

Wireless Networks for Mobile Applications

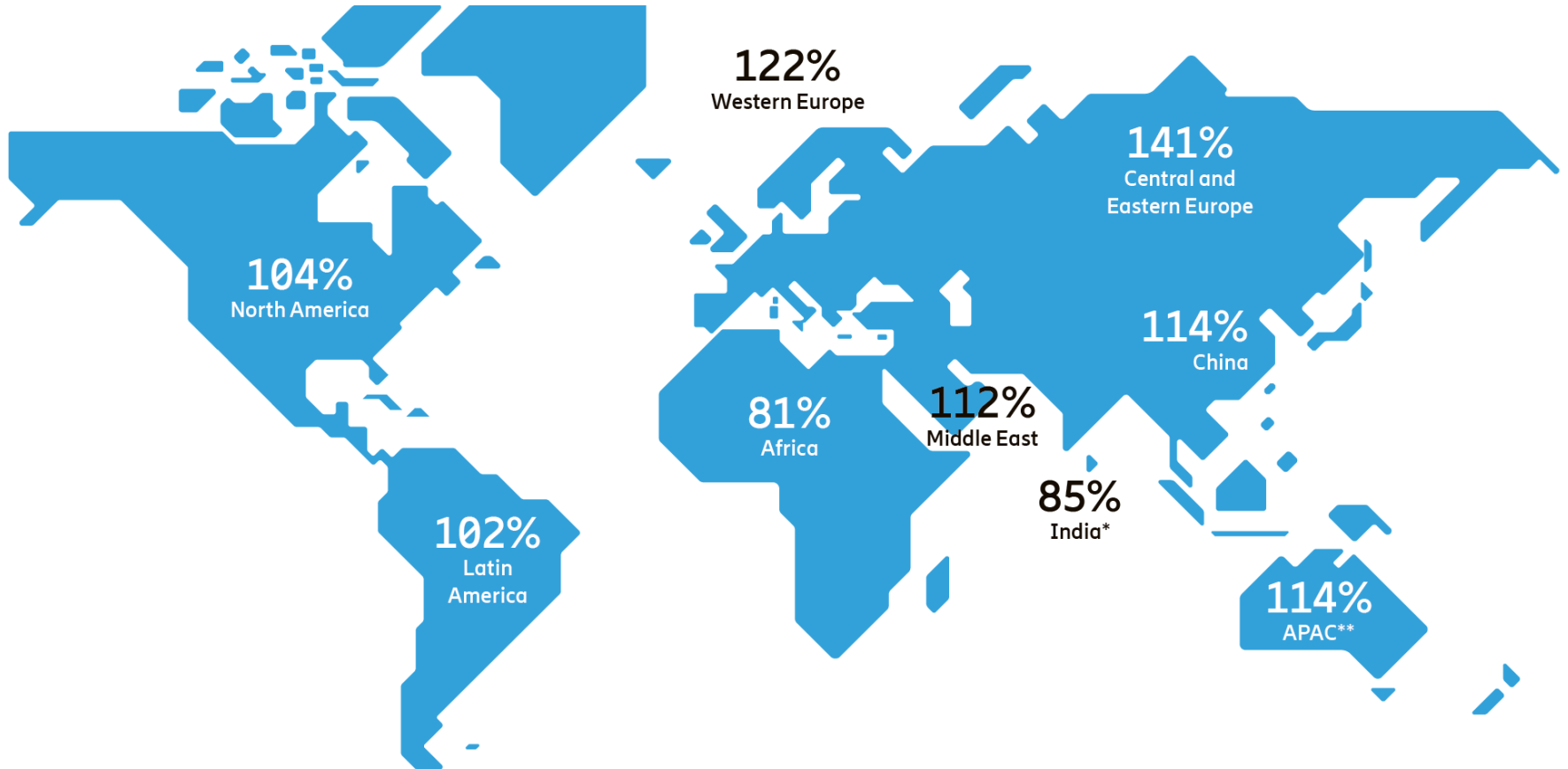
Prof. Claudio Palazzi
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Wireless Communication

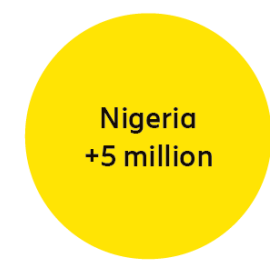
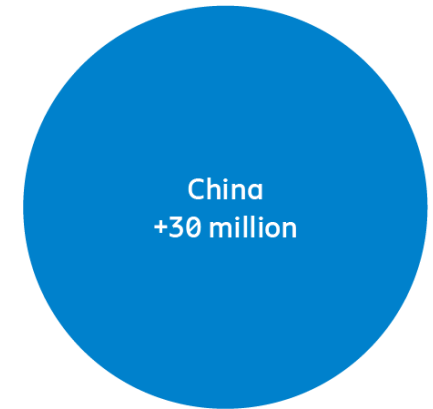
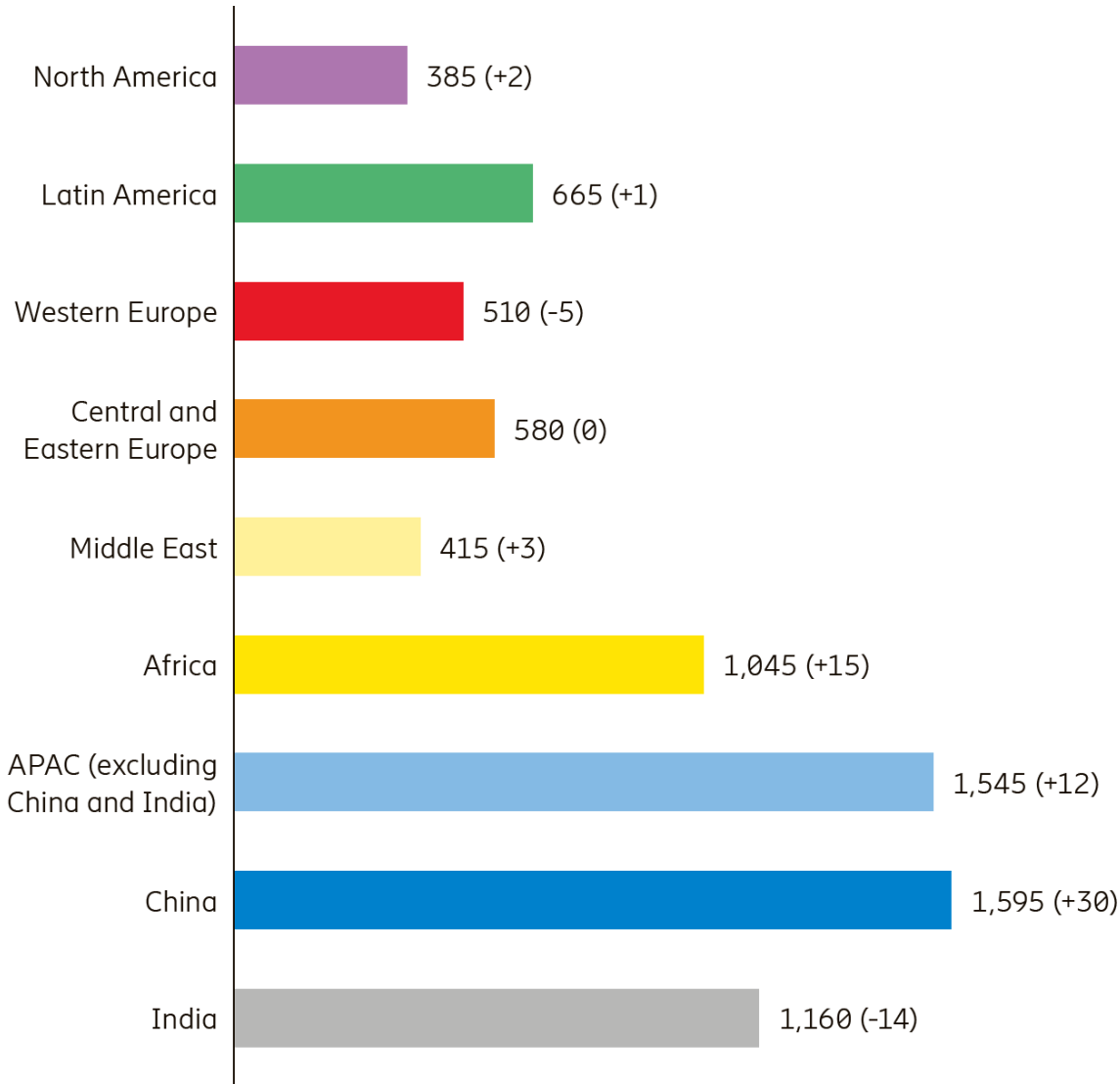
Some history

- **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)
 - 5G
 - 6G ??

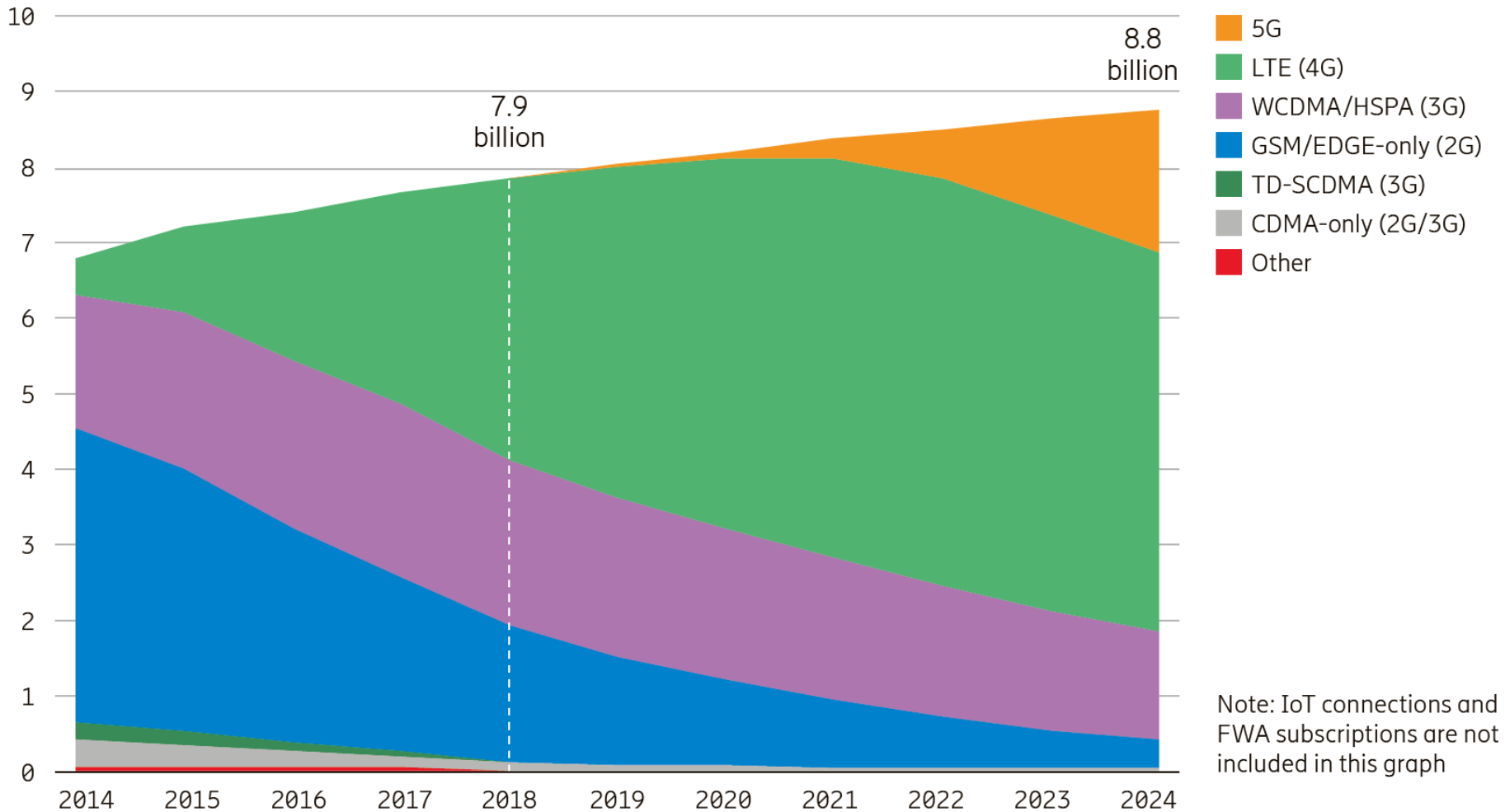
Subscription Penetration



Total and New Mobile Subscription

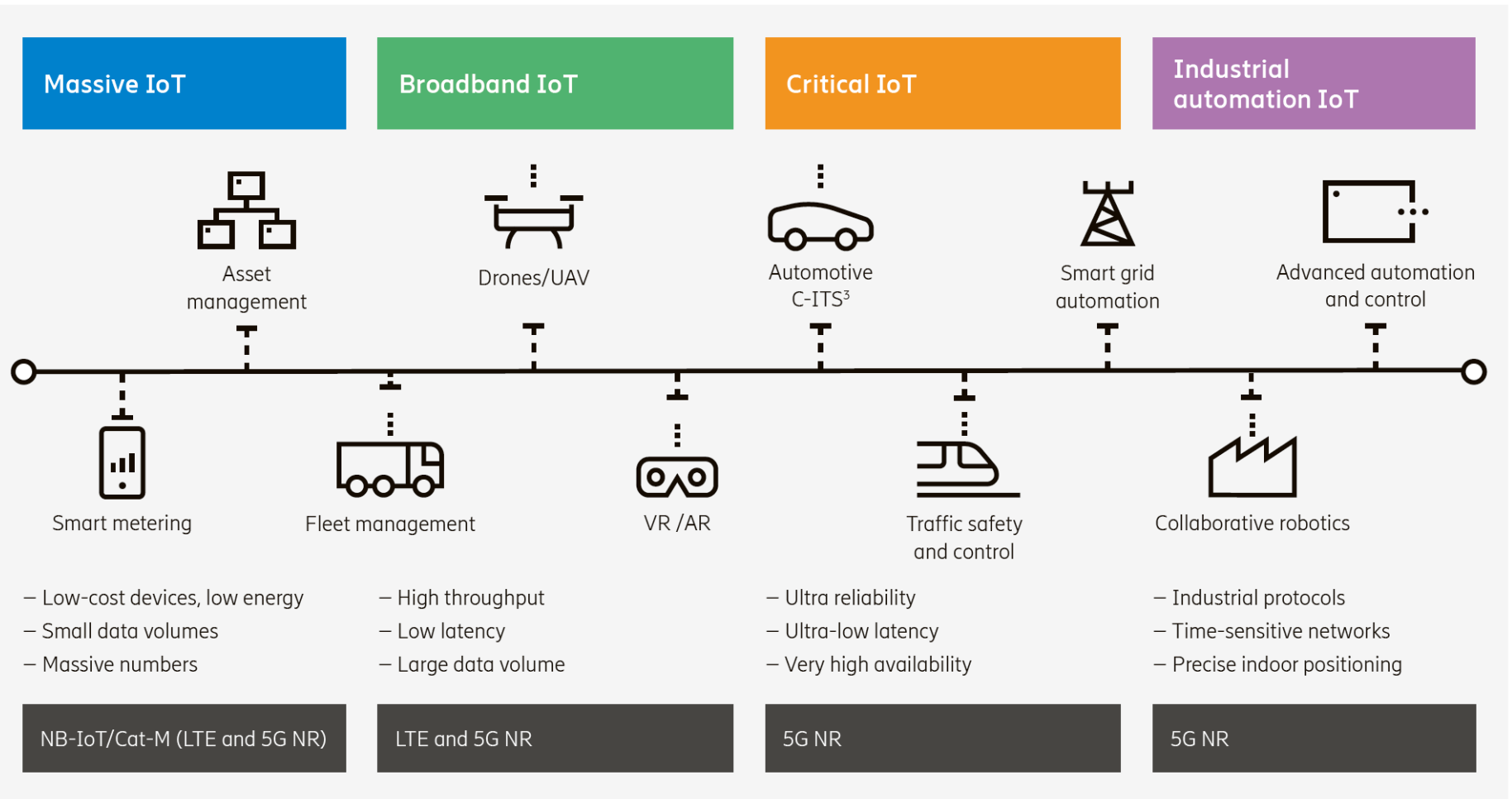


Mobile Subscriptions by Technology (Billion)



Note: IoT connections and FWA subscriptions are not included in this graph

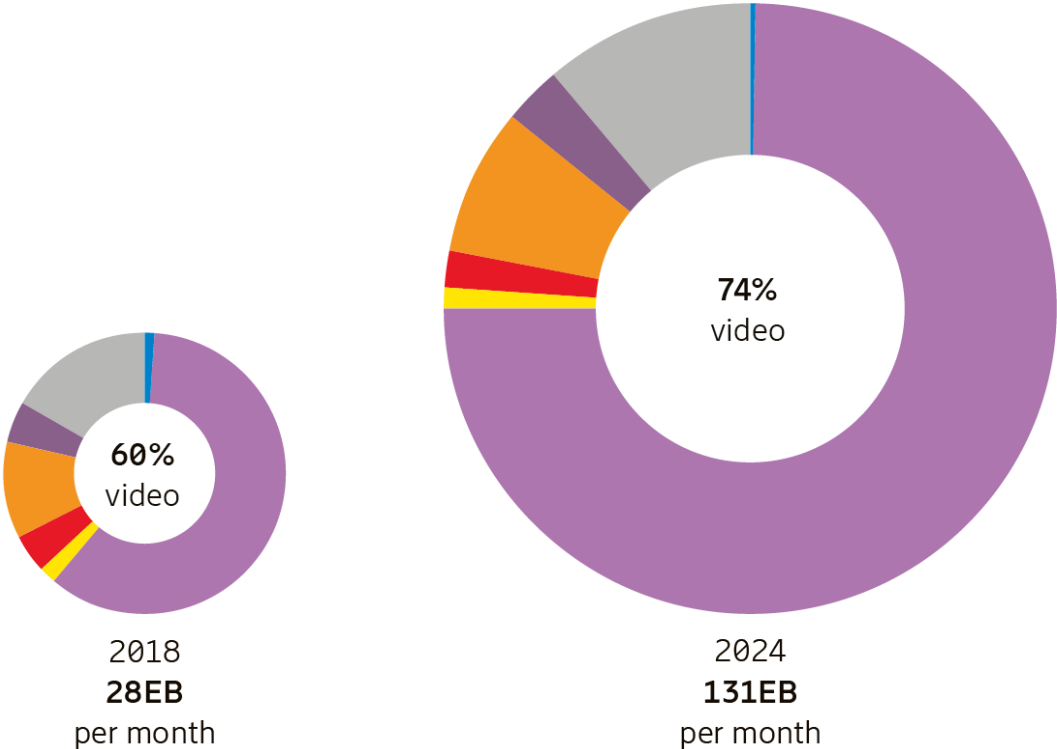
Cellular IoT Use Case Segment



Mobile Data Traffic by Application

Mobile data traffic by application category per month (percent)

■ Video
 ■ Audio
 ■ Web browsing
 ■ Social networking
 ■ Software download and update
 ■ Other segments
 ■ P2P file sharing

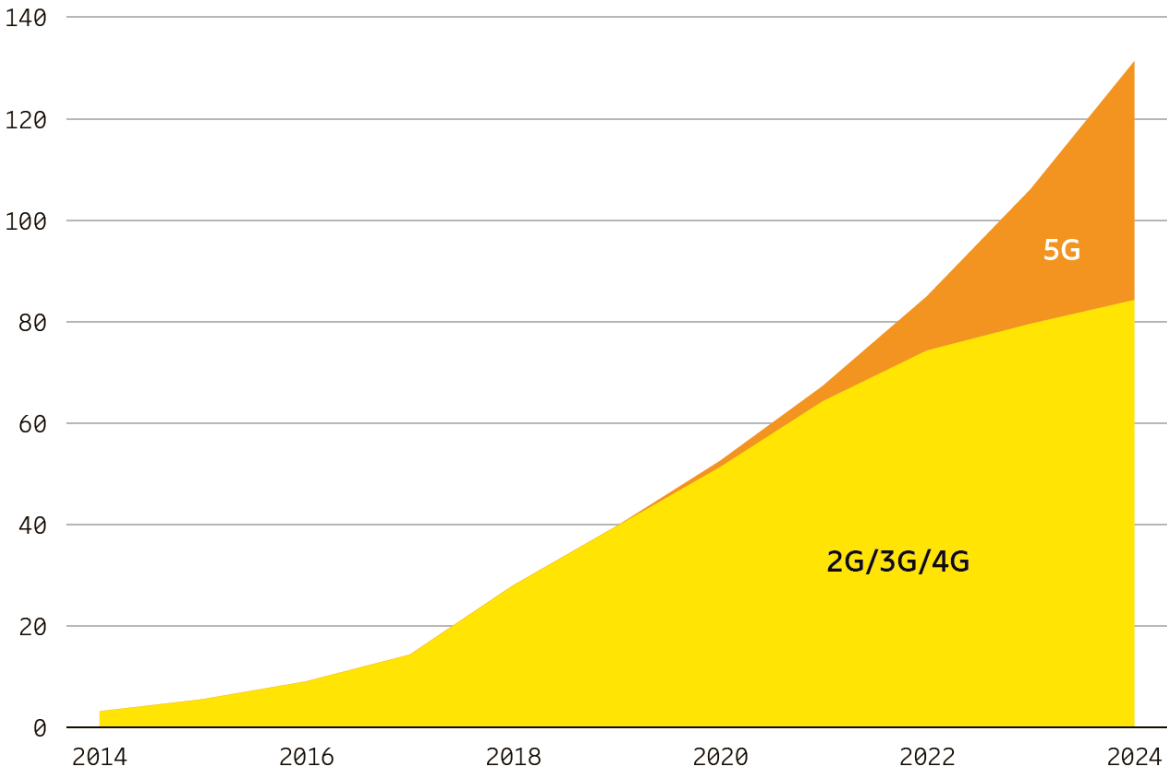


Main drivers for video traffic growth

- Video part of most online content (news, ads, social media, etc.)
- Growth of VoD services
- Video streaming services
- Changing user behavior – video being consumed anywhere, any time
- Increased segment penetration, not just early adopters
- Evolving devices with larger screens and higher resolutions
- Increased network performance through evolved 4G deployments
- Emerging immersive media formats and applications (HD/UHD, 360-degree video, AR, VR)

Global Mobile Data Traffic Trends

Global mobile data traffic (EB per month)



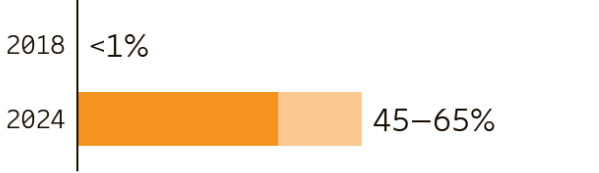
World population coverage by technology



LTE (4G)



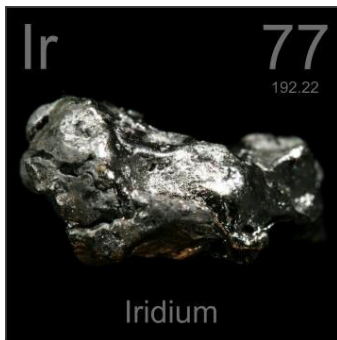
5G



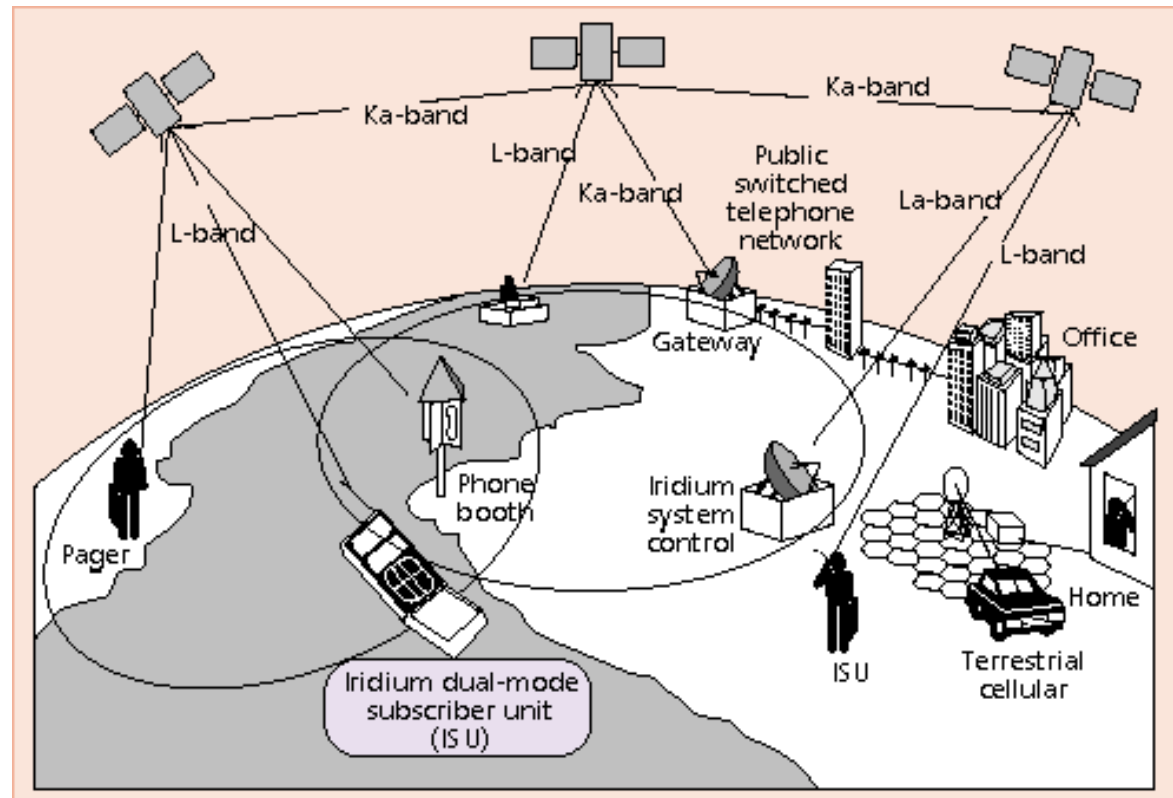
Also Some Spectacular Failures

- Iridium

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



HighSpeedSat

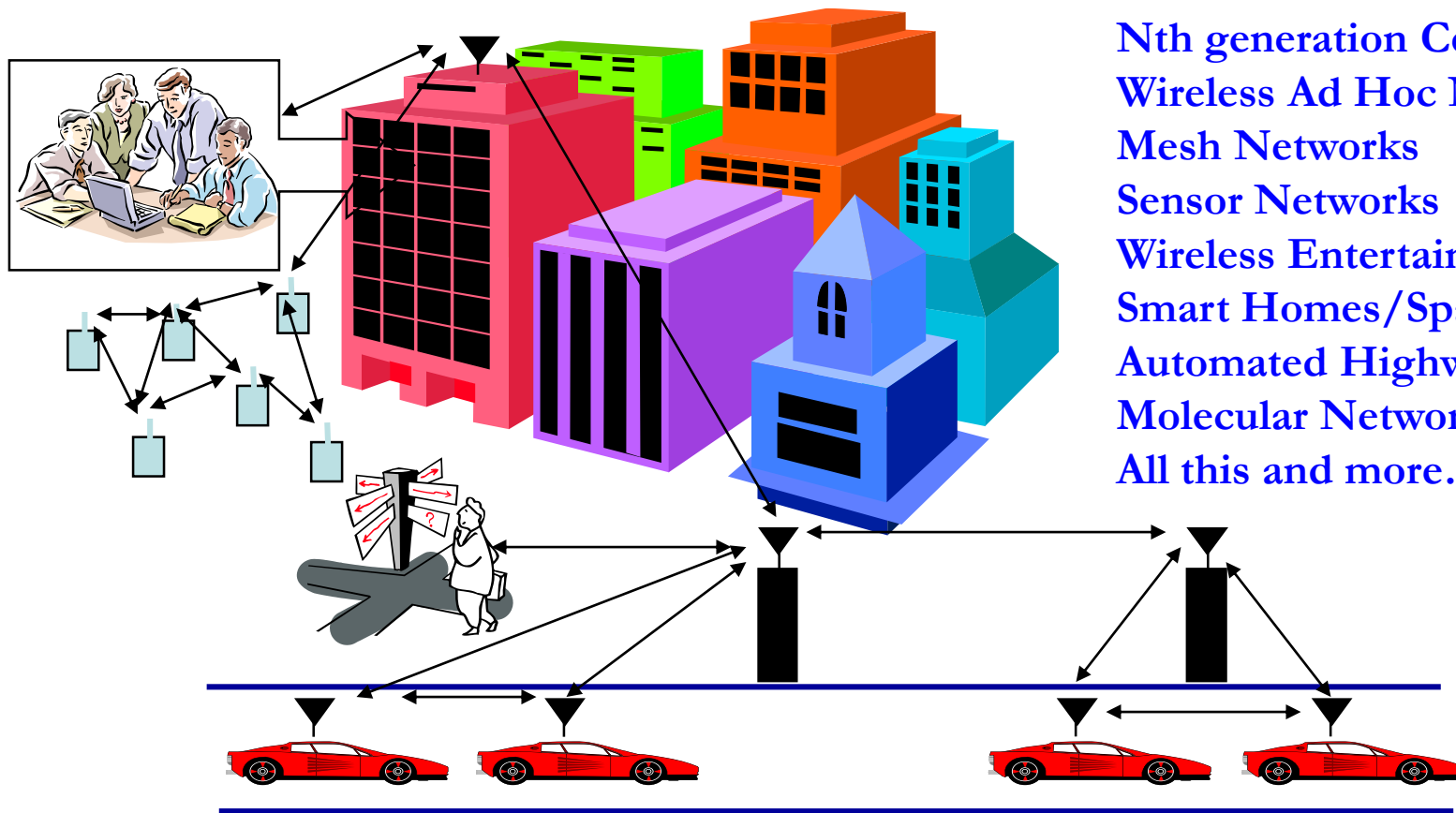


Current Wireless Development

- Internet and laptop use exploding
- Wi-Fi, 3/4/5/6G... are growing
- Both low and high rate data demand
- Emerging interdisciplinary applications
- Smartphones open new wireless scenarios
- AR/VR/MR/tele-presence
- Tactile Internet
- 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 (with respect to the wired counterpart) 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

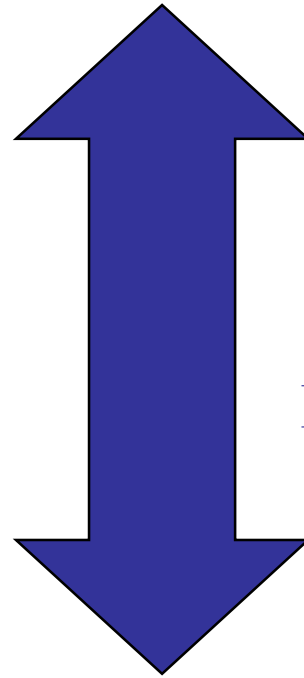
	Voice	Data	Video	Game
Delay	< 100ms	-	< 100ms	< 100ms
Packet Loss	< 1%	0	< 1%	< 1%
BER	10^{-3}	10^{-6}	10^{-6}	10^{-3}
Data Rate	8-32 Kbps	1-100 Mbps	1-20 Mbps	32-100 Kbps
Traffic	Continuous	Bursty	Continuous	Continuous

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

Wired networks use this approach, with poor results¹³

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

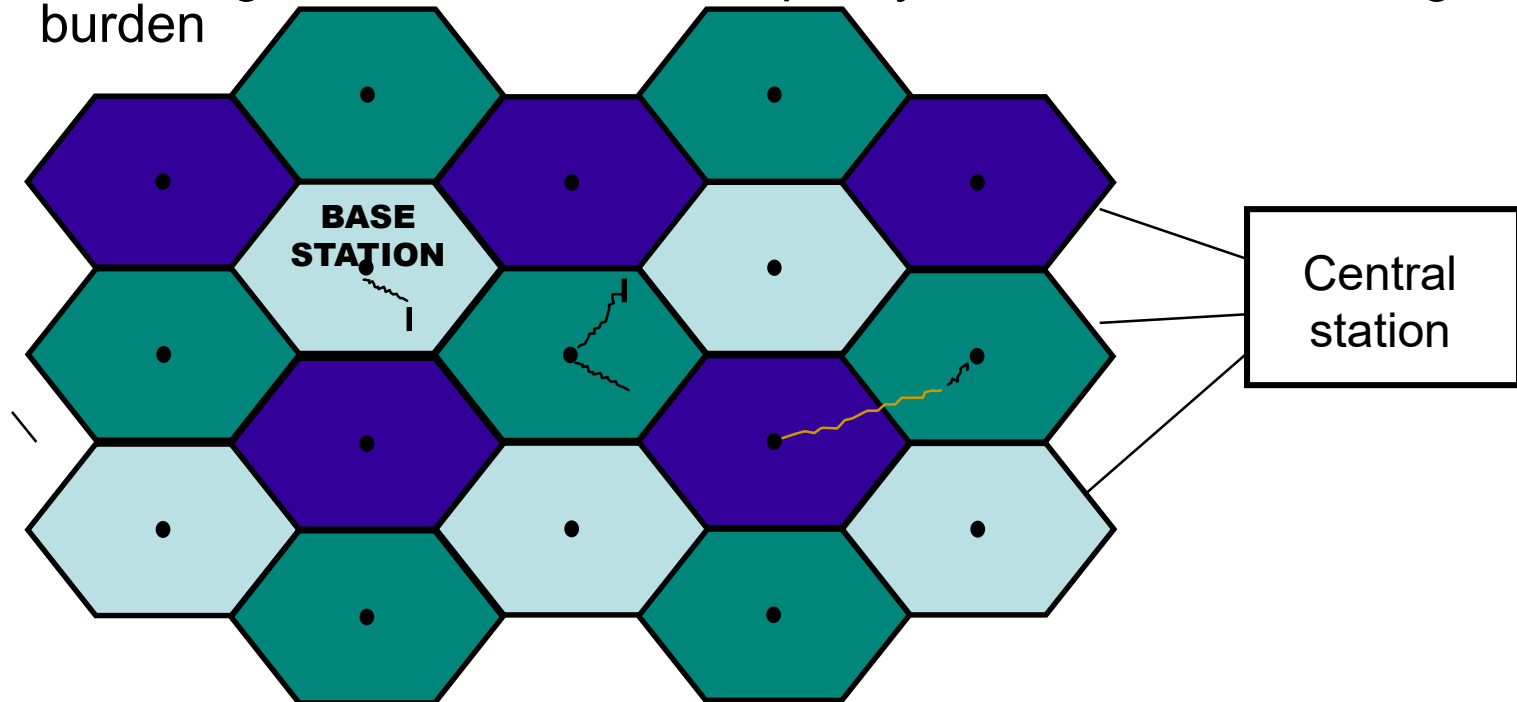
Current Wireless Systems

- Cellular Systems
- Wireless LANs
- Wireless Mesh Network
- Satellite Systems
- Bluetooth
- RFID
- D2D
- ...

Cellular Systems:

Reuse channels to maximize capacity

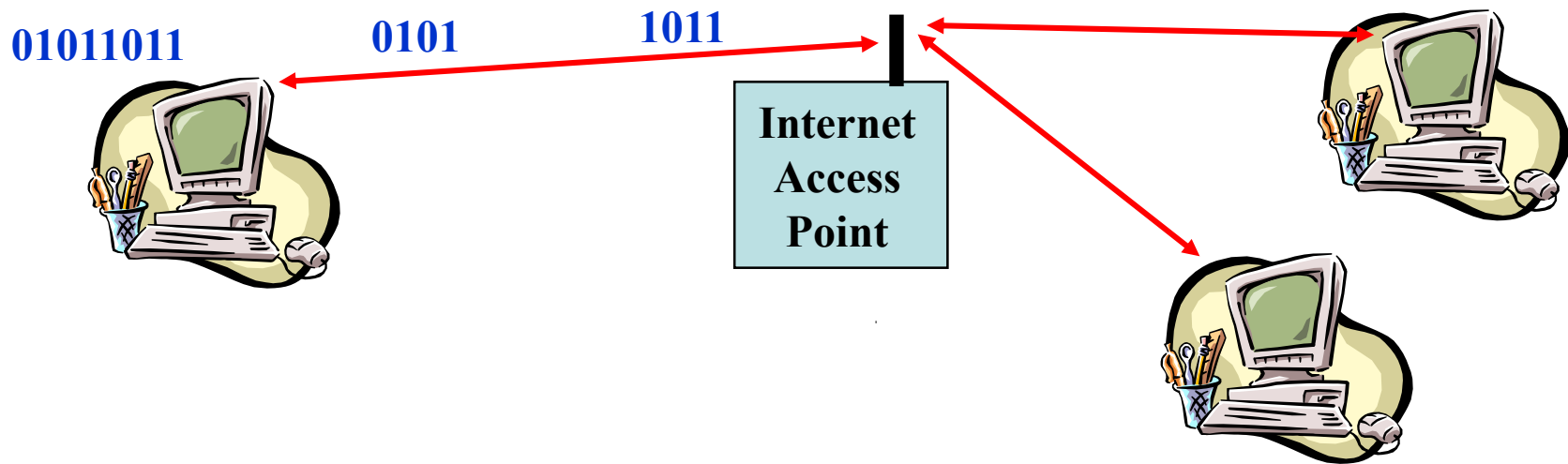
- Geographic region divided into cells
- Frequencies/timeslots/codes reused at spatially-separated locations.
- Co-channel interference between same color cells.
- Base stations coordinate handoff and control functions
- Shrinking cell size increases capacity, as well as networking burden



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... more and more focused on data
 - High bandwidth
 - High reliability
 - Low latency

Wireless Local Area Networks (WLANs)



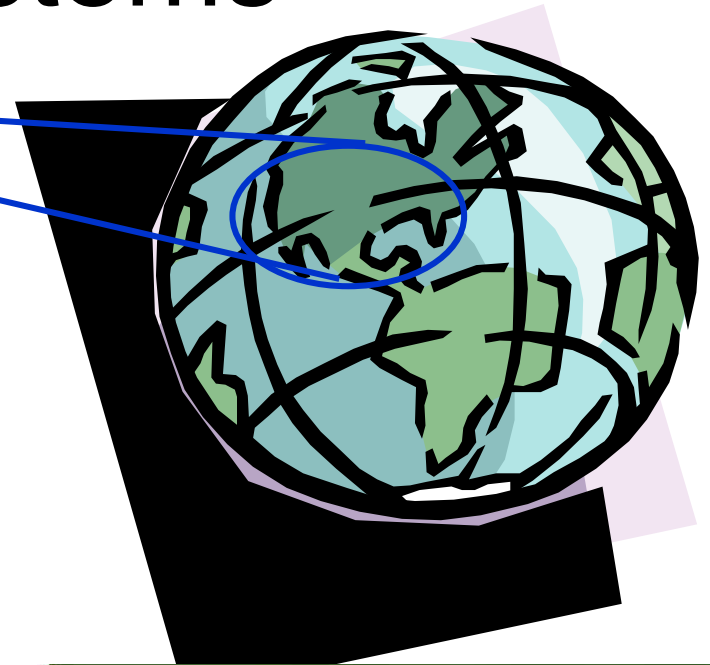
- WLANs connect “local” computers (100m range)
- Breaks data into packets
- Channel access is shared (random access)
- Backbone Internet provides best-effort service
 - Poor performance in some apps (e.g. video)

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 (Current/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



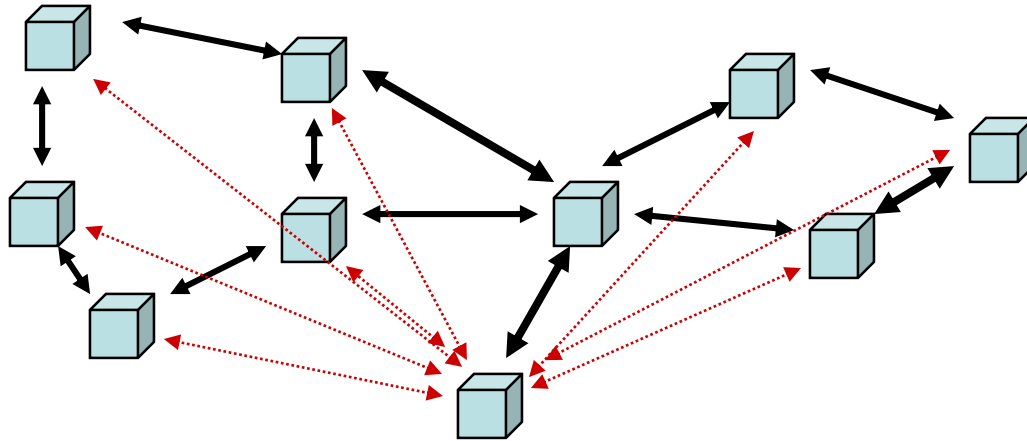
Bluetooth

- 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/FANET
- Underwater networks
- Molecular networks
- ...

Ad-Hoc Networks

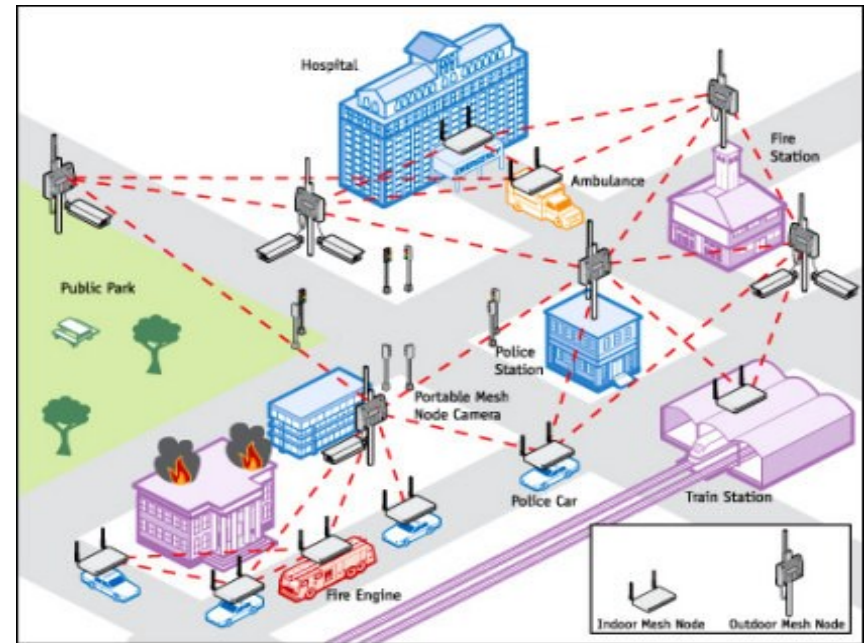
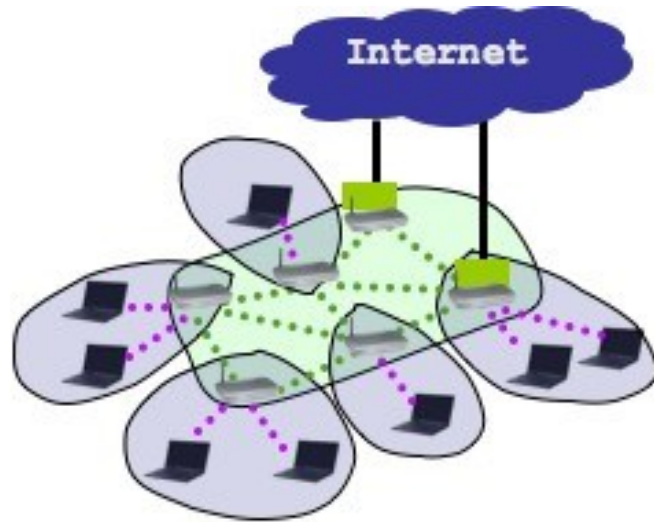


- Peer-to-peer communications
- No backbone infrastructure
- Routing can be multihop
 - to extend area of coverage or to reduce interferences (through short range communication)
- Topology is dynamic
- Fully connected with different links

Design Issues

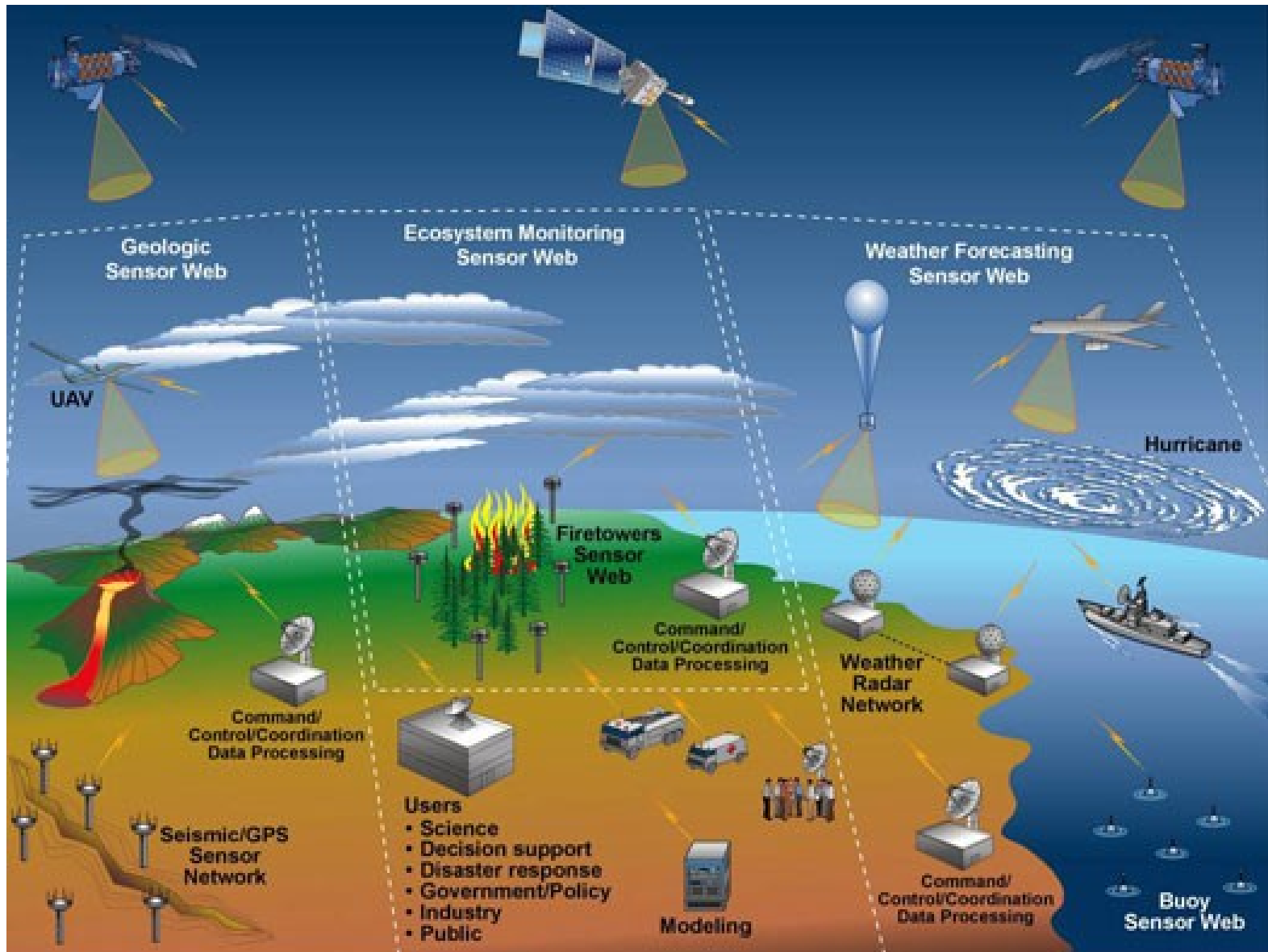
- Ad-hoc networks provide a flexible network infrastructure for many emerging applications
- The capacity of such networks is generally unknown
- Transmission, access, and routing strategies for ad-hoc networks are generally ad-hoc
- Crosslayer design critical and very challenging
- Energy constraints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

Mesh Networks



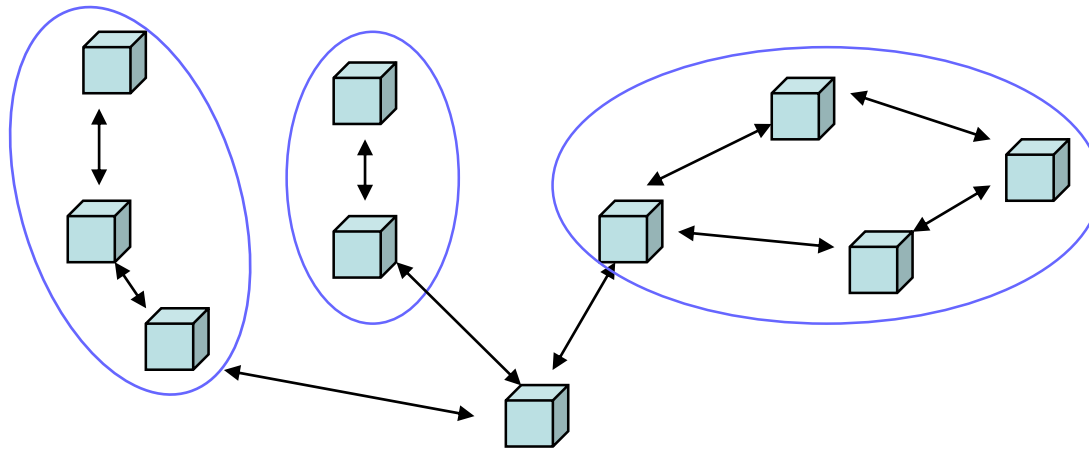
- Ad hoc opportunistic extension of a fixed urban infrastructure
- Purposes: to create a low-cost, easily deployable, high performance wireless coverage
- Challenges:
 - optimum routing protocols to achieve fairness and load balancing
 - quality-of-service (QoS)
 - MAC/network protocols for multimedia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

Sensor Networks



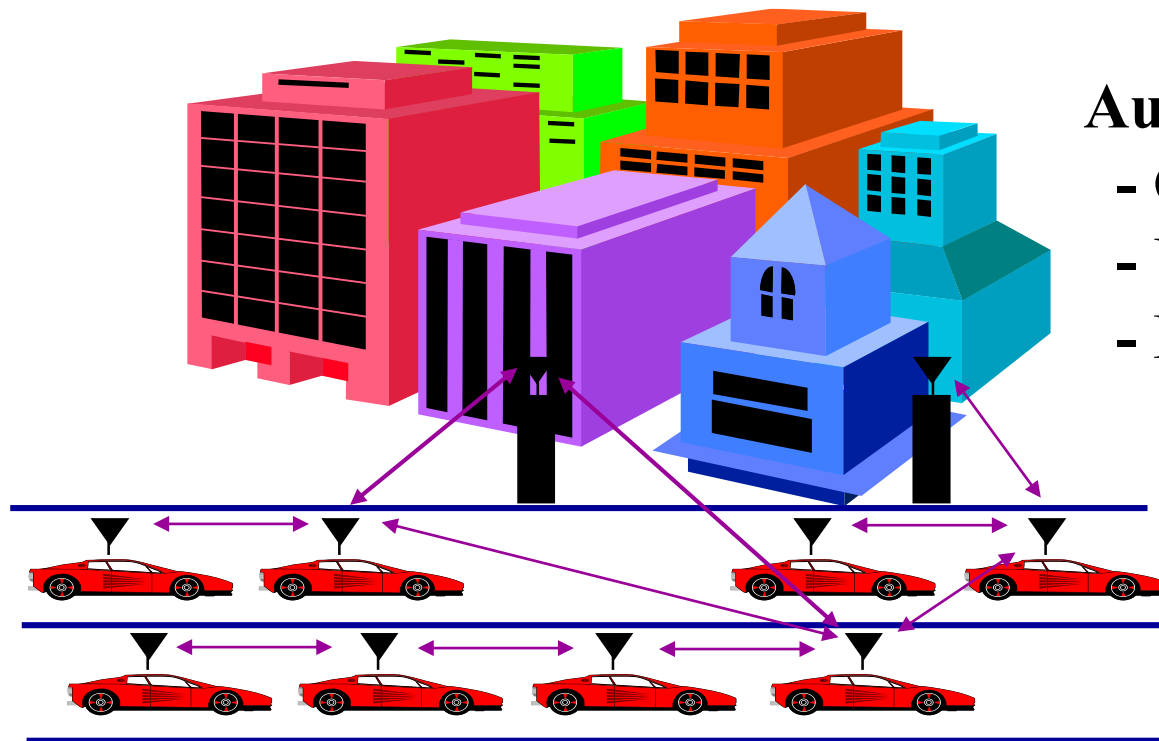
Sensor Networks

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



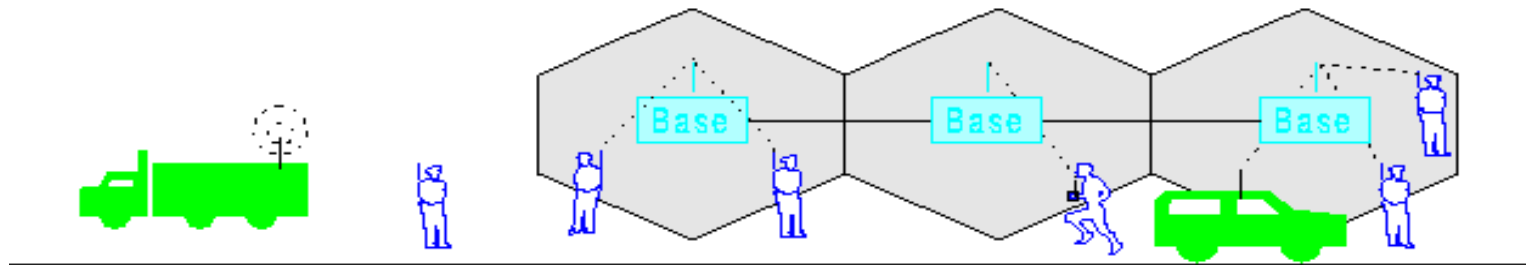
Automated Vehicles

- Cars
- UAVs
- Insect flyers

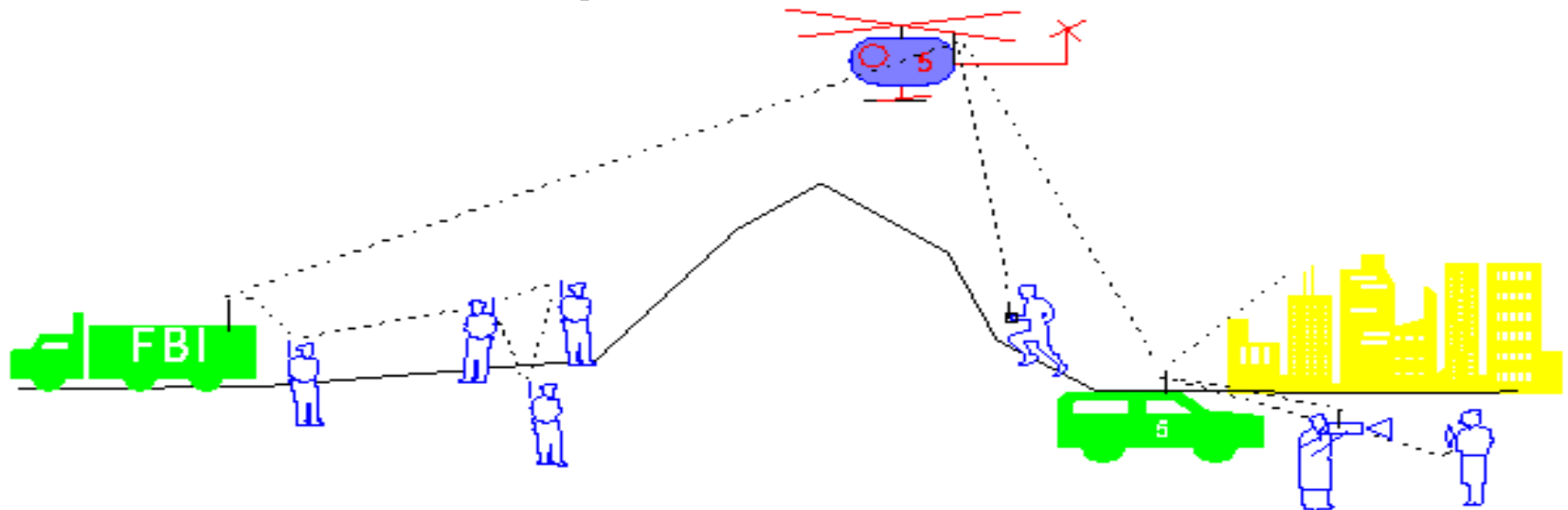
- Packet loss and/or delays impacts controller performance.
- Controller design should be robust to network faults.
- Joint application and communication network design.

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

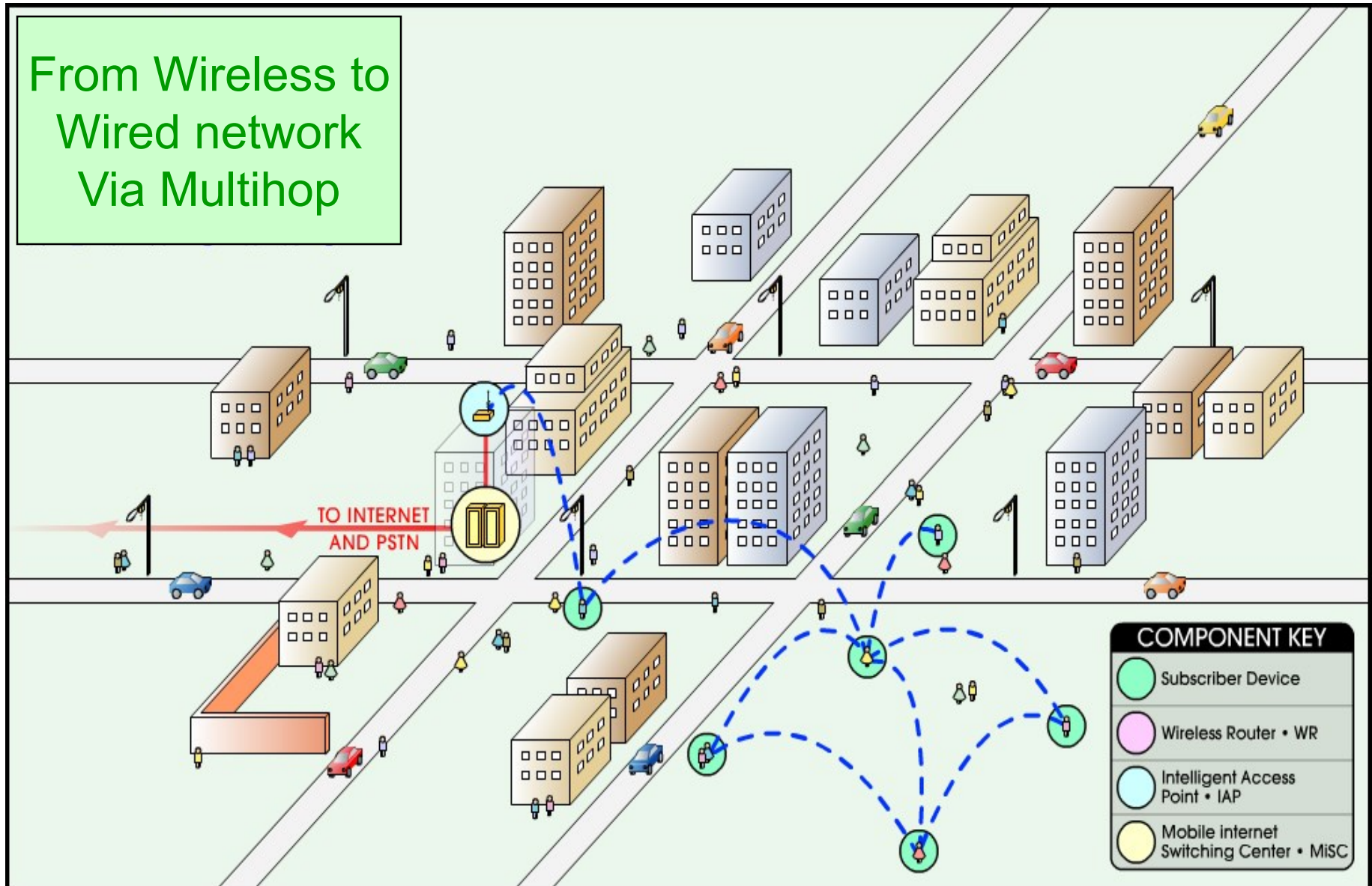
- Disaster Recovery (flood, fire, earthquakes etc)
- Law enforcement (crowd control)
- Homeland defense
- Search and rescue in remote areas
- Environment monitoring (sensors)
- Space/planet exploration

Opportunistic Ad Hoc Nets

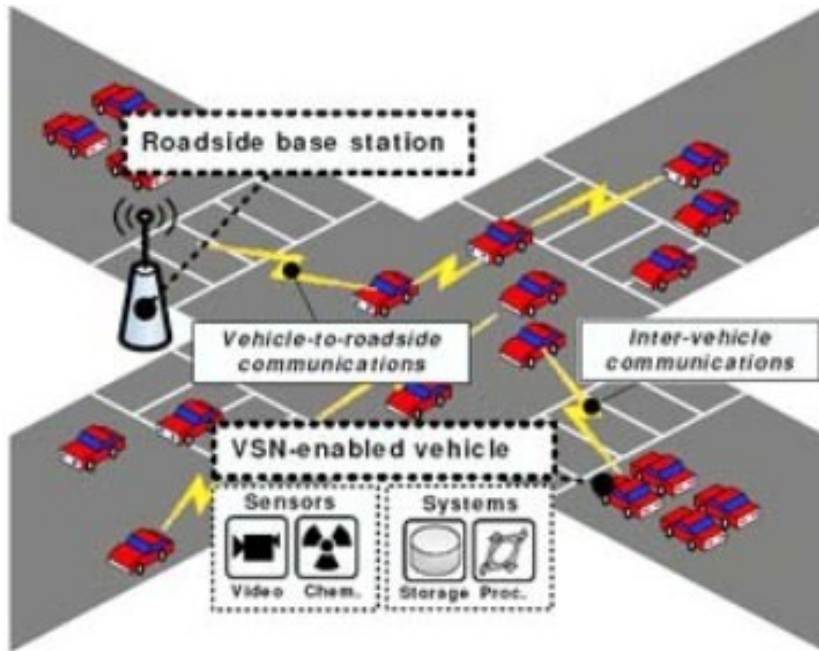
- Driven by “commercial” application needs
 - Indoor W-LAN extended coverage
 - Group of friends sharing via Bluetooth
 - Peer-2-Peer networking in the vehicle grid
- Access to Internet:
 - available, but it can be “opportunistically” replaced by the “ad hoc” network (if too costly or inadequate)

Urban "Opportunistic" Ad Hoc Nets

From Wireless to
Wired network
Via Multihop



Vehicular Ad-Hoc Network (VANET)



DSRC CHARACTERISTICS

Parameter	Value
Range	1000m
Frequency Band	5.9Ghz
Speed	≤ 85 mph
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!

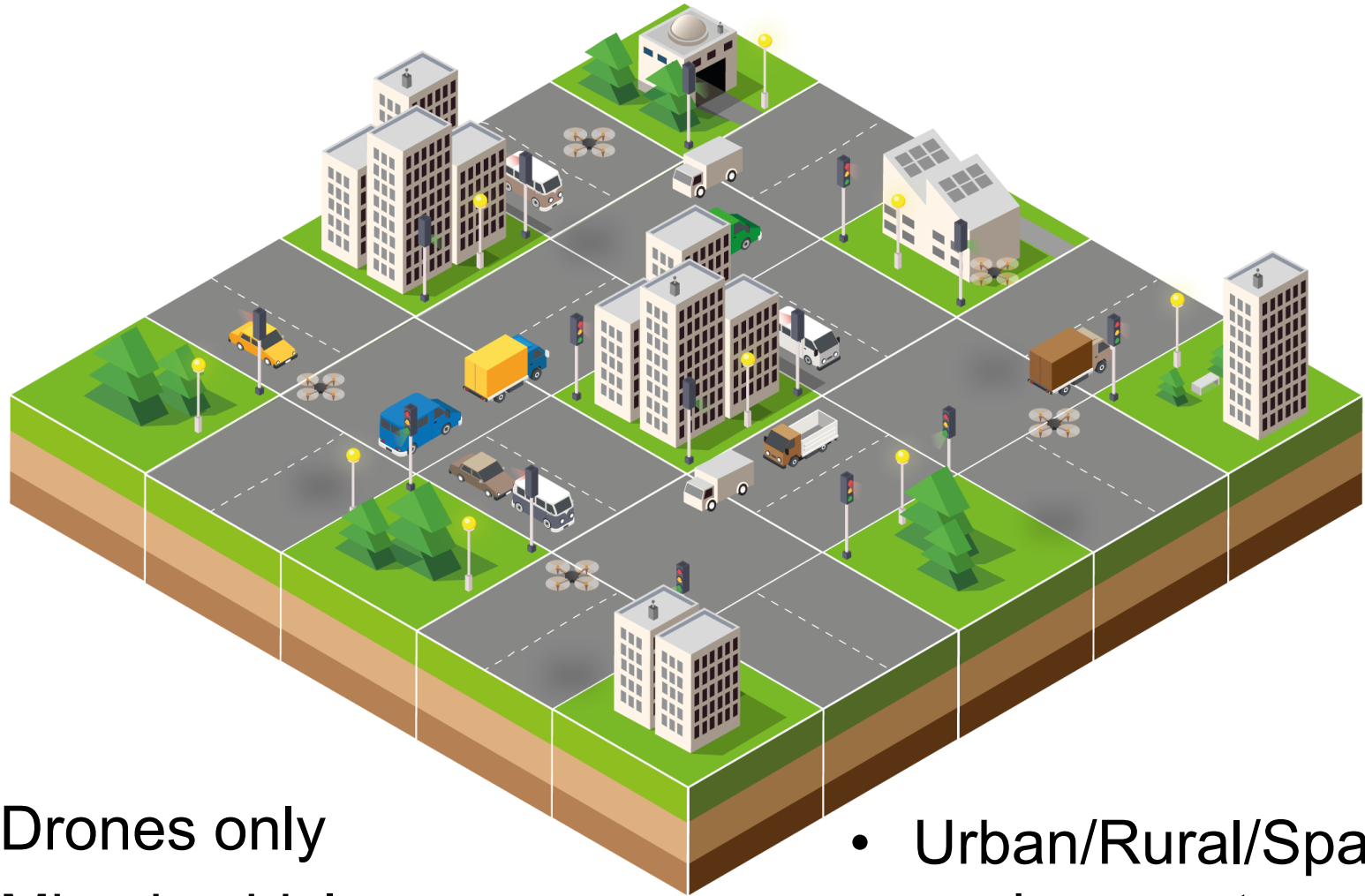
ATIS - Advanced Traveler Information Systems
CVO - Commercial Vehicle Operations

RED – Long Range Applications (up to 1000 meters)

BLUE – Medium/Long Range Applications (90-300 m)

BLACK – Medium Range Application (Up to 90 meters)

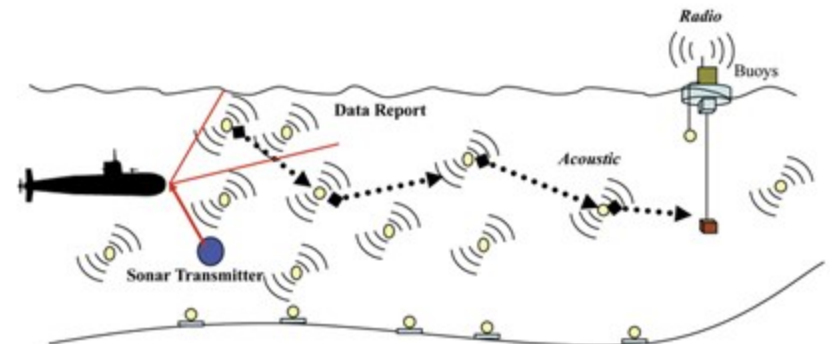
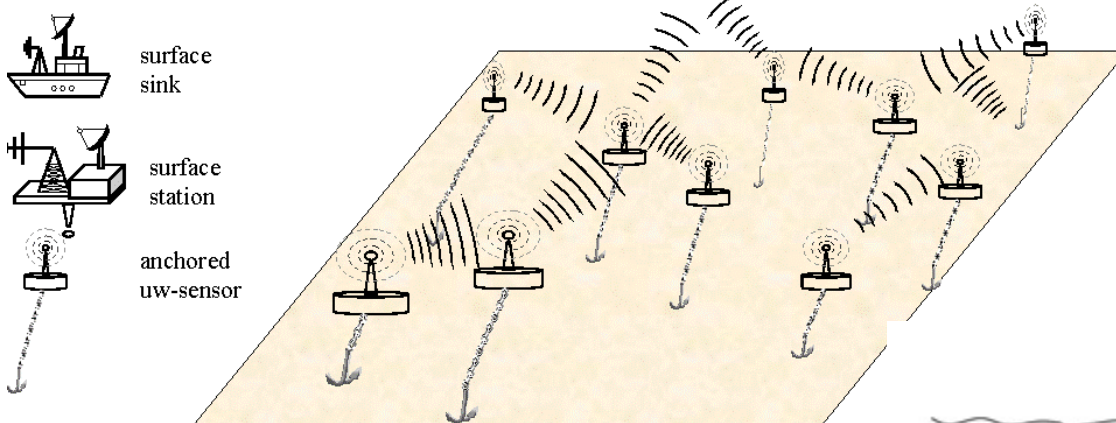
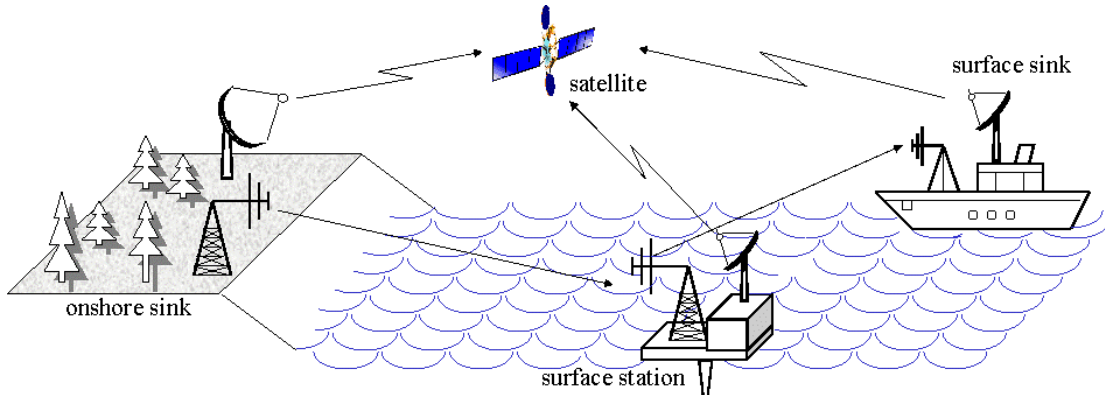
Flying Ad-Hoc Network (FANET)



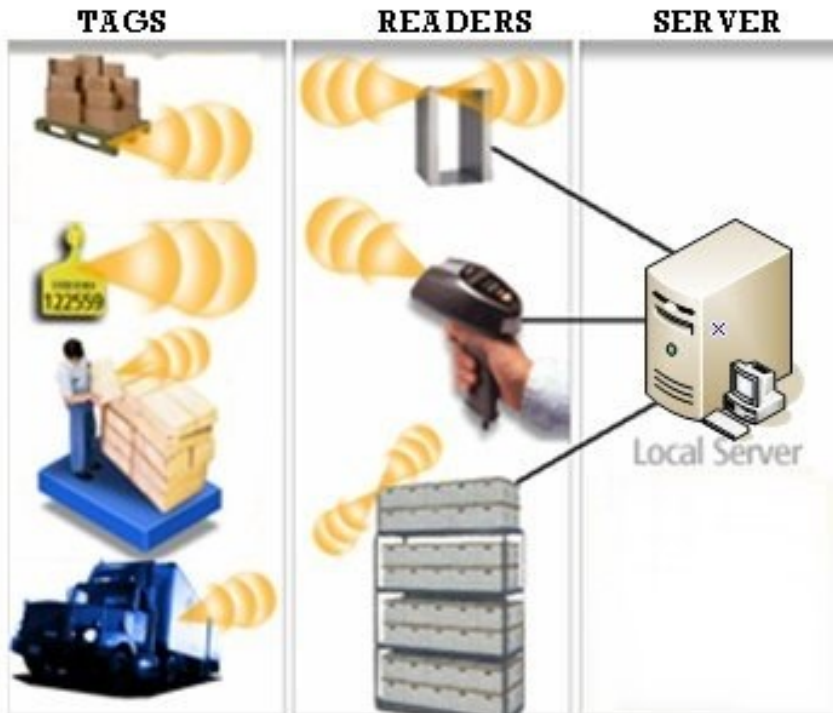
- Drones only
- Mixed vehicles

- Urban/Rural/Space environment

Underwater Sensor Networks



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



Nano-Networks

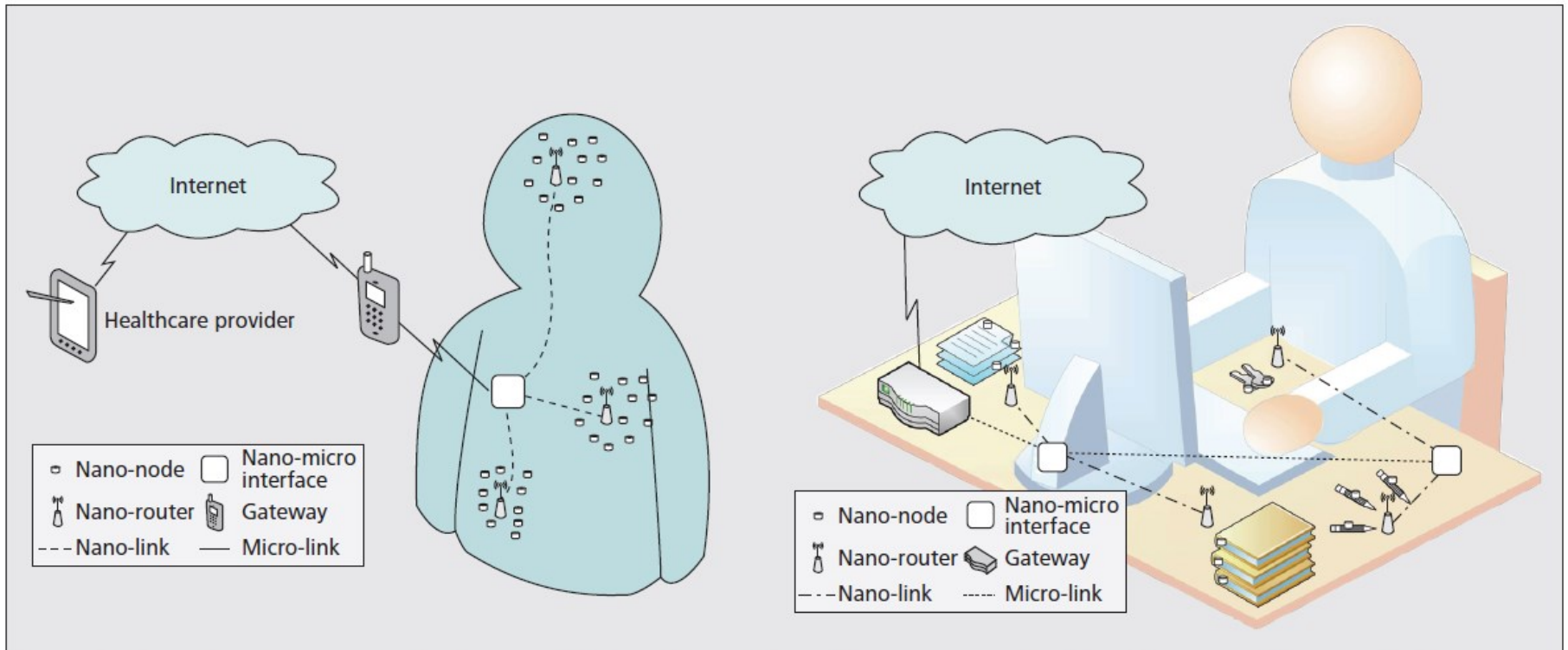
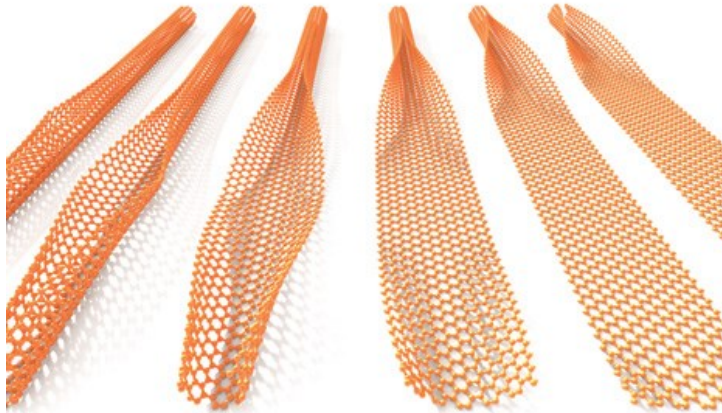


Figure 1. Network architecture for the Internet of Nano-Things: a) Intrabody nanonetworks for healthcare applications; b) The interconnected office.

2010 Nobel Prize in Physics

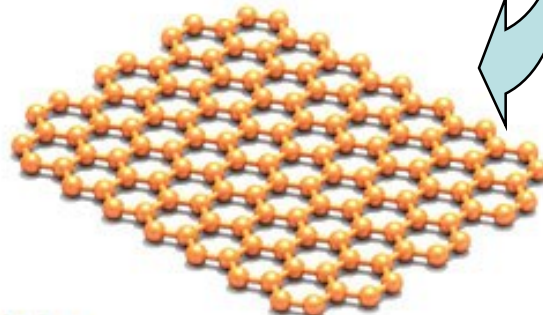
Through a mixture of sulfuric acid and potassium permanganate



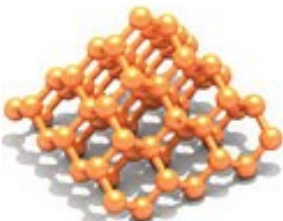
Unzip carbon nanotubes



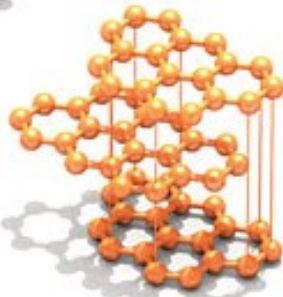
Nanotube



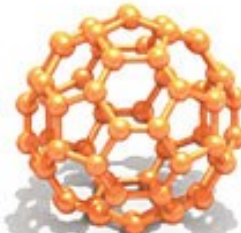
Graphene



Diamond



Graphite



Fullerene

Extraordinary applications



Main Points

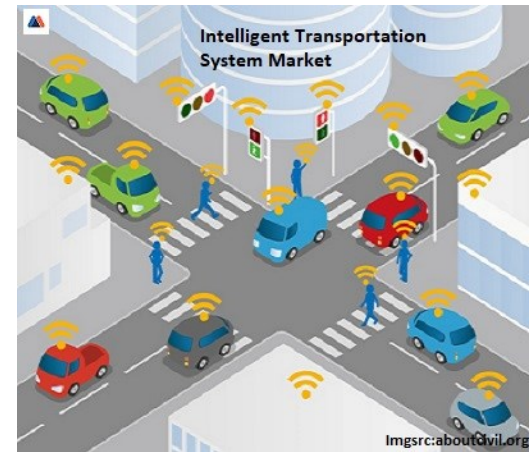
- The wireless vision encompasses many exciting systems and applications
- Technical challenges transcend across all layers of the system design
- Wireless systems have limited performance and interoperability
- Standards and spectral allocation heavily impact the evolution of wireless technology
- Huge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

Case Studies and Project Topics

Internet of Space Things (Cubesat)



Intelligent Transportation System



AR and Interactive Games

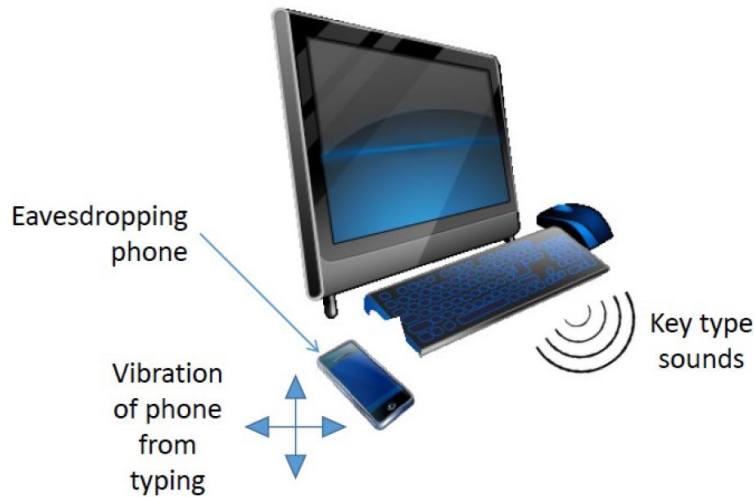


Industry 4.0

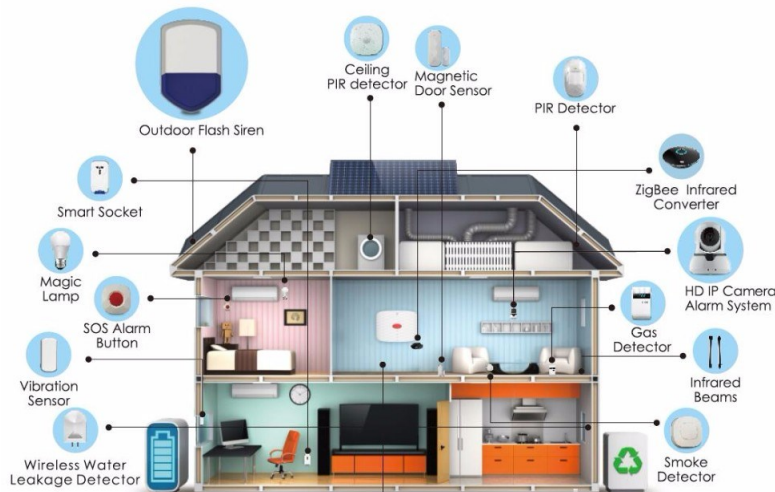


Case Studies and Project Topics

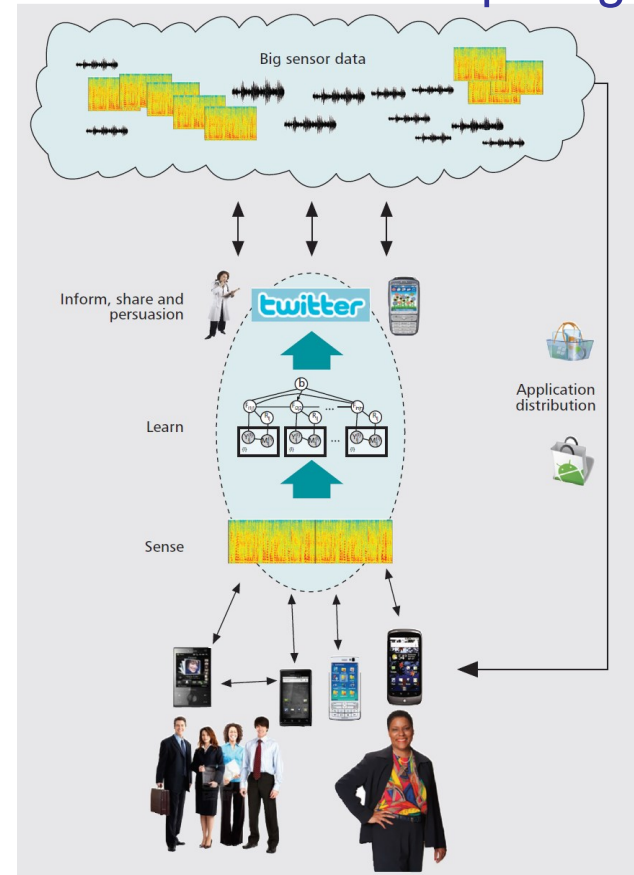
Side Channel Attacks



Smart Home



Mobile Sensing & Mobile Cloud Computing



And more...