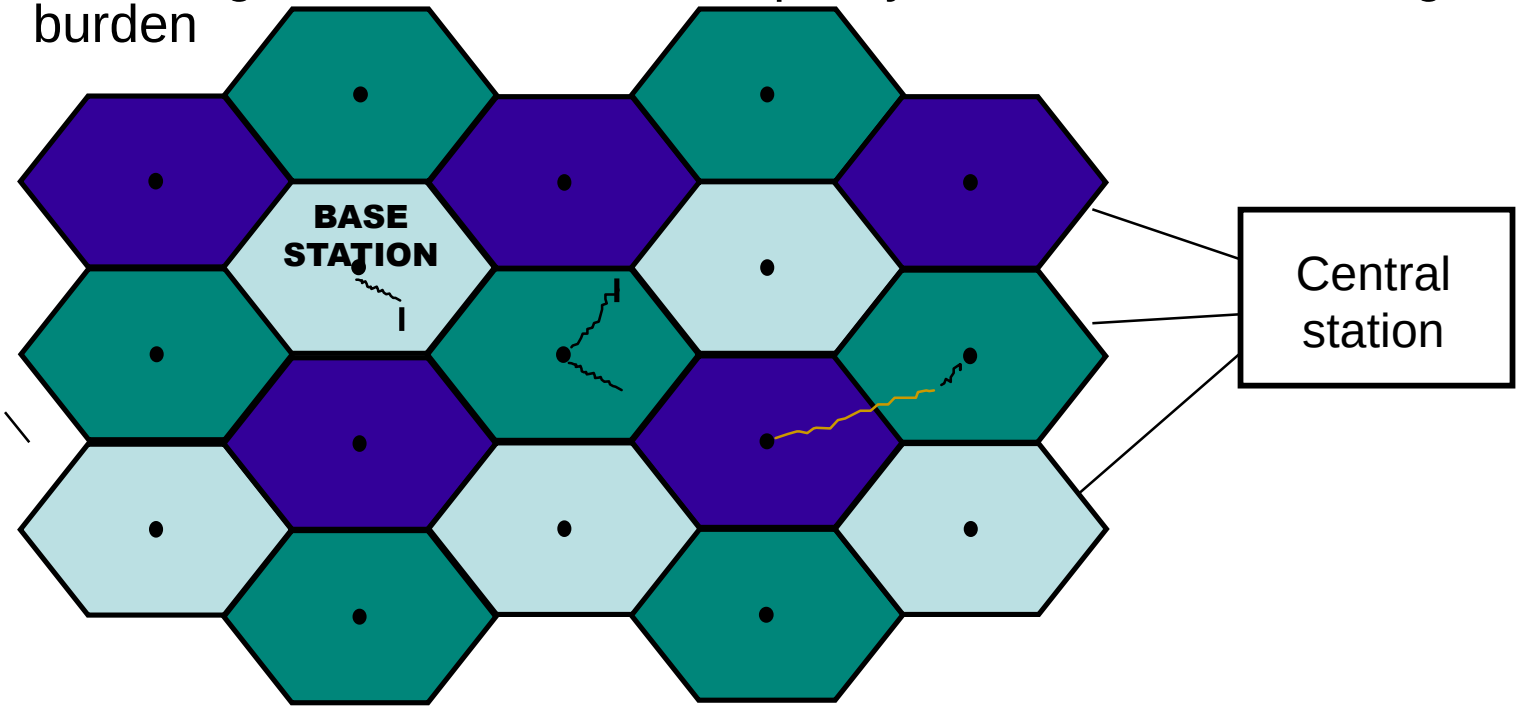
Adapt across design layers
Reduce uncertainty through scheduling
Provide robustness via diversity

Current Wireless Systems

- Cellular Systems
- Wireless LANs
- Wireless Mesh Network
- Satellite Systems
- Bluetooth
- RFID
- WiFi Direct
- …

Cellular Systems: Reuse channels to maximize capacity

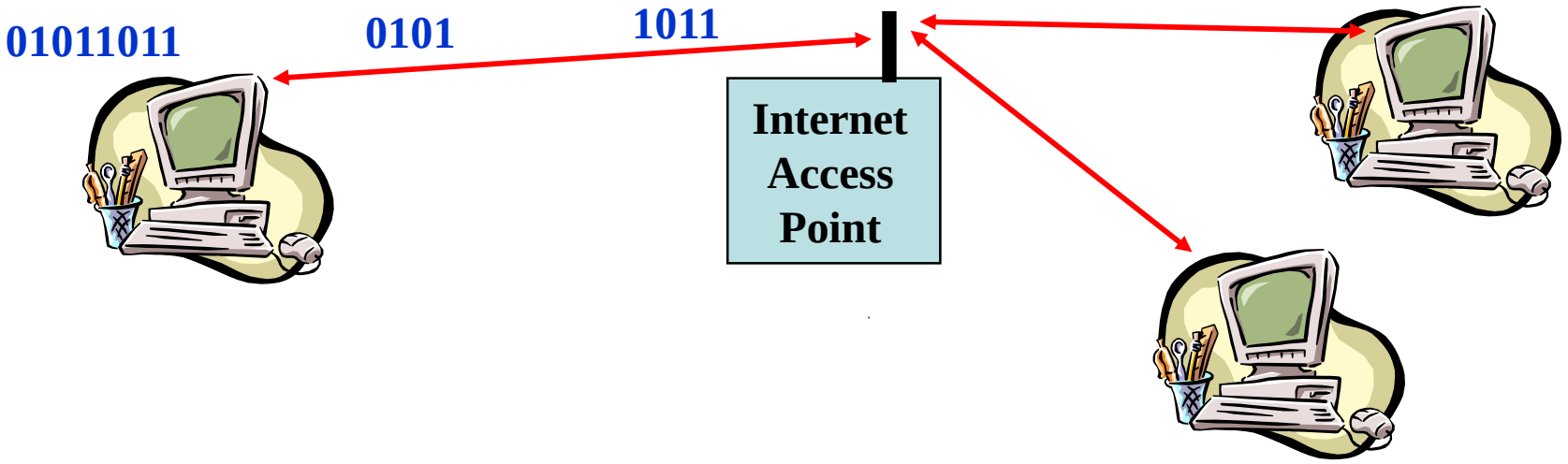
- Geographic region divided into cells
- Frequencies/timeslots/codes reused at spatially-separated locations.
- Co-channel interference between same color cells.
- Base stations coordinate handoff and control functions
- Shrinking cell size increases capacity, as well as networking burden



3G Cellular Design:
Voice and Data

- Data is bursty, whereas voice is continuous
  - Typically require different access and routing strategies
- 3G “widens the data pipe”:
  - 384 Kbps (now even 1.6 Mbps – 3.2 Mbps – 7.2 Mbps)
  - Packet-based switching for both voice and data
- 4G… 5G…

Wireless Local Area Networks (WLANs)



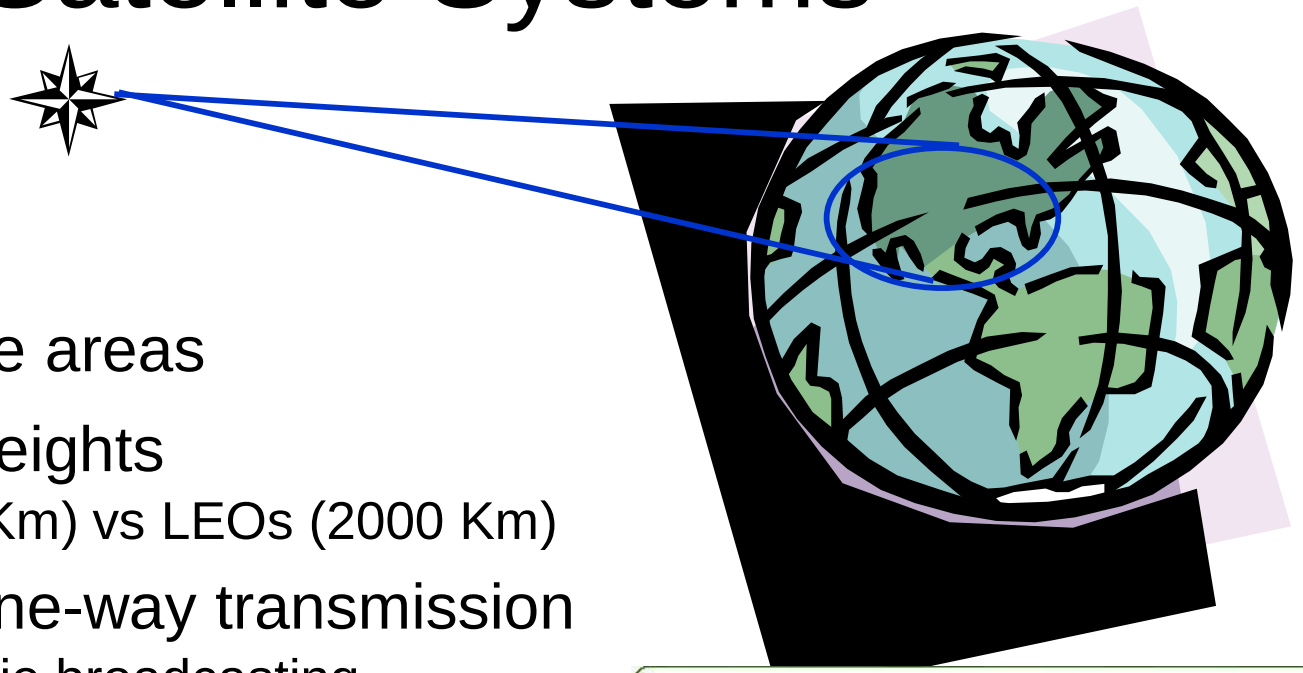
- WLANs connect "local" computers (100m range)
- Breaks data into packets
- Channel access is shared (random access)
- Backbone Internet provides best-effort service
  - Poor performance in some apps (e.g. video)

Wireless LAN Standards

- 802.11b (Old Generation)
  - Standard for 2.4GHz ISM band (80 MHz)
    - Frequency hopped spread spectrum
  - 1 - 11 Mbps, 100m range (nominal)
- 802.11g (Legacy Standard)
  - Standard in 2.4 GHz and 5 GHz bands
    - OFDM (***Orthogonal Frequency-Division Multiplexing***)
  - Speeds up to 54 Mbps (nominal)
- 802.11n (Current Generation)
  - Standard in 2.4 GHz and 5 GHz bands
    - OFDM with time division
  - With MIMO (**Multiple-Input and Multiple-Output**), multiple channels
  - Up to 300 Mbps (nominal)
- 802.11ac (Emerging Generation)
  - Standard in 2.4 GHz and 5 GHz bands
    - OFDM with time division
  - More MIMO (**Multiple-Input and Multiple-Output**), multiple channels
  - Up to 500 Mbps (nominal) for single connection
- 802.11s, 802.11p,…

Next years? all WLAN cards will have all standards

Satellite Systems



- Cover very large areas
- Different orbit heights
  - GEOs (39000 Km) vs LEOs (2000 Km)
- Optimized for one-way transmission
  - Radio and movie broadcasting
- Most two-way systems (Iridium) struggling or bankrupt
  - Expensive alternative to terrestrial system
  - A few ambitious systems on the horizon

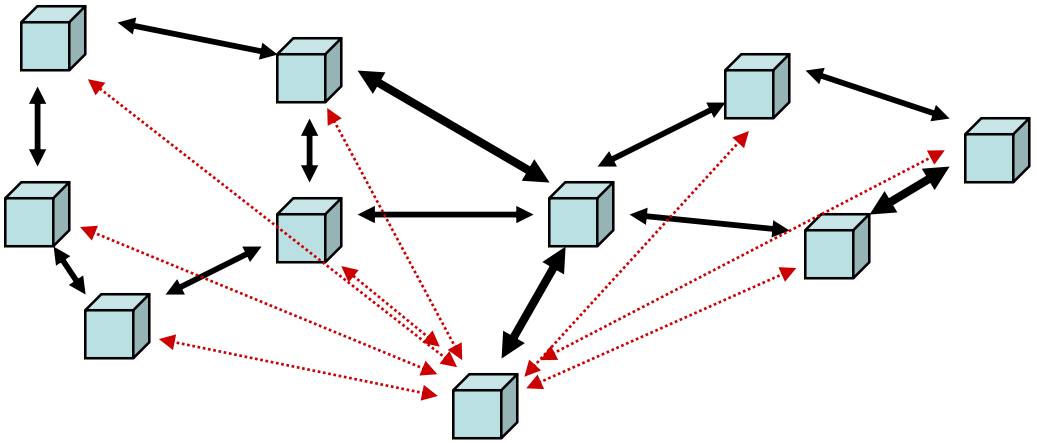
Bluetooth

- Cable replacement RF technology (low cost)
- Short range (10m, extendable to 100m through multihop)
- 2.4 GHz band (crowded)
- 1 Data (700 Kbps) and 3 voice channels
- Widely supported by telecommunications, PC, and consumer electronics companies
- Few applications beyond cable replacement

Emerging Systems

- Ad hoc wireless networks
- Mesh networks
- Sensor networks
- Distributed control networks
- MANET/VANET/DANET
- Underwater networks
- Molecular networks
- …

Ad-Hoc Networks

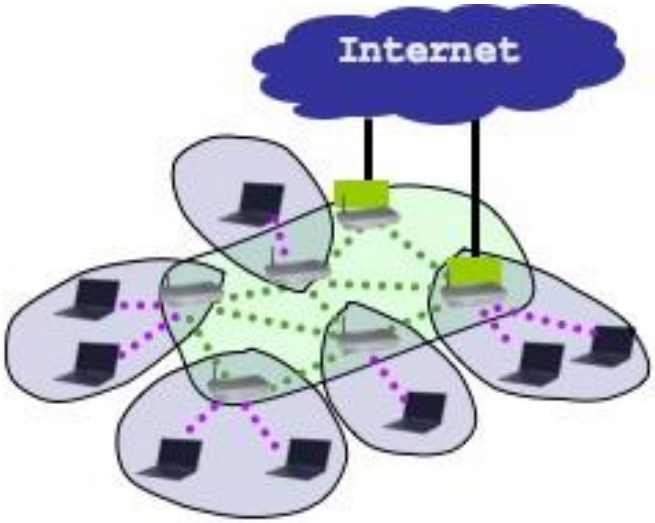


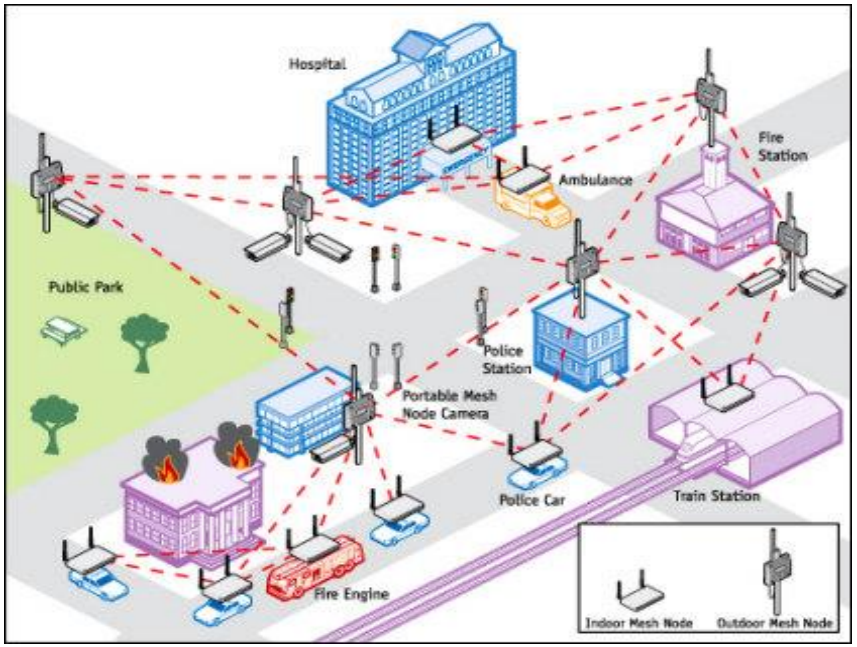
- Peer-to-peer communications
- No backbone infrastructure
- Routing can be multihop
  - to extend area of coverage or to reduce interferences (through short range communication)
- Topology is dynamic
- Fully connected with different links

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
- Crosslayer design critical and very challenging
- Energy constraints impose interesting design tradeoffs for communication and networking

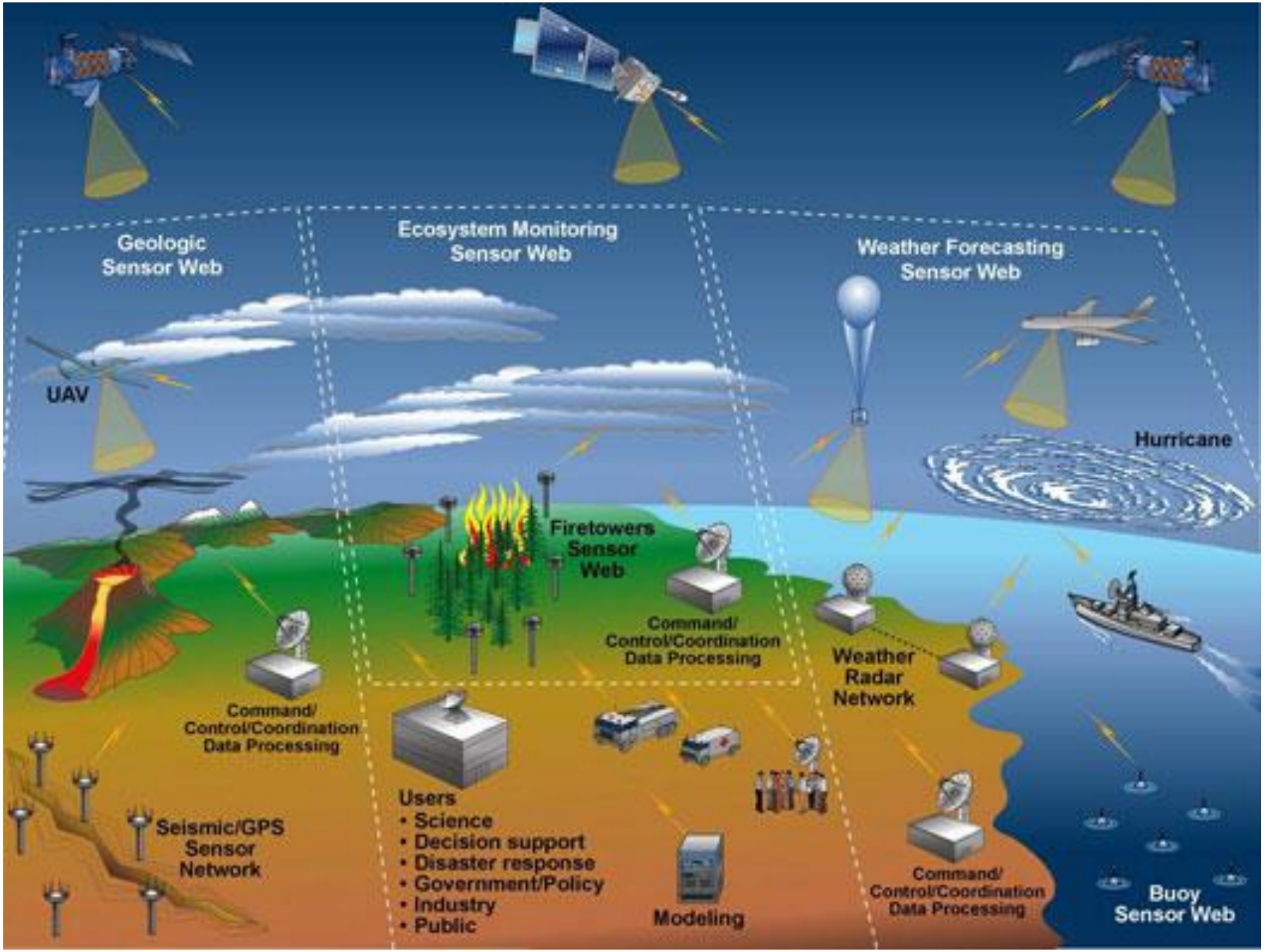
Mesh Networks





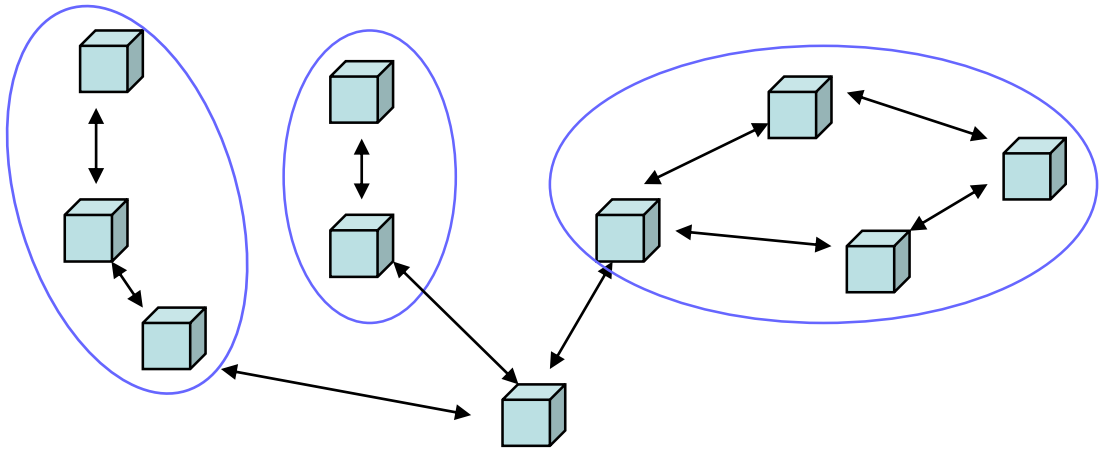
- Ad hoc opportunistic extension of a fixed urban infrastructure
- Purposes: to create a low-cost, easily deployable, high performance wireless coverage
- Challenges:
  - optimum routing protocols to achieve fairness and load balancing
  - quality-of-service (QoS)
  - MAC/network protocols for multimedia applications
  - efficient autonomous operation when the infrastructure fails.

Sensor Networks



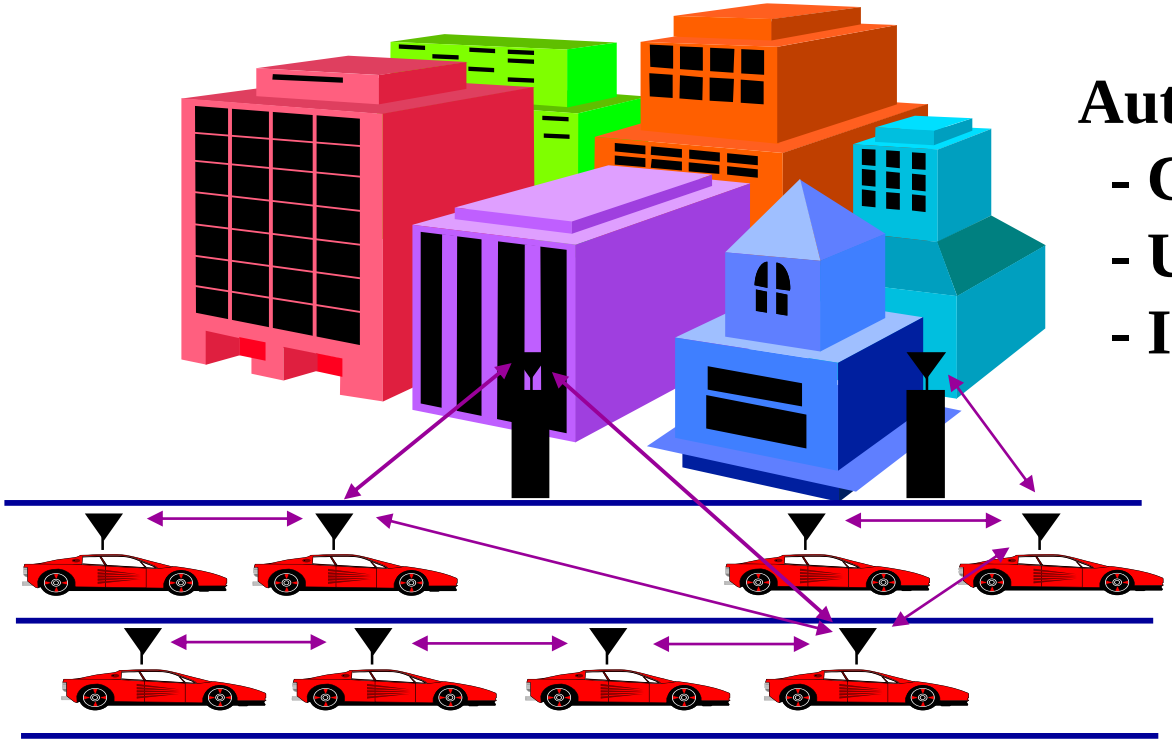
Sensor Networks

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

Distributed Control over Wireless Links

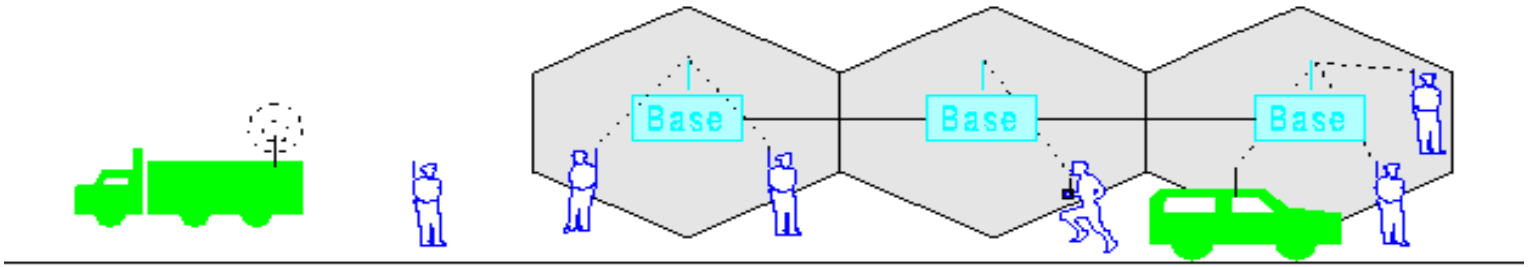


Automated Vehicles
- **Cars**
- **UAVs**
- **Insect flyers**

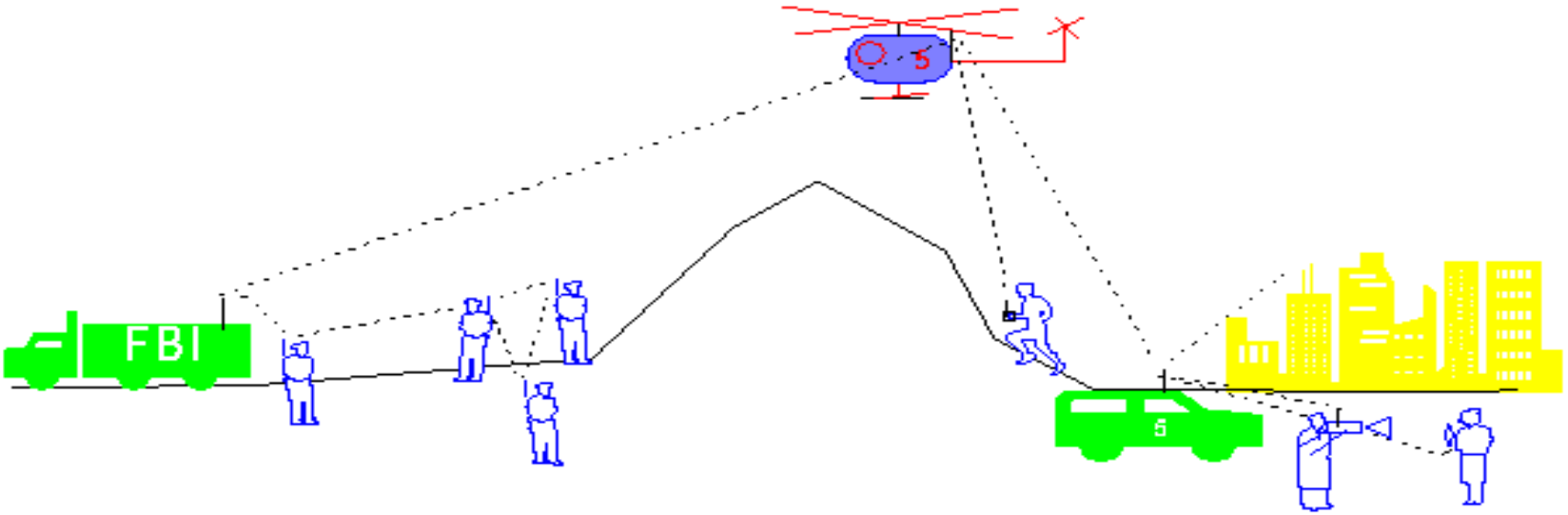
- Packet loss and/or delays impacts controller performance.
- Controller design should be robust to network faults.
- Joint application and communication network design.

Mobile Ad-Hoc Network (MANET)

Infrastructure Network (WiFi or 3G/4G)



Ad Hoc, Multihop wireless Network



Ad Hoc Network Characteristics (Again…)

- Instantly deployable, re-configurable (no fixed infrastructure)
- Created to satisfy a “temporary” need
- Portable (e.g., sensors), mobile (e.g., cars)

Traditional Ad Hoc Network Applications

Military

- Automated battlefield

Civilian

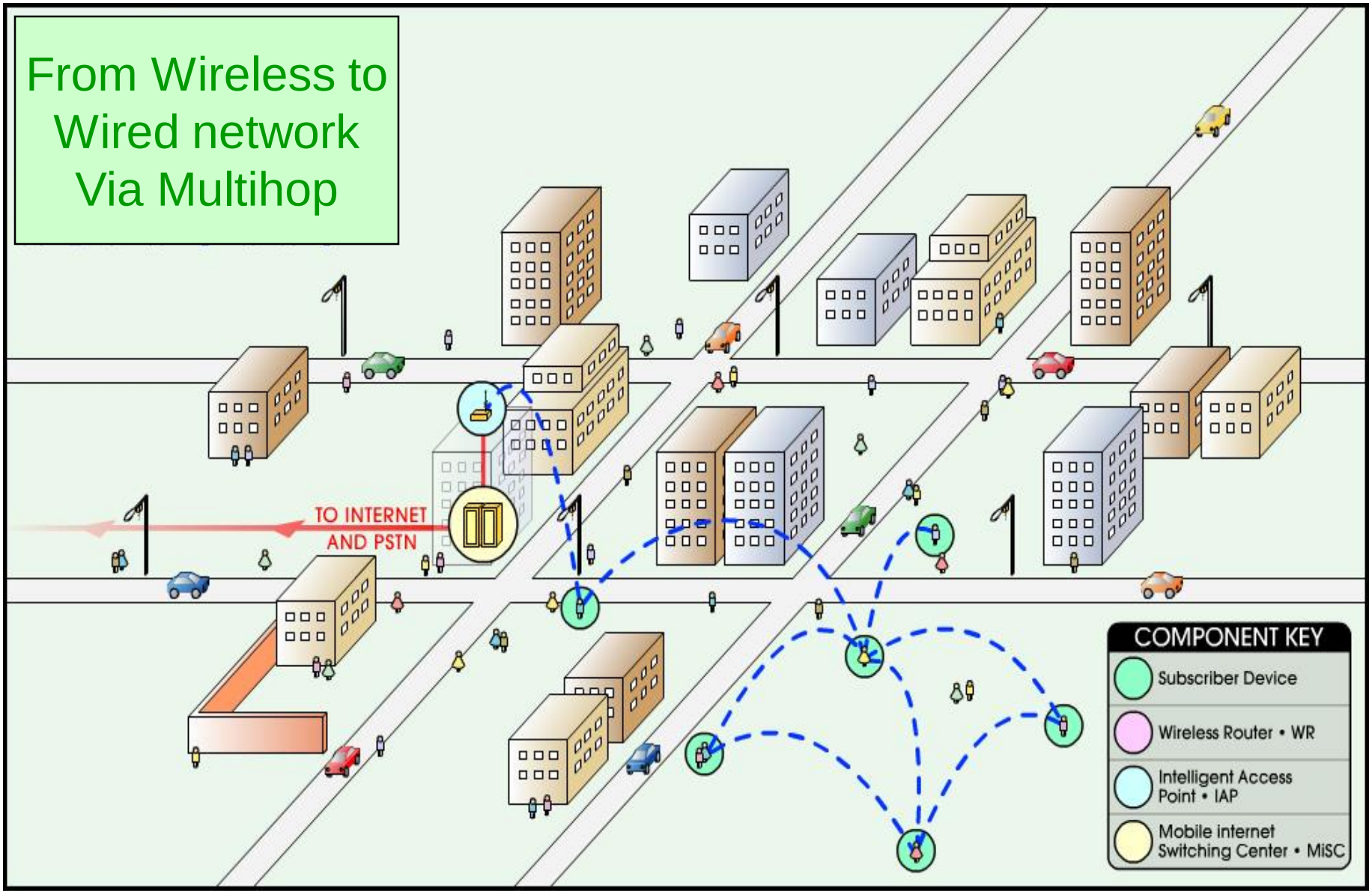
- Disaster Recovery (flood, fire, earthquakes etc)
- Law enforcement (crowd control)
- Homeland defense
- Search and rescue in remote areas
- Environment monitoring (sensors)
- Space/planet exploration

Opportunistic Ad Hoc Nets

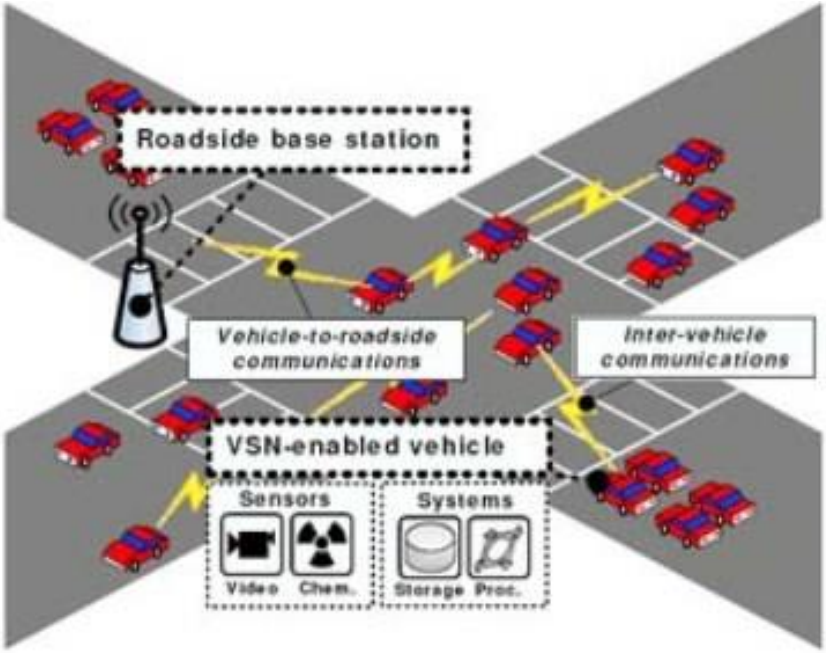
- Driven by “commercial” application needs
  - Indoor W-LAN extended coverage
  - Group of friends sharing 3G via Bluetooth
  - Peer-2-Peer networking in the vehicle grid

- Access to Internet:
  - available, but; it can be “opportunistically” replaced by the “ad hoc” network (if too costly or inadequate)

Urban “Opportunistic” Ad Hoc Nets



Vehicular Ad-Hoc Network (VANET)



DSRC CHARACTERISTICS

Parameter	Value
Range	1000m
Frequency Band	5.9Ghz
Speed	$\leq$ 85mph
Data Rates	6-27Mbps(depending on Range)

Vehicle Communications: Apps

PUBLIC / SAFETY

- APPROACHING EMERGENCY VEHICLE ASSISTANT
- EMERGENCY VEHICLE SIGNAL PREEMPTION
- OPTIMAL SPEED ADVISORY
- TRANSIT VEHICLE SIGNAL PRIORITY
- EMERGENCY VEHICLE VIDEO RELAY
- STOP LIGHT ASSISTANT – INFRASTRUCTURE
- INTERSECTION COLLISION WARNING/AVOIDANCE
- COOPERATIVE COLLISION WARNING [V-V]
- INFRASTRUCTURE BASED TRAFFIC MANAGEMENT – VEHICLES AS PROBES
- WORK ZONE WARNING
- ROAD CONDITION WARNING
- VEHICLE BASED PROBE DATA COLLECTION
- TRAFFIC INFORMATION
- COOPERATIVE VEHICLE SYSTEM – PLATOON
- RAILROAD COLLISION AVOIDANCE
- LOCATION BASED PROBE DATA COLLECTION
- TRANSIT VEHICLE DATA TRANSFER (gate)
- ON-BOARD SAFETY DATA TRANSFER
- VEHICLE SAFETY INSPECTION
- DRIVER'S DAILY LOG

PRIVATE

- DATA TRANSFER / CVO / TRUCK STOP
- DATA TRANSFER / TRANSIT VEHICLE (yard)
- ACCESS CONTROL
- DRIVE-THRU PAYMENT
- PARKING LOT PAYMENT
- DATA_TRANSFER / INFOFUELING
  - ATIS DATA
  - DIAGNOSTIC DATA
  - REPAIR-SERVICE RECORD
  - VEHICLE COMPUTER PROGRAM UPDATES
  - MAP and MUSIC DATA UPDATES
  - VIDEO UPLOADS
- ENHANCED ROUTE PLANNING and GUIDANCE
- RENTAL CAR PROCESSING
- UNIQUE CVO FLEET MANAGEMENT
- TRANSIT VEHICLE REFUELING MANAGEMENT
- LOCOMOTIVE FUEL MONITORING
- DATA TRANSFER / LOCOMOTIVE

Internet Applications!

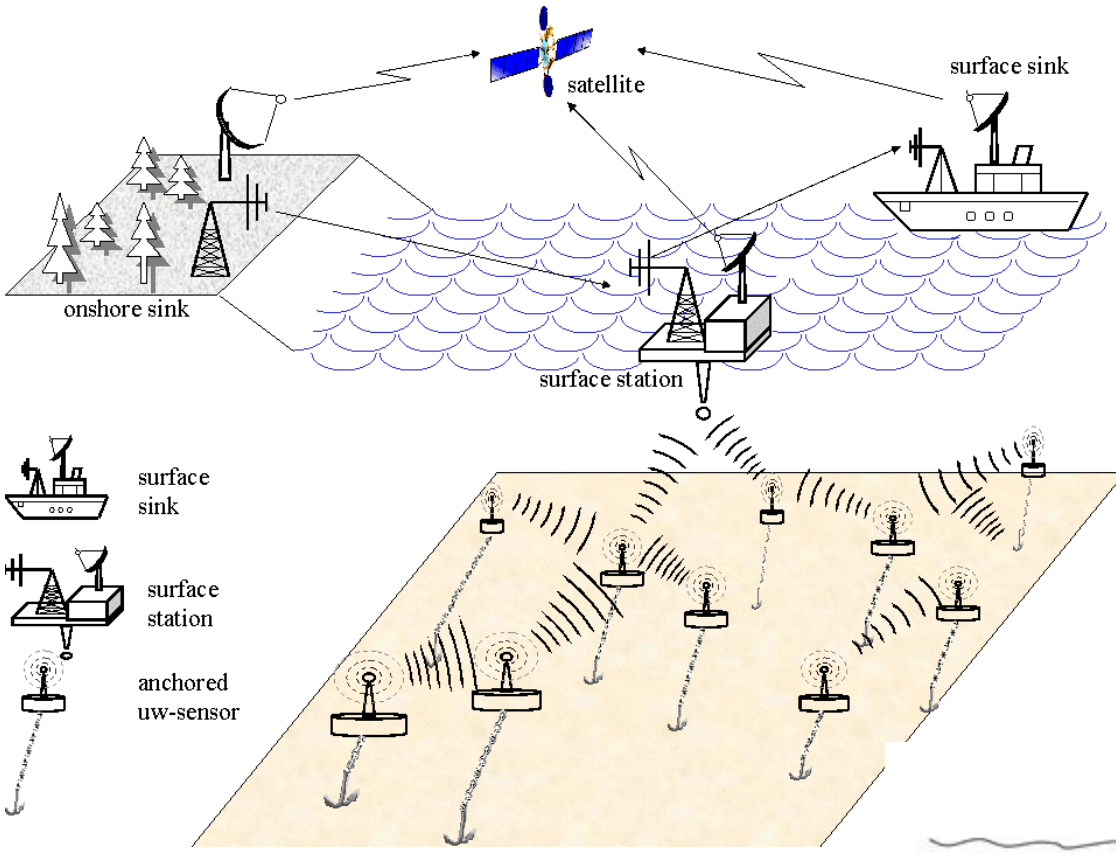
ATIS - Advanced Traveler Information Systems
CVO - Commercial Vehicle Operations

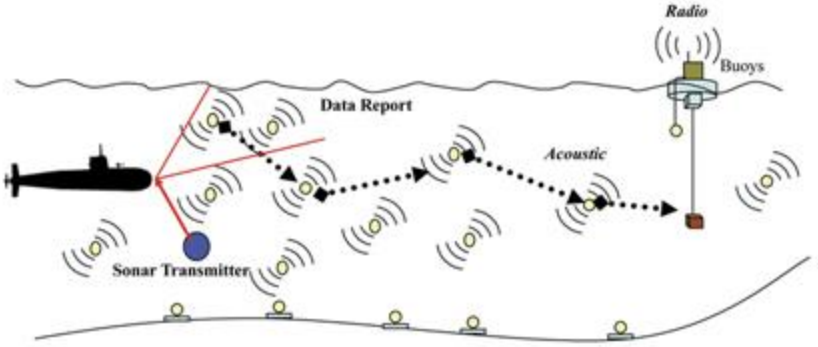
RED – Long Range Applications (up to 1000 meters)
BLUE – Medium/Long Range Applications (90-300 m)
BLACK – Medium Range Application (Up to 90 meters)

Radio Frequency IDentification (RFID)

- Based on magnetic fields
- Tags: active vs passive
- Used in supply chain instead of barcodes
  - No need for direct optical reading
- Standards under development

Underwater Sensor Networks





Nano-Networks

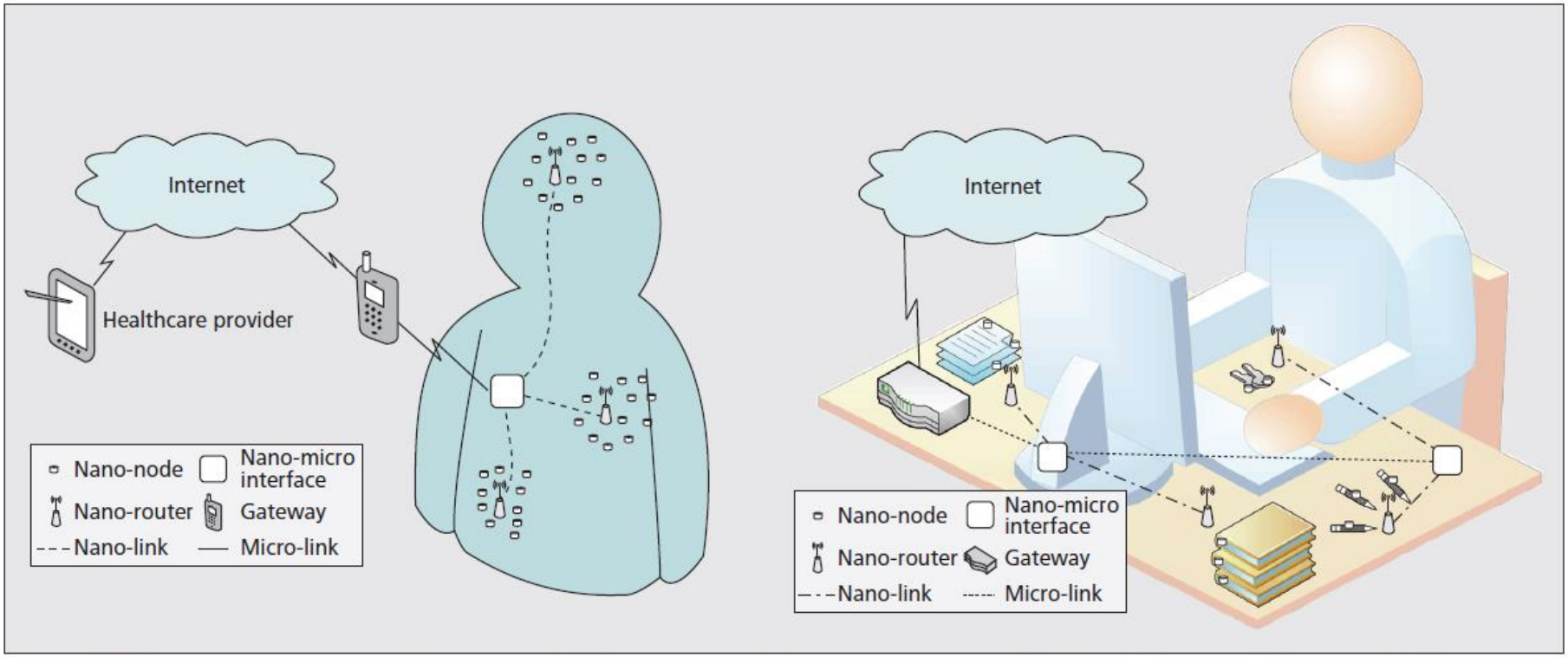
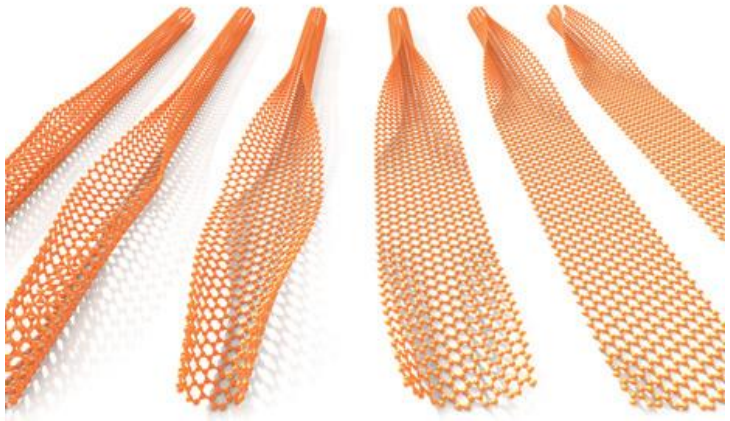


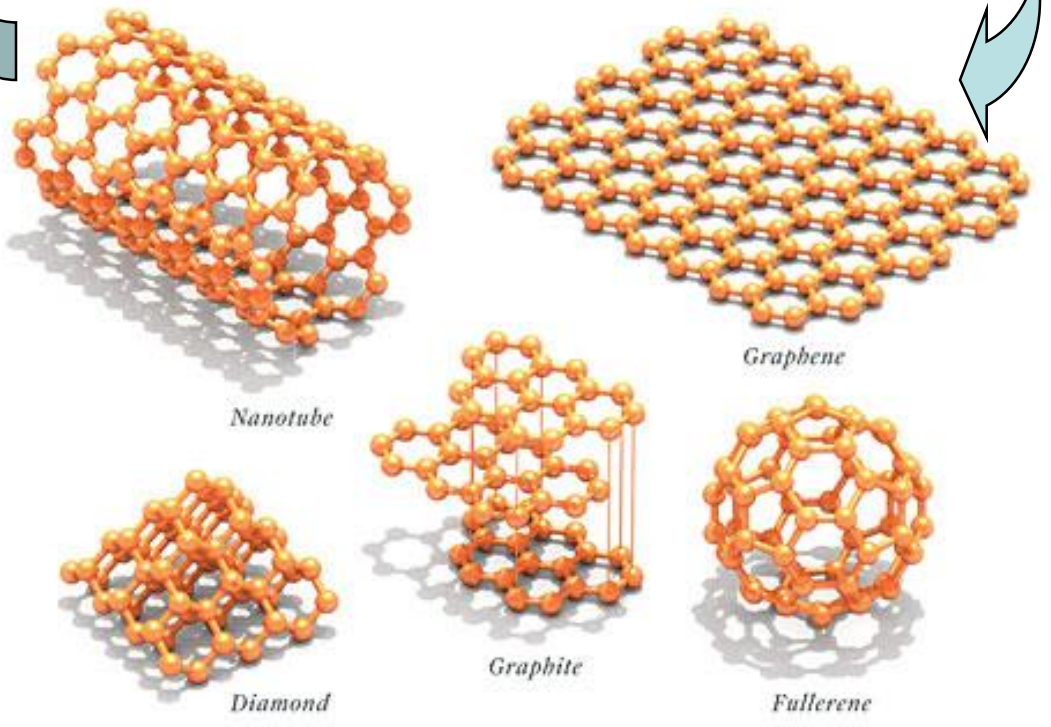
Figure 1. *Network architecture for the Internet of Nano-Things: a) Intrabody nanonetworks for healthcare applications; b) The interconnected office.*

2010 Nobel Prize in Physics

Through a mixture of sulfuric acid and potassium permanganate



Unzip carbon nanotubes



Extraordinary applications

Main Points

- The wireless vision encompasses many exciting systems and applications
- Technical challenges transcend across all layers of the system design
- Wireless systems have limited performance and interoperability
- Standards and spectral allocation heavily impact the evolution of wireless technology
- Huge potential for future applications and systems

Examples of What You'll Learn

- What's the difference between 802.11 b/g/n/p/s/e..?
- Why is the bandwidth really available in wireless networks much smaller (about half) than the nominal one?
- Why do VoIP and Online games scatter when there is someone else in the WLAN browsing the Internet? What solutions have been proposed?
- How do current protocols perform if we use them in a network of drones?
- How can smartphones be used to improve our lives and society?