Modern Wireless Networks

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Two Successful Domains

- The Internet
  - Information content
  - Supports multimedia services
  - Global penetration – millions of nodes
  - Decreasing cost
- Wireless networks (Cellular)
  - Supports voice
  - Total coverage in many countries
  - Decreasing cost
  - The boon – user mobility

Motivation

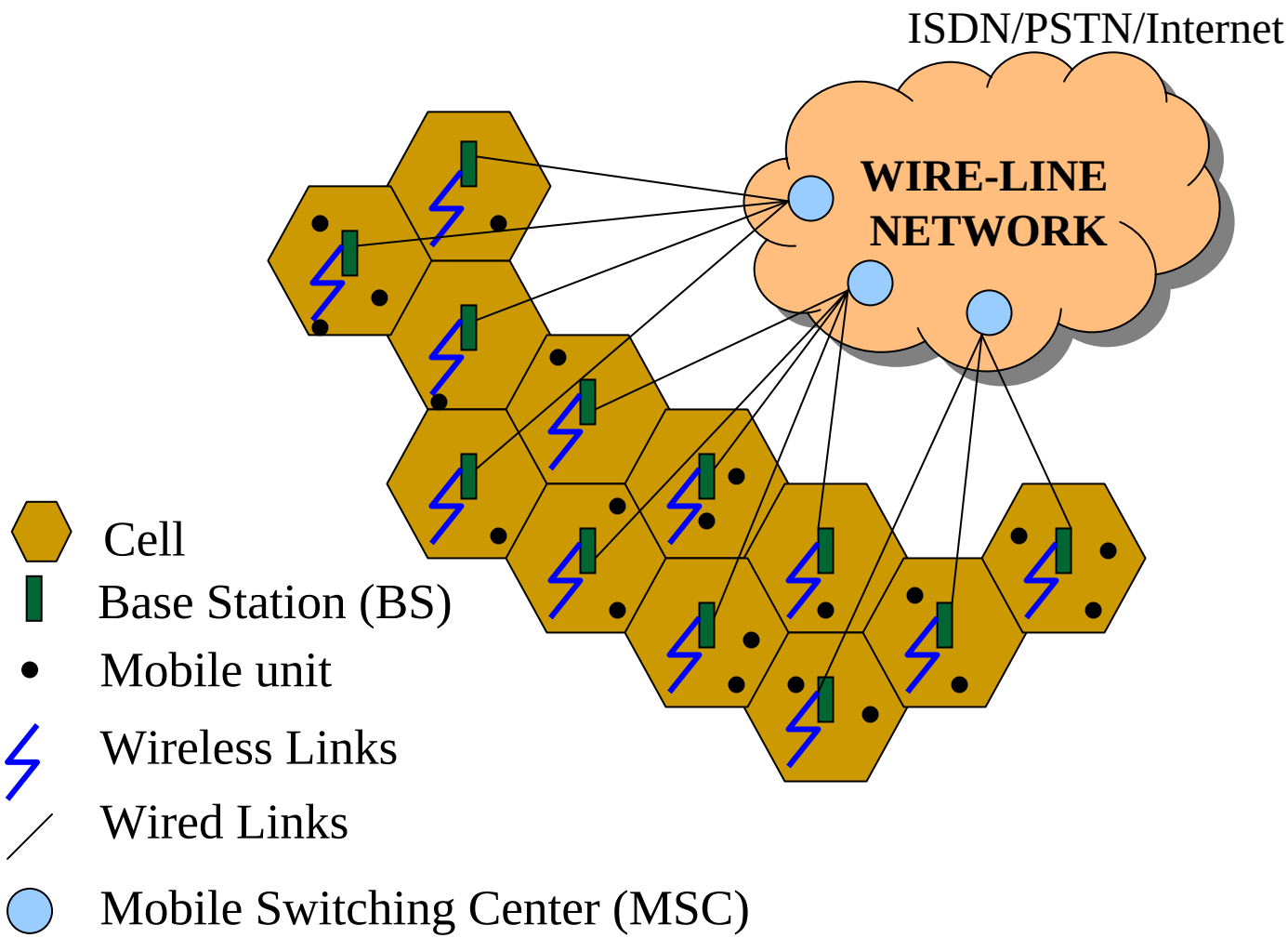
- Wireless and Internet are coming together creating significant opportunities and challenges
- Wireless mobile multimedia services will be a major drive for wireless Internet
- Technology challenges for wireless multimedia will be centered around how to support “simple, secure, reliable transactions for mobile users”
- How has been the transition from the past (2G) to the present (3G)? How will it be to the future (4G)?

Wireless Mobile Networks

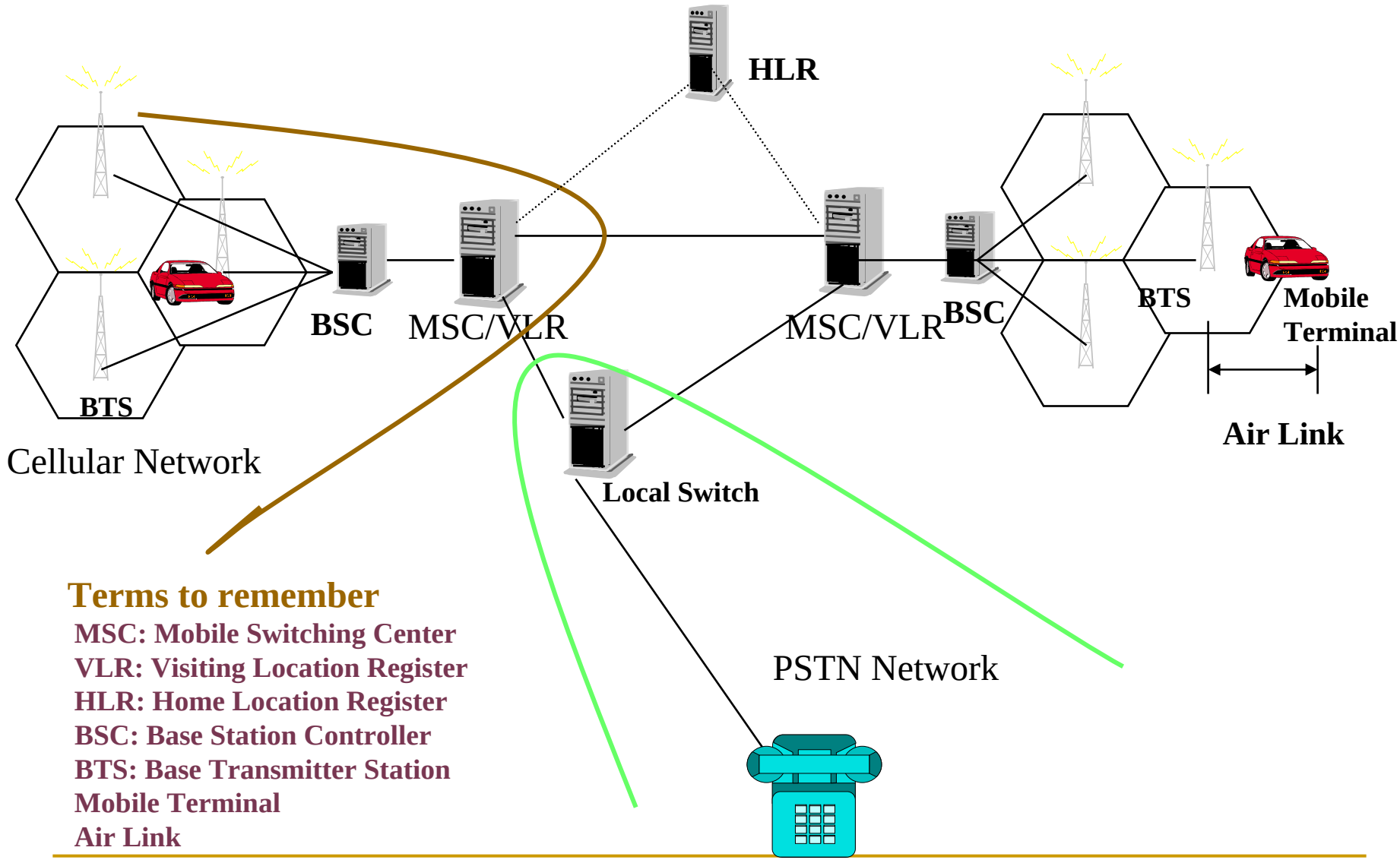
Inherent Characteristics:

- Resource scarcity
  - Limited bandwidth (~Kbps – Mbps)
- Unreliable wireless links
  - Varying channel conditions (multi-path fading, shadowing)
  - Error prone channels (high BER ~ $10^{-4} - 10^{-3}$)
- Continuously evolving network topology
- User mobility
  - Uncertain availability of network resources
- Power (battery) limited, unsecured

Cellular Architecture



Cellular Framework



Terms to remember

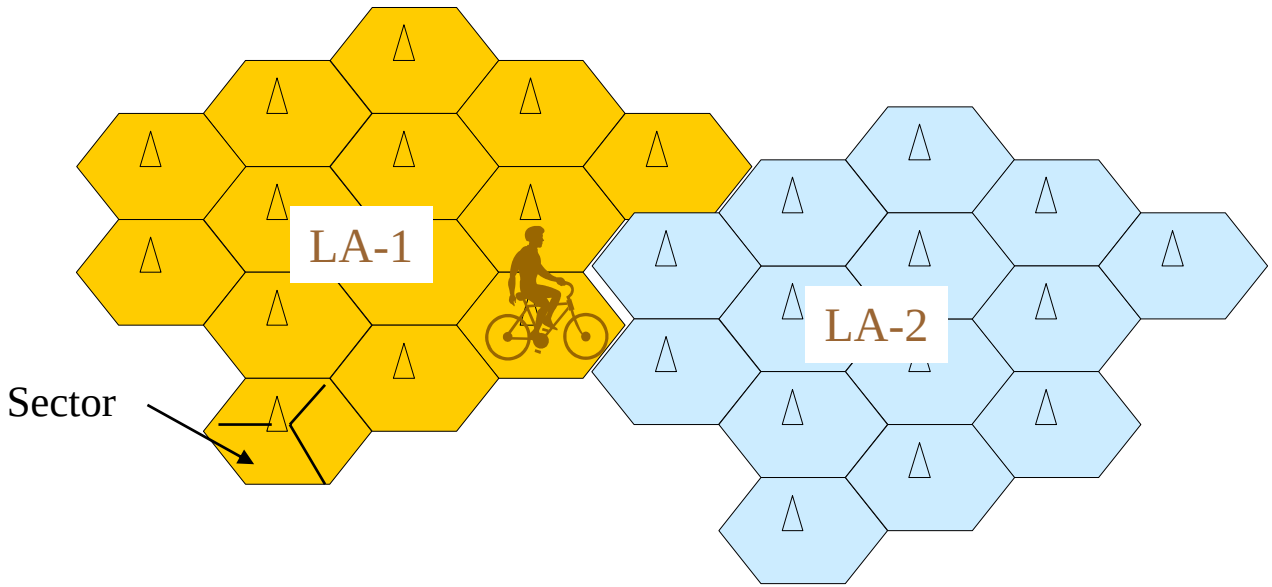
MSC: Mobile Switching Center
VLR: Visiting Location Register
HLR: Home Location Register
BSC: Base Station Controller
BTS: Base Transmitter Station
Mobile Terminal
Air Link

Mobility Management

Mobility is a new dimension – paradigm shift in computing

Functions:

- Registration
- Location Tracking during off session
- Paging to locate the terminal for a session
- Hand-off during Session



Cellular Mobility

Micro Mobility

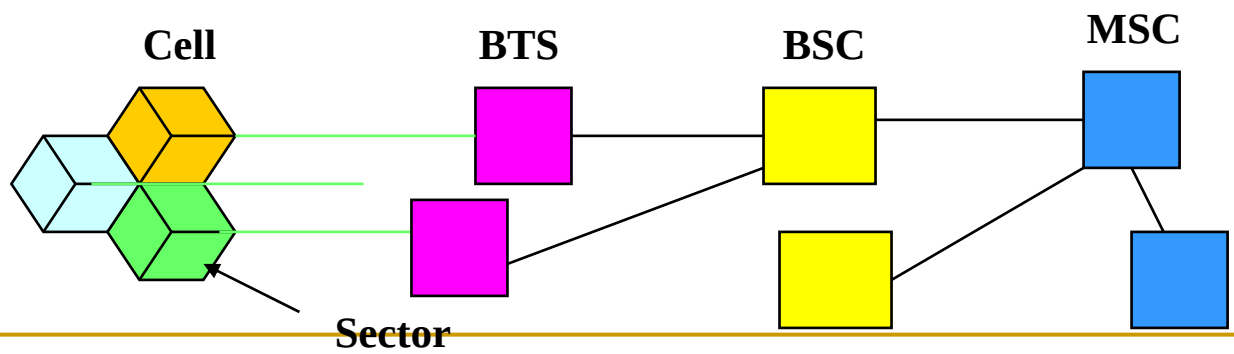
Mobility between Sectors: Hand-off
Mobility between BTSs : Hand-off
Mobility between BSCs : Inter BSC Hand-off

Macro Mobility

Mobility between MSCs : Inter MSC Hand-off

Global Mobility

Mobility between different administrative domain



Wireless Internet

Combine mobility with the rich multimedia content of the Internet

Wireless Internet = Wireless + Internet + Internet Mobility

Wireless

- **Ubiquitous services**
- **Mobility key driver**
- **Voice becoming commodity**
- **Advanced services**
- **38%: "most desired service" is Internet**
- **~300 M subscribers**

Internet

- **20+ million hosts**
- **~175 million users**
- **Users doubling every 6 months**
- **1000% annual traffic growth**
- **Base on global "networked economy"**

- **75% laptop users are also wireless voice users**
- **95% of palm size devices are also Internet users**
- **Ideal candidates for wireless data**

Mobile Multimedia Applications

Mobile Office

File Services
Real-time Support
Corporate Applications
Remote diagnostics/maintenance
Collaboration

E-Commerce

Broker Services
Electronic Ticketing
Online-banking
E-retail & Auction
Interactive Shopping

Communications

Messaging
Event notification
Email
Voice Services
Video Telephony

Entertainment

News, sports, weather updates
E-magazines
Interactive gaming
Audio on demand
Video on demand

Travel

Scheduling / Timetables
Navigation Services
Traffic Information
Directory Services
Tourist Services
Locator Services

Telemetry

Monitoring & Control
Data acquisition
Health monitoring
Surveillance

Characteristics of Multimedia Services

A picture is worth thousand words

Combination of various medium – text, audio/video, graphics

- Audio/video conferencing, shared whiteboard, surfing, email, etc.

- Varied requirements
  - Low bit error rate
  - High bandwidth
  - Low delay
- Synchronization of multiple data types
  - Proper scheduling
- Different coding schemes for different types
  - Source coding

Data on Wireless Networks!

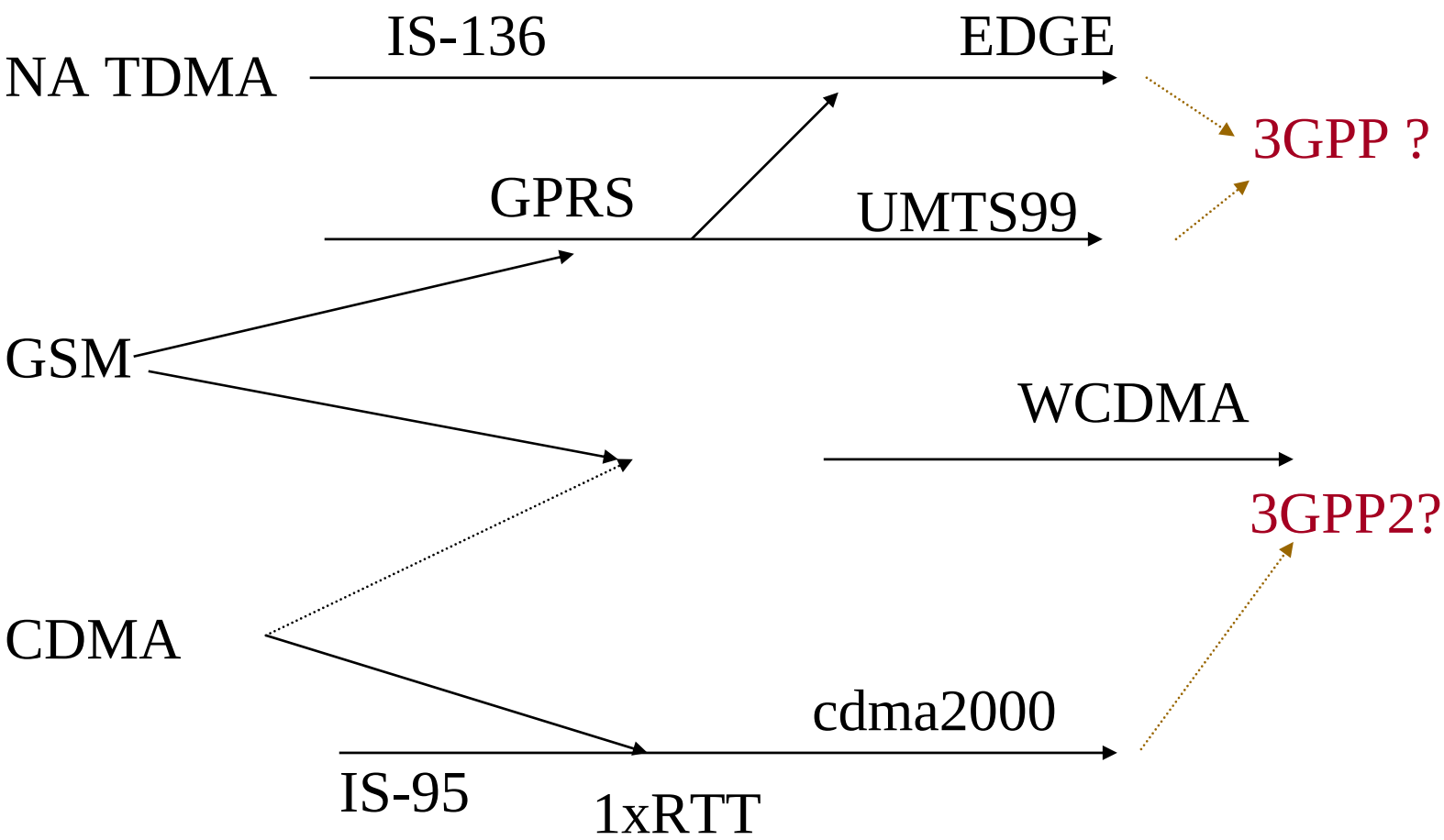
What are the Problems?

- True characterization of data traffic is yet unknown
  - Traffic modeling needs to be done
- Data services cannot tolerate bit errors
  - Corrupt packets need to be recovered
- Unpredictable nature of wireless medium
  - QoS provisioning becomes difficult
- Bottleneck due to the bandwidth limitation
  - Proper buffering / filtering required
- No differentiated service plans for customers
  - Class based services required

Evolution of Wireless Data Networks

- **2G** wireless systems (voice-centric, data loss unimportant)
  - IS-95 CDMA, TDMA, GSM
- **2.5G** systems (voice and low data rate)
  - CDPD, GPRS, IS-99 CDMA, IS-136+
  - Date rates: CDPD (19.2Kbps), HSCSD (76.8Kbps), GPRS (114Kbps)
- **3G** proposed standards (data-centric, high data rate)
  - UMTS, EDGE, W-CDMA, cdma2000, UWC 136, IMT-2000
  - Data rates: EDGE (384Kbps), cdma2000 (2Mbps), W-CDMA (10Mbps)

Cellular Standards



Proposals for 3G Standards

The most important IMT-2000 Systems → IMT-DS and IMT-MC

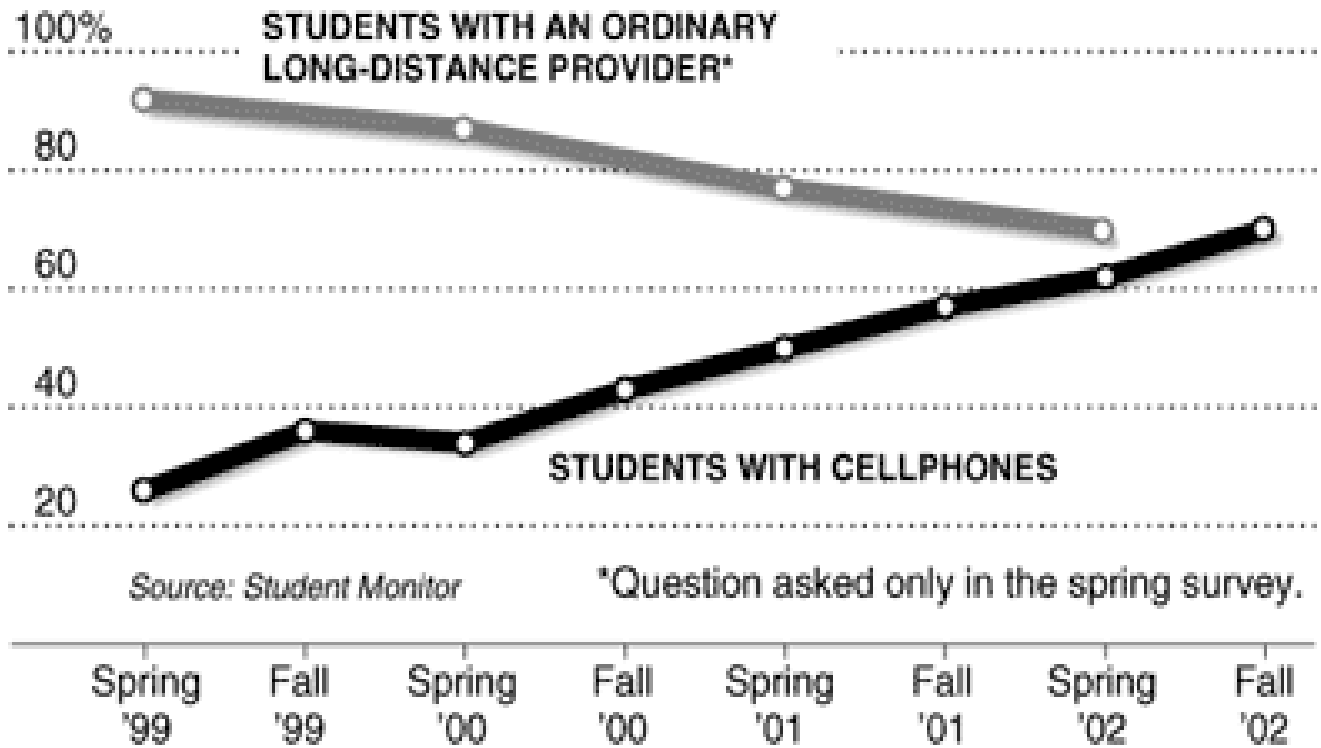
- W-CDMA (IMT-DS):
  - Developed by the 3G Partnership Project (3GPP)
  - UTRA TDD and UTRA-FDD
  - Backers → Ericsson, Nokia, NTT DoCoMo.
- cdma2000 (IMT-MC):
  - Compatible with IS-95
  - Further developed by the 3G Partnership Project Number 2 (3GPP2)
  - Backers → Qualcomm, Lucent, and Motorola.

Today's Wireless Market Ecology

- Some basic market concerns remain
  - Six companies in the U.S. are battling for market share, offering hundreds of minutes at bargain rates and giving away service on nights and weekends.
  - Doubts remain as to whether 3G is a technology push, but without market pull
    - Less expensive, higher bandwidth alternatives [802.11/Wi-Fi] are growing dramatically.
    - Mobile operators continue to grapple with issues such as spectrum availability, infrastructure and licensing costs, and lagging customer demand for what some consider too little bandwidth too late.
  - But, there is a big-time paradigm shift with the explosive adoption of WiFi/802.11 wireless data communications ---recently, some telecom carriers have come to regard "WLAN hotspots" as immediate revenue generators for data services.
  - Wireless data is starting to permeate society as phones become cameras, mobile games access the Net, and car dashboards become wirelessly enabled control centers --- across 2G, 2.5G, 3G/HDR/HSDPA, WiFi, and Bluetooth.

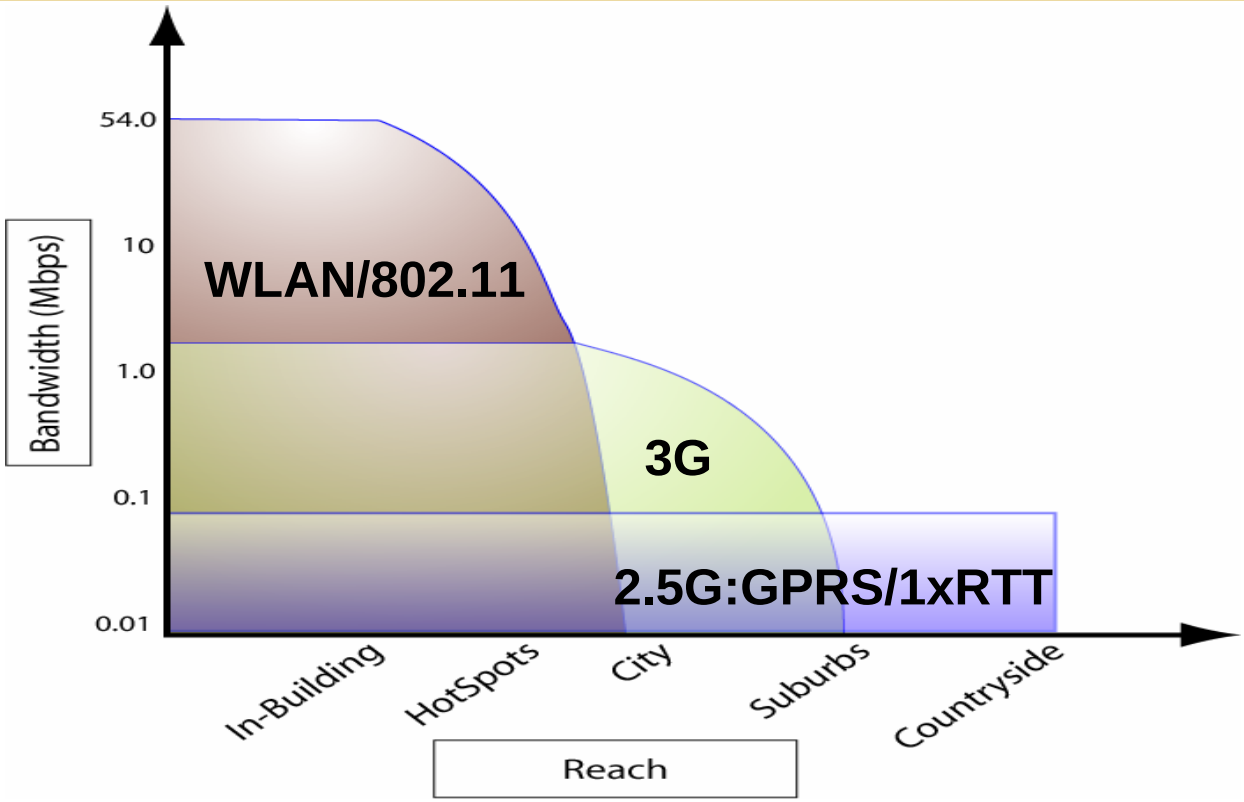
Voice Paradigm Shift: Cellular on Campus

- 70% of the US college population of 5.6 million students owned cell phones, up from 29% in 1999 ---compared to 52% of the general population.
- Student cellphone use has been accompanied by a decline in the use of wired phones ---to only 70% last spring, down from 92% three years ago.



[New York Times, January 20, 2003]

2.5G, 3G, and WLAN Systems ---Bandwidth vs. Reach



3G is said by some to not be good enough, while others say that 2.5G systems will meet users needs for quite a while.

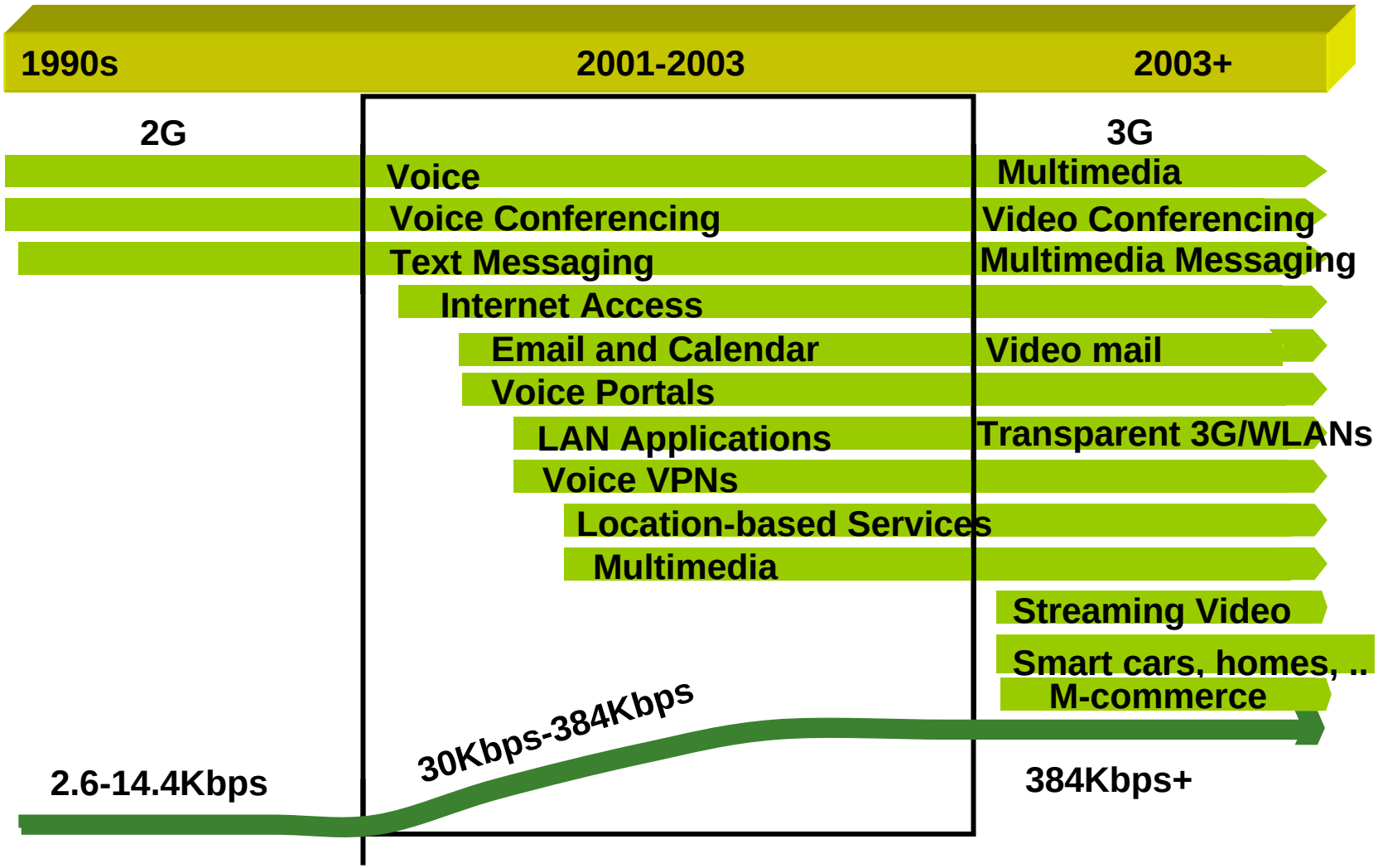
- Wi-Fi is currently one-tenth the price of 3G, and > 5 times as fast.
- There are applications that are matched to each domain, and there are many apps that do require transparency between 3G and 802.11, so expect to see dual-mode WLAN/3G NICs or devices.

Most Agree On The Need for Speed

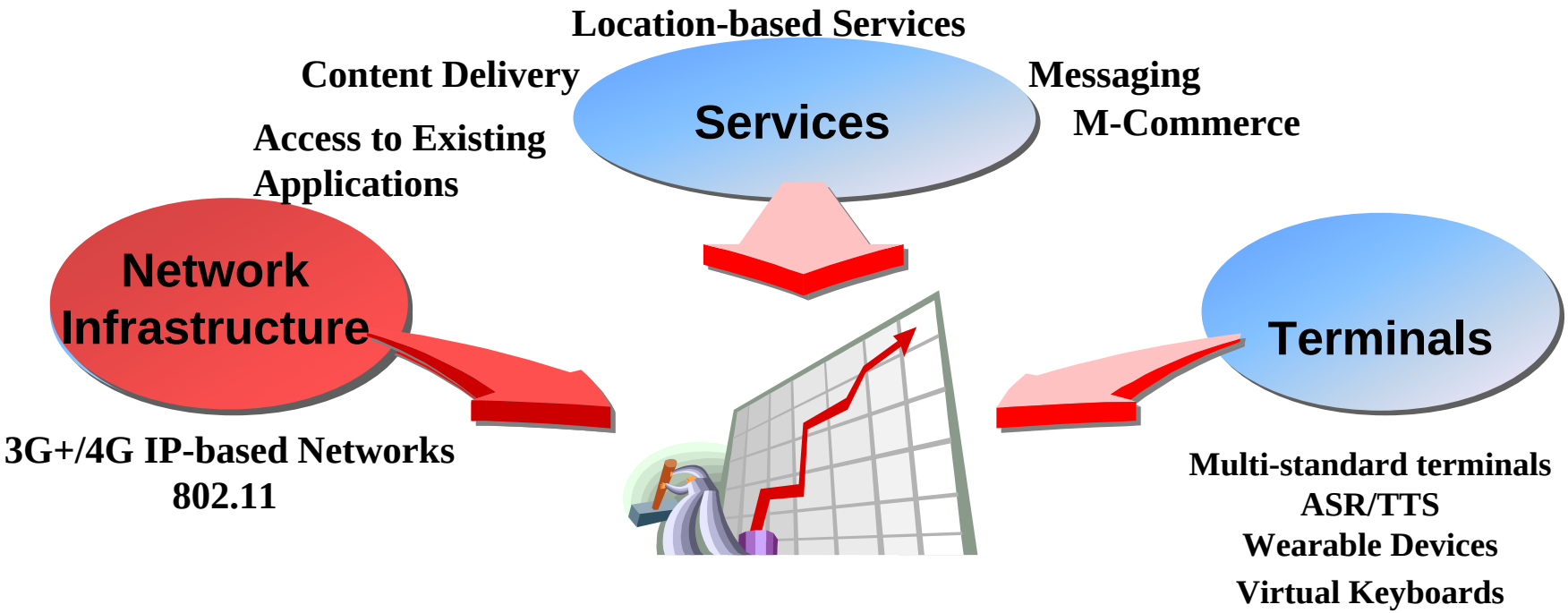
Broadband Wireless

- Many of the applications that providers once assumed for 3G wireless networks may be more appropriately served by 802.11 WLANs.
- The WLAN industry will continue to experience stellar growth and some of that growth will come at 3G's expense.
- Why the fascination with 802.11: people often forget that the combination of the development of new, smaller, faster, cheaper technology - will lead to a market for new products with new features that can often be hard to imagine - even if you are in the inventing business!
- For many emerging applications
  - Gaming
  - Streaming audio/video content
  - MMS and picture messaging
  - Location-aware services

Evolution of Wireless Capabilities ---The Need for Speed



Powerful Forces are Driving the Growth of Wireless Data



3G Terminals

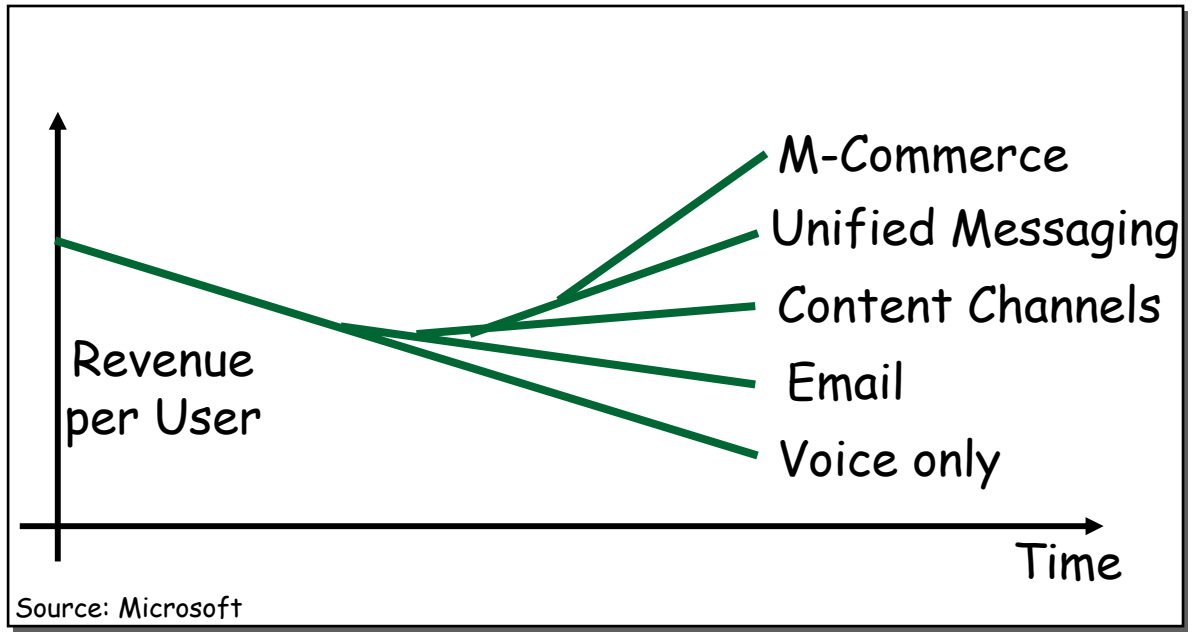
- To be successful, 3G networks will need to deliver high quality, high speed, media-rich content
- To support such advanced services, 3G handsets need to be feature-rich and will likely contain some combination of:
  - Computer-style keyboards, built-in CMOS cameras that facilitate e-mailing of video clips, along with significantly larger TFTD color screens.
  - Improved user interfaces: e.g. Virtual Keyboard [Canesta]
  - Wearable" communications:

NEC N2051 3G for DoCoMo

Canesta

Wireless Services are Critical

- Margins for basic voice service are getting slimmer.
- Service providers need to extend their service offerings to include data services beyond basic access.



- Value-added data services [e.g., the Mobile Internet] provide an opportunity for additional revenue and differentiation, e.g.:
  - Content delivery to wireless devices,
  - Messaging,
  - Additional services, such as location-based services, M-commerce.

WLAN/Wi-Fi Business Environment

- Private corporate/campus/home WLAN market is exploding---and have >90% of the traffic --- 55% of U.S. companies have WLANs installed

- But, public WLANs are spreading fast:
  - US Mobile WAN operators running commercial Wi-Fi services today T-Mobile [Starbucks], AT&T Wireless/Wayport[GoPort], others are planned ---Sprint PCS
  - Cometa Networks [AT&T, Intel and IBM] will provide wholesale nationwide broadband wireless Internet access using Wi-Fi technology.
  - Avaya, Proxim, and Motorola are collaborating on VoIP roaming over cellular and WLAN networks for business customers.
  - Worldwide: wired and wireless carriers are deploying WLANs: Deutch Telecom (T-Mobile), NTT DoCoMo, BT, Sonera, KT, KDDI,…

- But, carriers are still trying to construct a business model that provides recurring revenue to balance the daunting capital requirements necessary to build out public WLAN coverage.

WiFi: "Everyone" is Connecting, but Challenges Remain

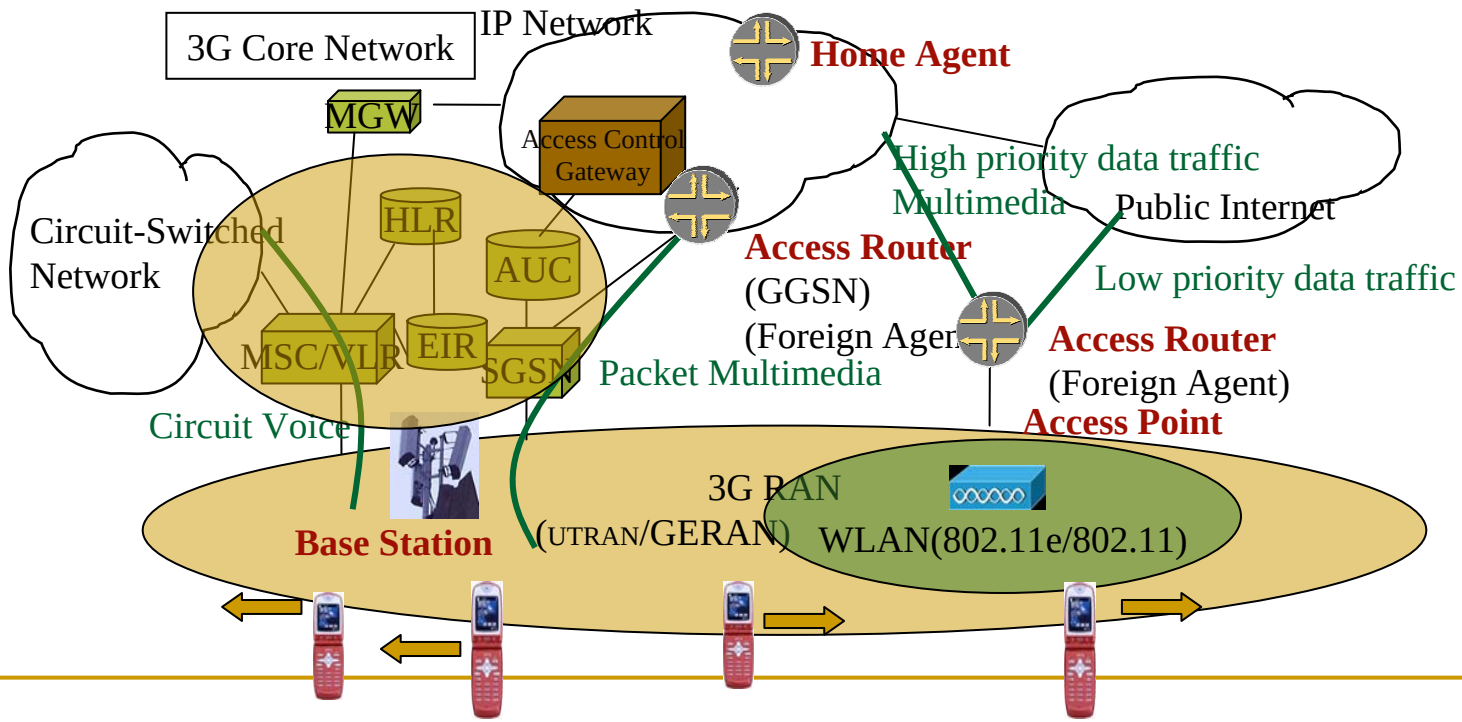
- Ease of use : simplicity of operation, ease of establishing and re-establishing sessions, ….
- Security: for both the corporate and public "hot spot" user.
- Mobility: extending sessions from in-building to "hot spots" to internetworking with cellular networks ---all in a transparent, seamless mobility manner that preserves the "always on" feel..

WLAN: Cellular Operators and End User Perspectives

- Cellular Operators: Initial view --- WLAN may reduce wireless data revenues.
  - Opportunity realization : By offering combined services, can acquire cheaper wireless bandwidth, access network facilities from roaming agreement with WLAN operators
    - Acquire more subscribers from roaming agreement with corporations, government organizations and schools.
    - Sell the cellular network based services such as SMS to WLAN users.
- End Users: Need Anytime Anywhere high speed Internet access
    - Prefer single device, single account, single bill
    - Automatic network selection for highest bandwidth and cheapest price
    - Convenience : easy-to-learn, portability, worry-free
- Seamless interoperation and *applications transparency* of WLAN and 2/2.5/3G is what end users need => will increase wireless operators' revenue

Internetworking of 2G/3G and WLANs:

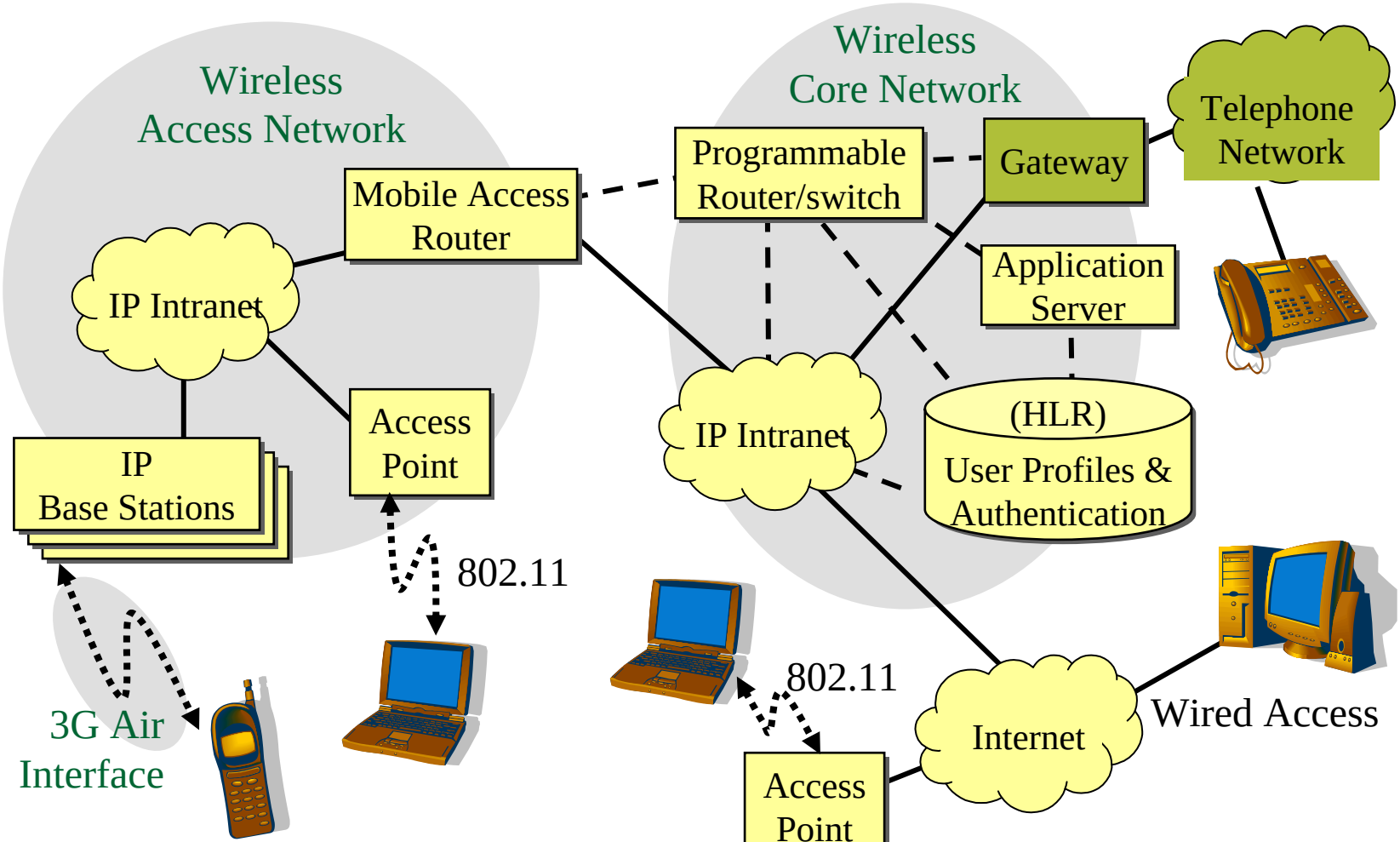
- **Seamless roaming across 3G and WLAN creates new wireless services**
  - Mobile users routed to the *best* available wireless network
  - Corporate wireless networks seamlessly extended to wide area
  - Off-load data traffic from cellular networks and create bigger wireless data services markets
- Use IP networking and hide L1/2 details of 3G networks and 802.11



Next-Generation all-IP Wireless Networks: Architectural Principles

- Embrace Internet technologies and services: uniform adoption of IP technology, provide rapid service creation, and global alignment
- Support for a wide range of services, including real-time, non-real-time, multimedia, as well as rapid service creation
- Separation of service from delivery/transport:
  - Separation of transport and signaling
  - Separation of mobility management from session control
  - Improve operators/ISPs ability to upgrade subsystems
- Independence from wireless access technology **(2G/3G, W-CDMA/cdma2000, 802.11)**
  - End-to-end IP transport of traffic and control
- Wireline Performance, Reliability, and Quality of Service
- Security: mutual authentication, confidentiality, and non-repudiation
- Distributed, scalable, *smart* architecture with open interfaces
  - Intelligence distributed in the network and end points
  - Introduction of proxies/agents to do service enhancements
  - Standardized APIs
  - RAN (radio access net) internal interfaces, core network interfaces: SW/smart radios

Enabling Network Technology:
3G with All-IP Backbone



Note: range of 802.11 is 500 feet with an omni antenna, but ~30 miles with a directional antenna!

Beyond 3G: 4G/5G

- "Requirements"
  - Open, IP-based service architecture--hides network infrastructure from applications
  - A new radio interface that provides enhanced performance [~100 Mbps downlink].
  - Integration of existing [and new] technologies to provide high-speed mobile services.
  - Convergence of diverse access technologies to provide seamless delivery of the best quality of service and lowest cost to the user ---- always provide the *best* connectivity.

Beyond 3G: 4G/5G

- Challenges
  - Mobility Management: service transparency and QoS to user location and network (e.g. updated routing tables follow user movement between cellular WLAN/802.11)
  - Paging/Power Conservation: support for mobile terminals on standby
    - Distributed paging functionality for increased reliability.
    - Mechanisms for locating inactive users for delivering incoming messages
  - Common authentication, authorization, and security
    - Single credential allows users to authenticate across different access networks. Use a unified data base for user information.
  - Wireline reliability, security, and QoS
    - Achieve wired network performance via new wireless-tuned protocols.
    - Support for new services: video conferencing, multimedia, e-commerce, …
  - Achieving the Bandwidth, Bit Error Rate and Loss for Multimedia Services
    - Use recent breakthroughs in space-time processing, advanced modulation [e.g., OFDM] turbo and low-density parity check codes
    - Smart (SW) radios: beyond multi- mode ---plans and negotiates mode.

4G: Current Assumptions

- Services: Real-time gaming, video streaming, and anywhere, anytime access to information --- mix of low and high- bandwidth and latency.
  - High data-rate service coverage may not be ubiquitous but confined to small cells on a dense broadband network. High rates (~10 Mbps) confined to urban areas, main highways, and offices, and rural areas limited to ~1 Mbps
  - Persistent inter-machine communications: all consumer items have an addressable wireless interface [e.g., scale to refrigerator, PC/TV exchanging info with a camera, ….]

4G: Current Assumptions

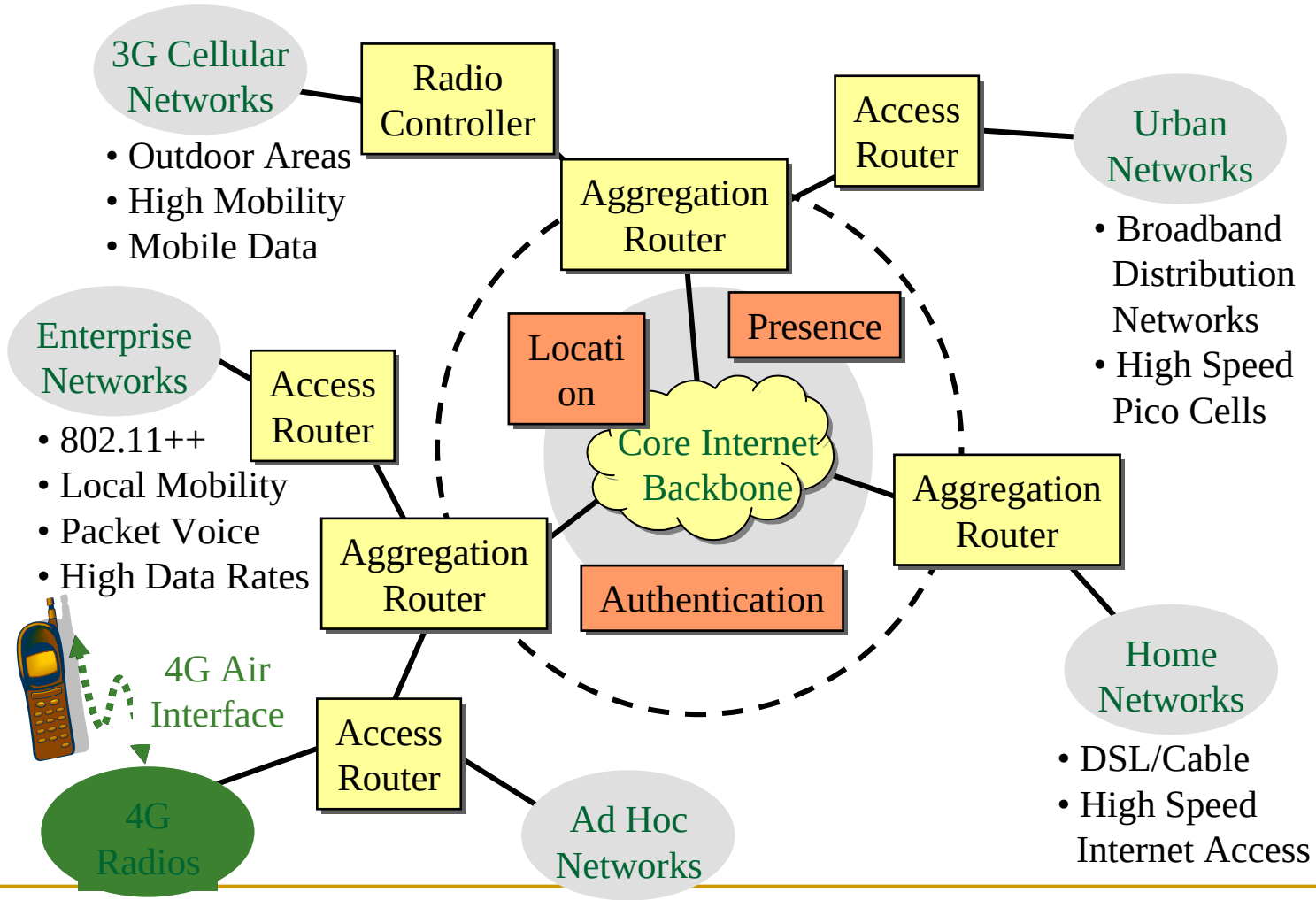
- Technology:
  - Non-homogeneous infrastructure: multitude of physical media, multiple air-interfaces, IP backbone network, spectrum from 5 to 60 GHz, rates approaching 100 Mb/s, and an overlaid architecture provides seamless internetworking.
  - Security is paramount: data integrity and protection against unauthorized access are key features for e-commerce
  - Ad-hoc, unlicensed operation may dominate: use of the “free” unlicensed spectrum, along with *ad-hoc* networking dominates the PAN [personal area networking], LAN, and possibly WAN access. Techniques need to be developed for fair and efficient sharing of the unlicensed spectrum.
  - Multimode Access Ports in Public Systems: Support multi-mode, multi-band operation with a SW defined radio and antenna arrays. Low-cost access ports [i.e., gateways for ad-hoc systems] flourish.
  - Dynamic resource allocation to match resources with traffic density will be a common theme for layers one and two to maximize bps/Hz/$.
  - Terminals: large range of bandwidths [10kb/s to 100 Mb/s (*telepresence*?), long-lasting batteries, multi-mode, multi/dedicated function, SW radios, smart antennas]

4G: Key Research Issues

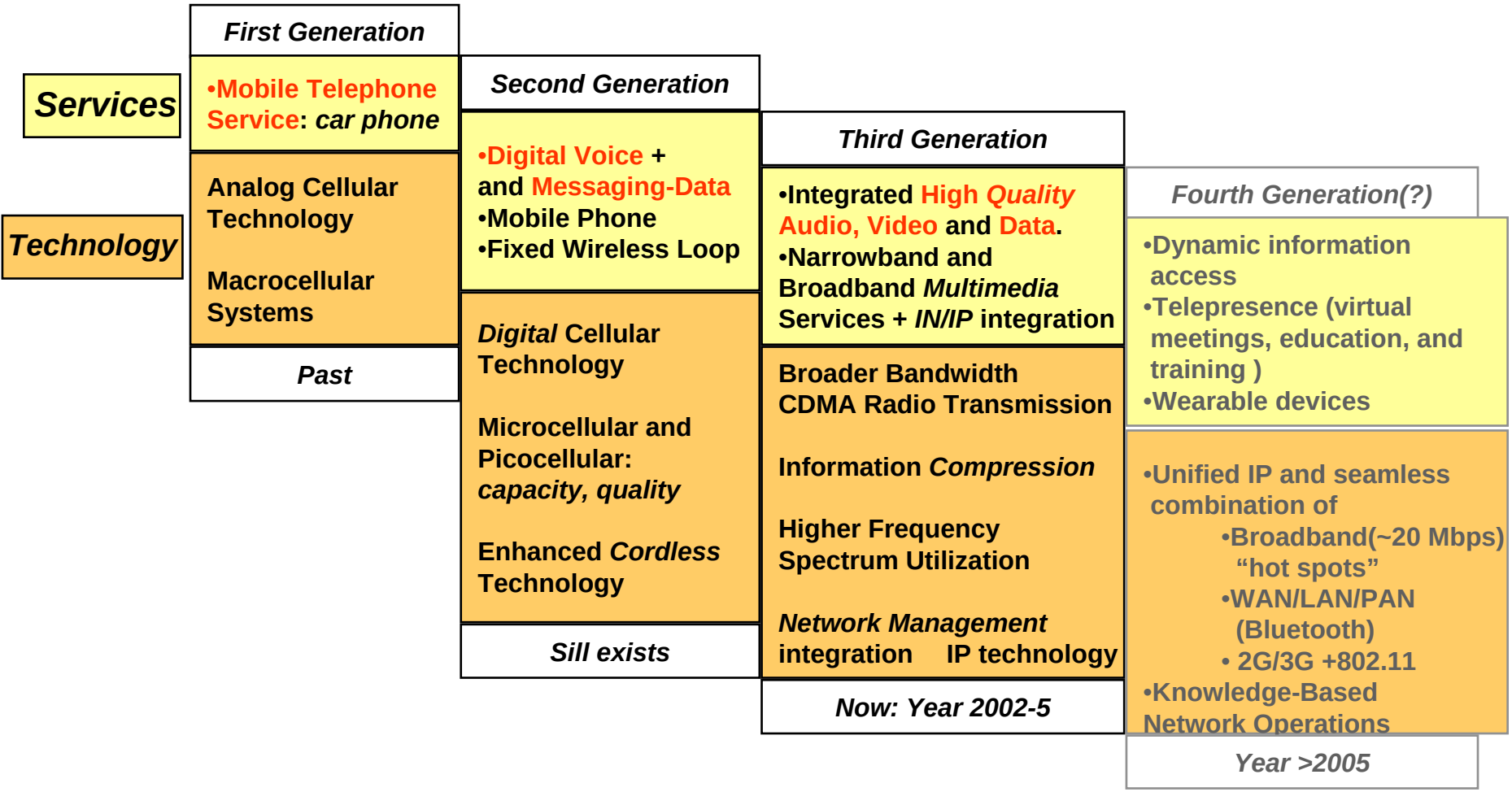
- Terminal and service adaptability to various standards, infrastructures, bandwidths. Requires rethinking of which layer is responsible for different functions [eg, security]. Big opportunity for SW radios and embedded network processors.
- Unlicensed public operation: how can multiple operators and users, fairly and efficiently share the spectrum, and how do they interwork with licensed spectrum users.
- Support for new and more complex services: e.g. *telepresence* would be a major challenge for wireless systems; the design of intelligent/local/distributed wireless multicasting can significantly improve spectral utilization.
- Infrastructure deployment: how should systems be designed such that the equipment can provide coverage and capacity, yet be incrementally/evolutionally deployed --- and only increased when business demand justifies expansion.
- Self-configuring, ad-hoc, multi-hop networks: users operate their own “store and forward” networks and become wireless operators in their own neighborhoods [low-cost base stations, “802.11” style networking]. This calls for techniques that automate configuration, detection of other devices, creation of ad-hoc networks, devices that can control their own handovers, and management of the radio spectrum. Applicable technologies may be efficient protocols (how functions are associated with layers), smart dynamic resource allocation, adaptive antennas and efficient modulation techniques.

4G/5G Network:

Integrated Packet Data Architecture



Wireless Network and Service Evolution



Evolution driven by merging of three areas:

Wireless communications + Internet + Digital Audio/Video