

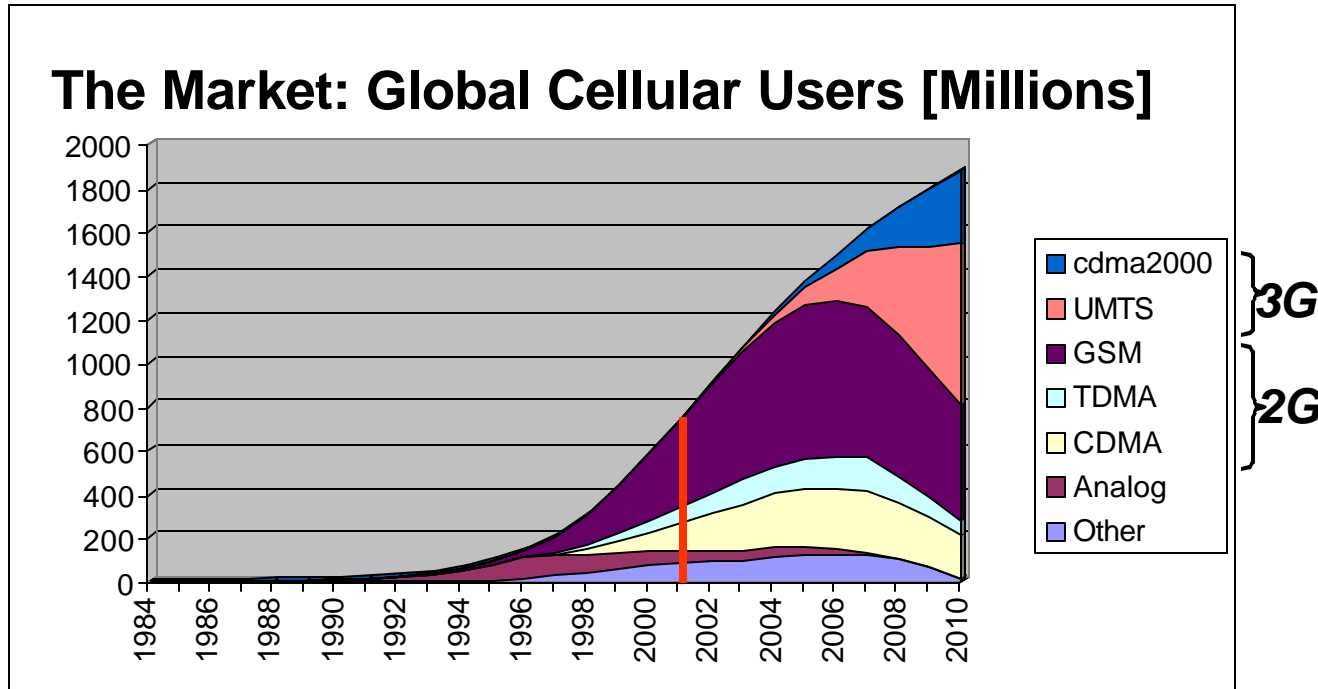
**North Jersey Chapter of the IEEE Vehicular Technology Society
Fairleigh Dickinson University
October 17, 2001**

Next-Generation Wireless Networking

**Richard D. Gitlin
Columbia University
rich@ee.columbia.edu**

Outline

- **Wireless market, current state, and trends**
- **3G: system(s), standard(s), and technology**
- **Evolution/Revolution from a circuit to a mobile IP [MIP] network**
- **Research issues in achieving a reliable MIP network for isochronous [i.e., voice, video] traffic**
- **A look at the wireless future: 4G**



- **View of the cellular market at the beginning of 2001**

- Cellular subscribers well past the 500 million mark, wireless projected to outnumber fixed-service around 2005. Currently, mostly voice users.
- In 2000, Japan, Finland, and Israel had more mobile than fixed subscribers.
- By 2003 likely more cell phones than PCs will be connected to the Internet! (Data growth spurred a planned build out of 3G *packet-based* networks)

- **Current Market State: “Irrational exuberance” has turned to “rabid pessimism”**

- Fundamental imbalance between expenditures on spectral licensing [especially in the EU], planned capital expenditures on an almost totally new 3G infrastructure [\$~100 per user versus \$10 per user for a 2.5G upgrade], and projected service revenues
- Voice minutes growth spurred by dropping prices, but revenue growth remains small

Global Changes Impacting Wireless Networks

- ***Deregulation*** forcing new forms of competition.
- ***Social Trends*** promoting data applications (e.g., Virtual Office, Internet, Location-based Services, Electronic Money).
- ***Seamless Access*** from merging of wireless and wireline Services.
- ***Spectrum*** continuing to be scarce and expensive.
- ***Services and Technologies*** deployed at accelerating pace.
- ***Miniaturization*** making anytime, anyplace deployment practical.

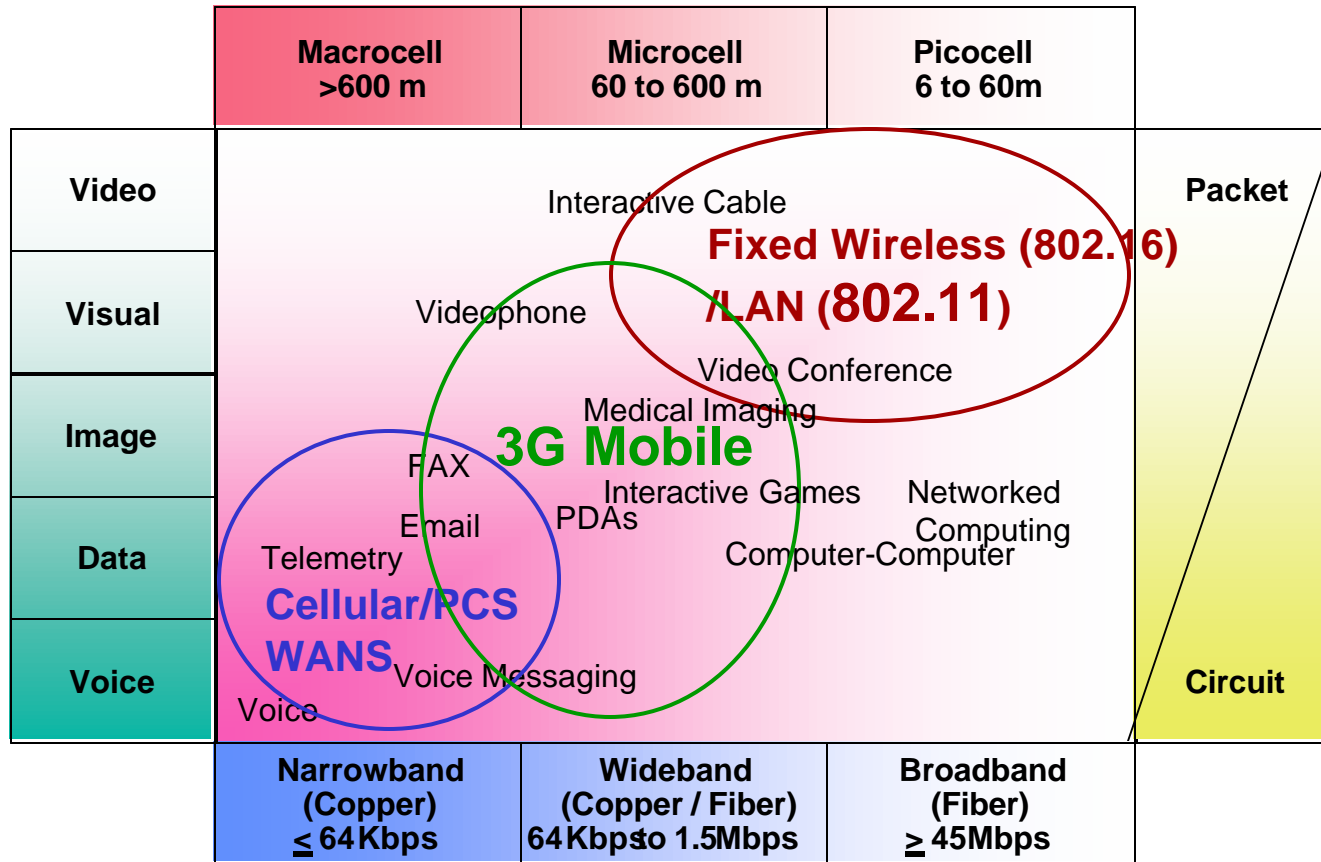
Exemplified by the success of the NTT DoCoMo *mobile internet i-mode* service.

Evolution From 2G to 3G/4G Networks: It will be a *Packet* world

	2G (2000)	EARLY 3G (2001)	LATE 3G (2003)	4G (2005)
AIR INTERFACE				
VOICE	CIRCUIT	CIRCUIT	CIRCUIT	PACKET
DATA	CIRCUIT	PACKET	PACKET	
ACCESS NETWK				
VOICE	CIRCUIT	CIRCUIT	PACKET	PACKET
DATA	CIRCUIT	CIRCUIT		
CORE NETWK				
VOICE	CIRCUIT	PACKET	PACKET	PACKET
DATA	OVERLAY PACKET			

3G and Beyond Evolution Driven by Merging of: Wireless communications + Internet + Digital Audio/Video [Content]

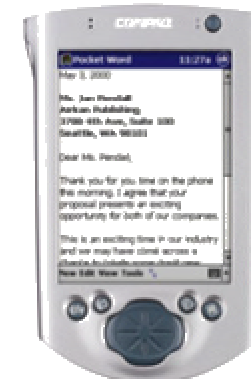
Data Rates for Wireless Services are Increasing and will keep increasing



3G: UMTS[W-CDMA] and CDMA2000

- High-Speed Packet Data (~384 Kbps for mobile and 2 Mbps indoors)
- Simultaneous Circuit Voice and Packet Data
- IP Backbone for Core Network

3G Prototype Terminals: some will not have keypads, but will operate like PDAs [with voice capability]



Compaq [PDA]

iPACK H3600

- Add voice
- Access via 3G and/or 802/11

A GSM handset now takes about 250,000 flops [floating-point operations per second and a 3G handset is going to take ~ 12 megaflops — a Cray computer in 1984!

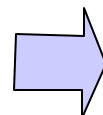
3G: Towards a Wireless Multimedia Society

**Global standard
(worldwide travelers)**

**Multimedia services
(Internet)**

- It is expected that data traffic will exceed voice traffic in 2003

**Increased capacity
(consistent growth
of markets)**



3G System(s)

- New wideband wireless access technique incorporates many technological achievements.
- DS-CDMA [Direct Sequence Code Division Multiple Access] is quite flexible in providing multi-rate services, support for *packet* mode, and very effective in combating multipath fading.

3G Global Vision: Key Goals and Some Business Challenges

- Quality of Service
 - Quality, coverage, and cost are three issues rated by customers as most important
- New Services and Capabilities
 - Integrated voice, data and video; bandwidth on demand
- Flexibility: Multi-Environment, Multi-Mode, Multi-Band Capabilities
 - Seamless roaming by mobile terminals
 - Flexible control and service negotiation
- Minimal Impact on Existing Spectral Utilization
- Evolution and Migration Capabilities
- System Coverage, Capacity and Billing
 - Complex calculation for Coverage and Capacity
 - Coverage will vary with data rate
 - Kbyte/\$ instead of minutes/\$?
- Capacity may be calculated based upon
 - Voice channels only
 - Data only
 - Mix of voice and data

Global Partnership Projects

- **Two Global Partnership Projects (GPP) were established in late 1998 to develop regional intra-system standards for 3G systems: 3GPP and 3GPP2**
- **3GPP is developing 3G standards for the evolution of GSM-MAP and the UTRAN (UMTS Terrestrial Radio Access Network) using *W-CDMA* [Wideband CDMA]**
- **3GPP2 is developing 3G standards for the evolution of ANSI-41 based networks and the **Cdma2000** air interface**

3G Commercialization Arenas: The Market Segments

- High data rates
- Multimedia capabilities
- Global roaming
- Land-line QoS
- Low cost to user

3G Services

- General Communication
- Entertainment
- E-Commerce
- Travel

3G Network

3G Terminals

- Wide variety
 - PDAs, palmtops, laptops
 - Smart phones
 - Dual/Triple Mode
 - Software Radio
- Low Cost

DoCoMo "i-mode" Services in Japan (a preview of 3G services)

As of April 2001, there are 20 million customers who pay \$3 a month plus \$0.003 per packet; in addition there are premium sites that charge an extra \$1-5 per month. Customers are provided useful applications with an easy-to-use interface and home pages driven by a user profile database to facilitate user accessibility to IP web sites.

DoCoMo "i-mode" Services:

Call (PDC)

E-mail

Transactions

- Reservations for flights, accommodations
- Banking
- Stock trading



めざすは、モバイルの頂点。
インターネットザウルス「アイクルーズ」誕生。



Database Access

- Town page
- Restaurant guide
- Dictionary
- Public transportation info.
- Cooking recipes, etc.

Lifestyle Information

- Weather
- News
- Local information
- Stock information

Entertainment

- Karaoke
- Network gaming
- Movie listings
- Fortune-telling

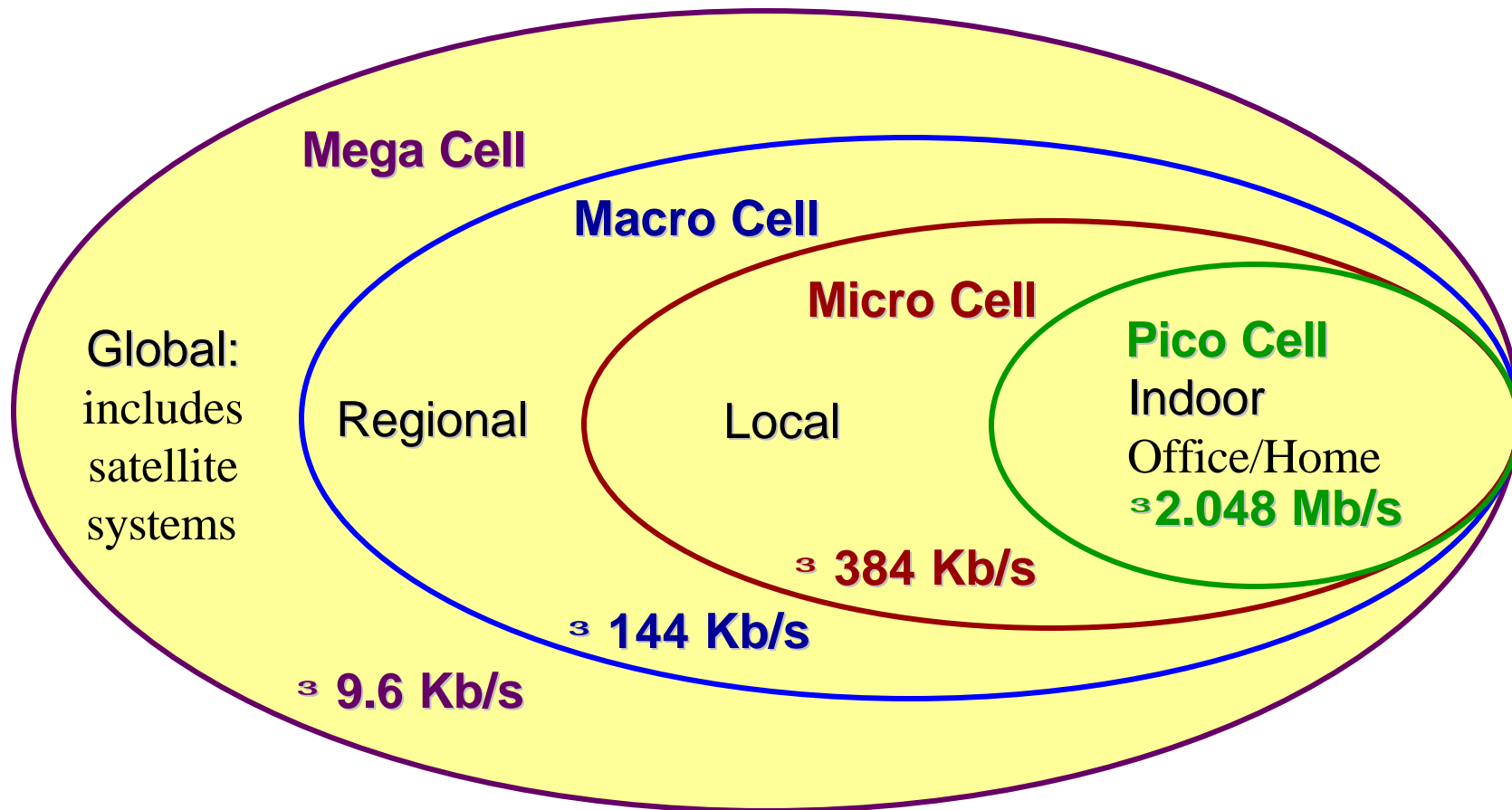
Internet Web Sites

Information Bill Collection System for IP

Portal Service based on User Profile DB

Entertainment (41%), E-mail(21%), and mobile banking (16%) most popular

ITU's IMT-2000 Requirement for Minimum Data Rates



- IMT-2000 User Requirements
- High data rates: bandwidth on demand
 - Integrated voice, data, and video: QoS, BW on demand
- Backward compatibility and co-existence with 2G
- Global roaming: terrestrial and satellite networks
- Toll quality voice: higher capacity at lower cost
- Light-weight terminals: low power and long talk time
- High security

UMTS QoS [Quality of Service] Classes

Traffic Class	Conversational	Streaming	Interactive	Background
Fundamental Characteristics	Preserve time relationship (variation/jitter/low delay) between information entities	Preserve time relationship (variation) between information entities	Request-response pattern Preserve data integrity (errors)	Little or no time expectations on delay Preserve data Integrity
Example Application	Voice, videotelephony, and video games	Streaming multimedia	Web browsing and network games	Background download of e-mails

UMTS allows a user/application to negotiate bearer characteristics that are most appropriate for carrying information. It is also possible to change bearer properties, via a bearer re-negotiation procedure in the course of an active connection. Bearer negotiation is initiated either by the application or the network (upon handoff)

Main WCDMA [UMTS] Parameters

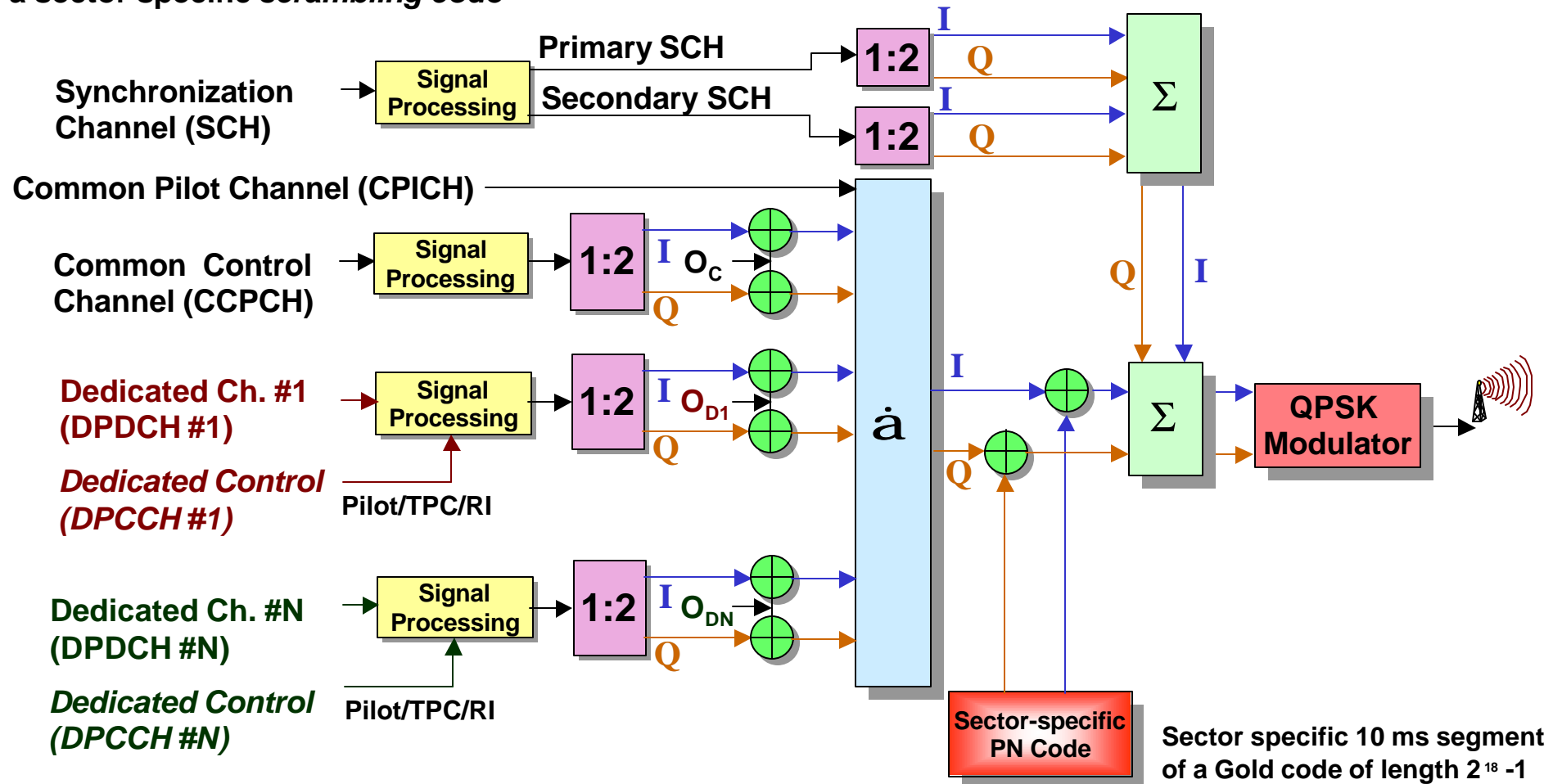
Multiple Access Method/Mode	DS-CDMA/ Circuit or Packet (based on GPRS)
Duplexing Method	<ul style="list-style-type: none"> • FDD [5 MHz carriers up and down links] • TDD [single 5 MHz carrier shared between up and down links ---designed for unpaired bandwidth allocations]
Base Station Synchronization	Asynchronous [no need for GPS as in IS-95]
<ul style="list-style-type: none"> • Chip Rate • Pulse Shape • Modulation 	<ul style="list-style-type: none"> • 3.84 Mcps [0.26μs , which corresponds to a path length difference of at least 78m \rightarrow works in microcells] • Raised cosine (22% rolloff) • QPSK
Pilot Structure	<ul style="list-style-type: none"> • Reverse link:Dedicated I/Q-multiplexed pilots • Forward link:Dedicated time-multiplexed pilots <ul style="list-style-type: none"> • Common pilot channel (CPICH)
Frame Length	10 ms, with 15 slots per frame [longer period for the sytem frame period with a 12-bit system frame number]
Service Multiplexing	Multiple services with different quality of service requirements multiplexed on one connection
Channel Coding	Voice: Convolutional code (R = 1/3, K = 9) Data: Turbo code (R = 1/3, K = 4)
Multirate Concept	Variable spreading factor and multicode
Detection	Coherent detection on uplink and downlink using pilot symbols or common pilot
Multiuser Detection, Smart Antennas	Supported by the standard; optional in the implementation

W-CDMA and CDMA2000: Similarities and Differences

	UMTS	CDMA2000
Chip rate Frame length Physical layer control info	3.84 Mc/s 10ms [speech interleaved over 20 ms] control information in DPCCH	3.6864 Mc/s [direct spread] 20ms control info carried via in-band signaling on the fundamental channel [cannot alter parameters on a frame basis]
Transport/Logical Channels	Transport Channels	Logical Channels
Physical Channels [have much the same functionality, but some differences]	<ul style="list-style-type: none"> • Common Channels • Downlink shared channel 	<ul style="list-style-type: none"> • No direct counterpart [implemented differently] • Supplemental channel [for data]
MS/BS link terminology	Downlink/Uplink	Forward/Reverse
Uplink Spreading and Modulation [modulation is very similar]	<ul style="list-style-type: none"> • Spreading: OVSF codes • Variable rate • Code period = 256- 38.4 Kchips [but 2^{15} chips for access channel] 	<ul style="list-style-type: none"> • Spreading: Walsh Function • Variable rate not used with Walsh Functions • $2^{42} - 1$ [much greater]
Downlink Spreading and Modulation	<ul style="list-style-type: none"> • Direct Spread • Scrambling: single code entire system 	<ul style="list-style-type: none"> • Multi-carrier [terminal can demod them all] • Scrambling: different codes per cell
Uplink Data Transmission	<ul style="list-style-type: none"> • Data rates from 15 kbps to 5.7 Mbps [on same channel] 	<ul style="list-style-type: none"> • Maximum rate on fundamental channel is 14.4 kbps -additional data is carried on the Supplemental Channel(s)
Downlink Data Transmission	<ul style="list-style-type: none"> • Dedicated channel: DPDCH • Power control via DPCCH 	<ul style="list-style-type: none"> • User data is divided between three parallel CDMA sub-carriers [lower data rates on the Fundamental Channel, and higher rates on the Supplemental Channel • Power control via puncturing the data stream [800 bps] ---uplink power control muxed with pilot channel.

W-CDMA Forward Link: Simplified Block Diagram

On the downlink multiple codes are transmitted with possibly different spreading factors for the different DPCHs depending on the service. Spreading is performed by the *channelization codes*, O_C and O_{Di} , and by a sector-specific *scrambling code*



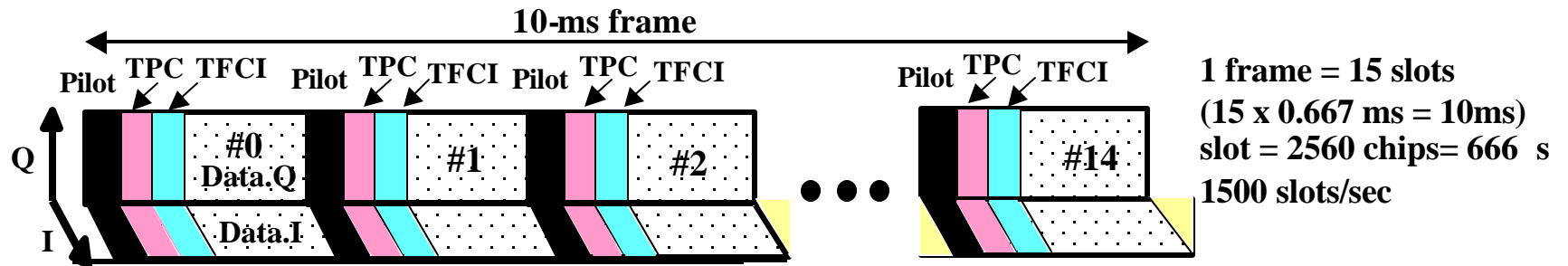
CCPCH: Common Control Physical Channel
 DPCCH: Dedicated Physical Control Channel
 RI: Rate Information

DPDCH: Dedicated Physical data Channel
 TPC: Transmit Power Control
 O_{CD} : orthogonal variable spreading factor codes (OVSF)

W-CDMA Physical Channels

Forward/Downlink

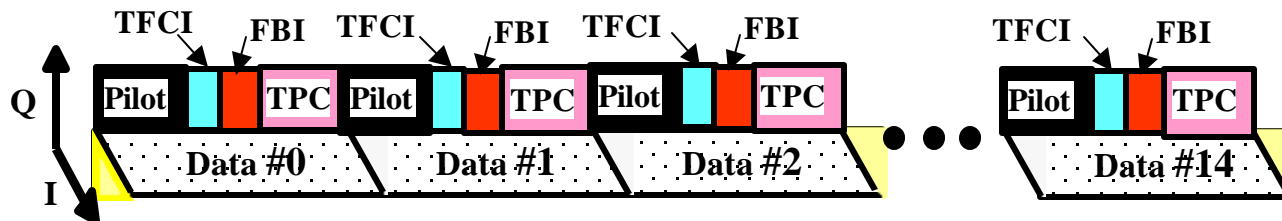
Common pilot channel and Dedicated time-multiplexed pilot



- Dedicated pilot may be applied to smart antennas

Reverse/Uplink: I/Q-multiplexing of DPDCH and DPCCH

[the 10 ms frame corresponds to one power control period]

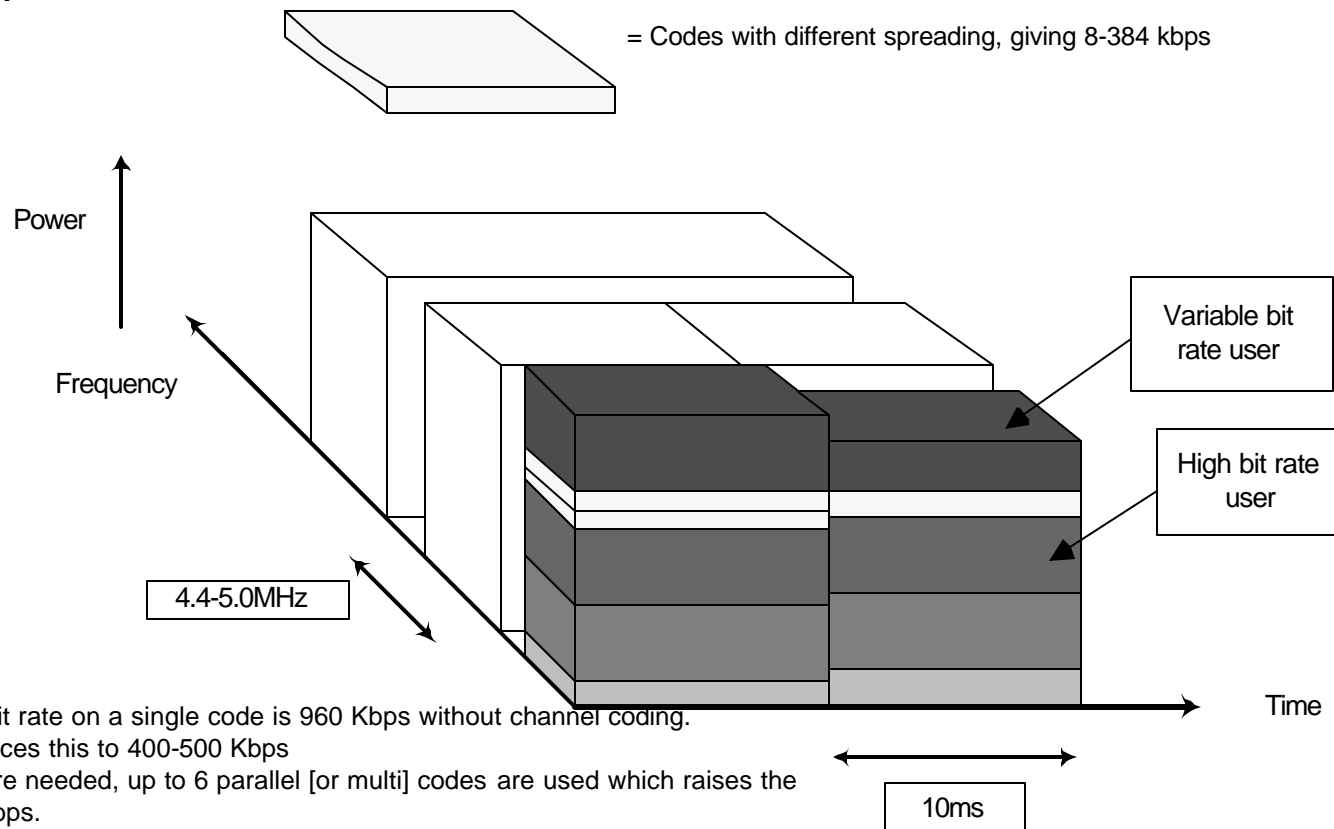


Pilot bits with a known sequence are similar to the training sequence/midamble bits in GSM) and are used for channel estimation in the receiver

TPC: Transmit Power Control
TFCI: Transport Format Combination Indicator
FBI: Feedback Information [0,1, or 2 bits]

Packet Scheduling Algorithms: The Time-Frequency-Code Space

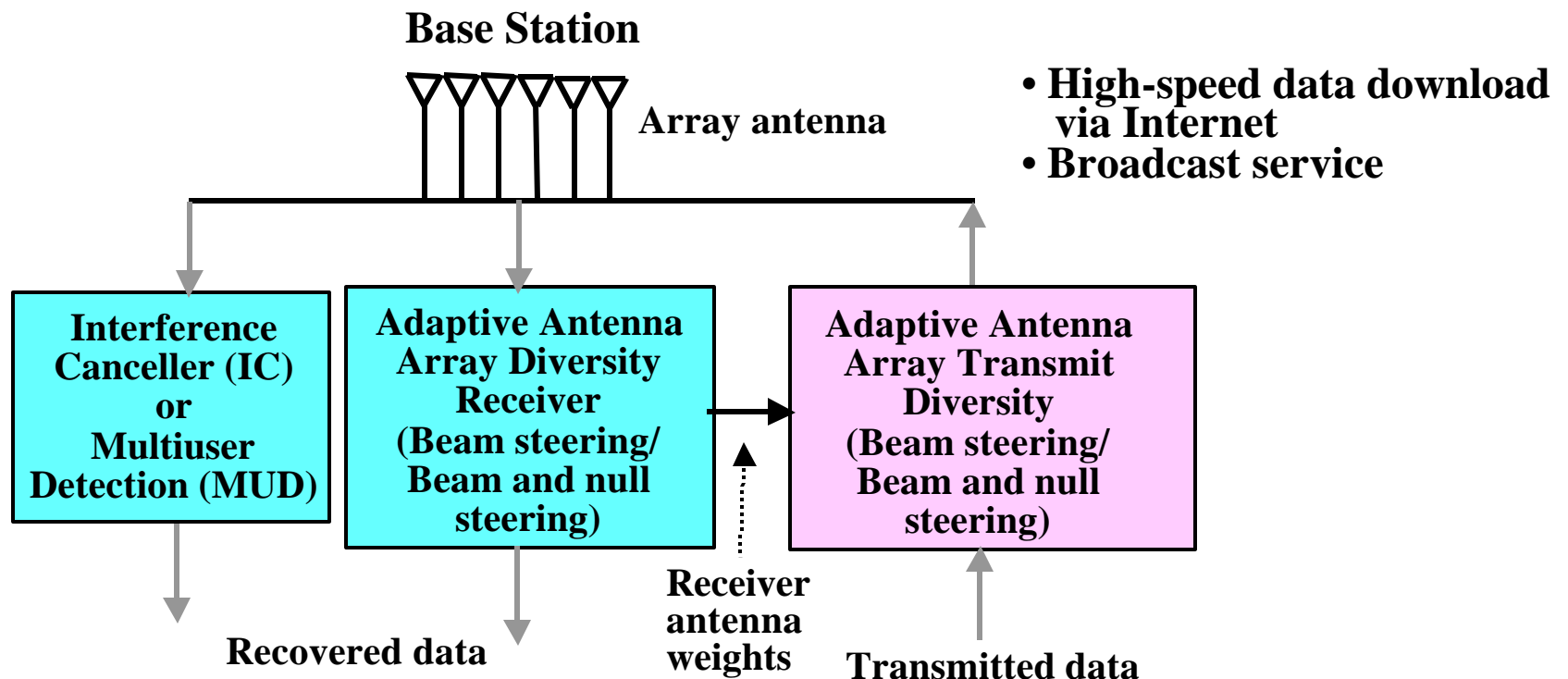
- The packet scheduler shares the available air interface capacity between packet users and decides the allocated bit rates and the length of the allocation.
- In WCDMA this can be done in two ways
 - code division: a large number of users can have a low bit rate channel available simultaneously (when the number of users increases, then then the bit rate for each user decreases).
 - time division: capacity is given to only one user at each instant of time (when the number of users increases, then each user has to wait longer for transmission in the 10ms frame).
 - In practice, packet scheduling is a combination of the time and code division approaches shown below



- The maximum user bit rate on a single code is 960 Kbps without channel coding.
- Channel coding reduces this to 400-500 Kbps
- When higher rates are needed, up to 6 parallel [or multi] codes are used which raises the coded rate to > 2 Mbps.

W-CDMA Capacity Enhancing Technologies

- Orthogonality in same path is maintained by new OVSF codes; however suppression of multipath interference, especially from high rate users, will accommodate a larger number of high bit-rate users.



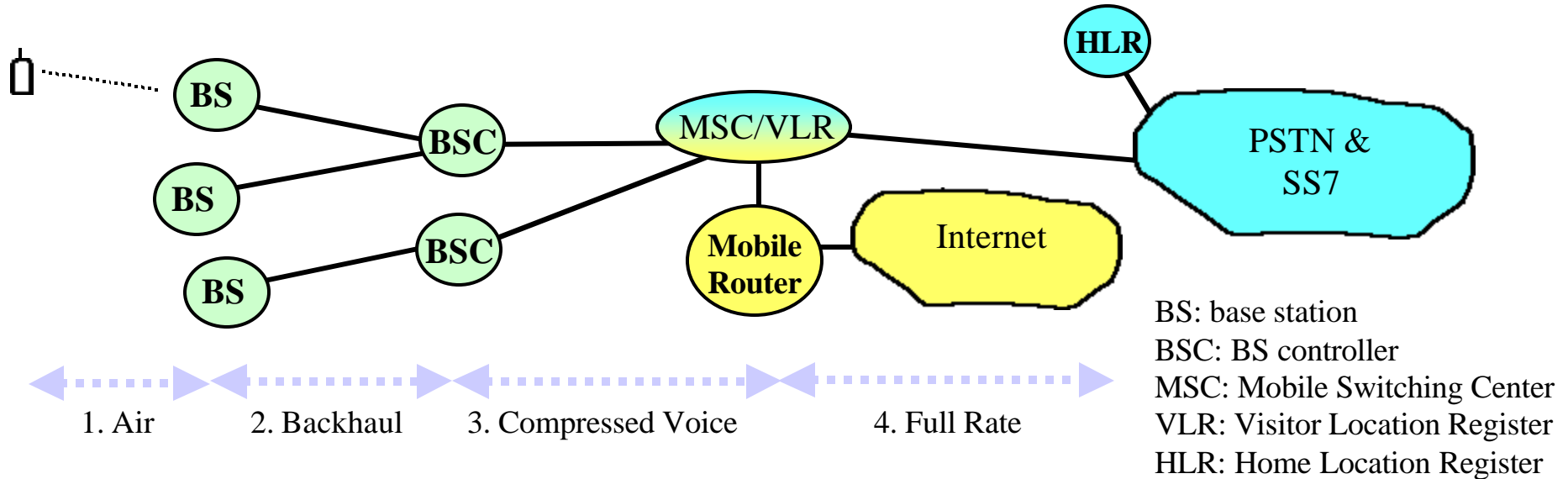
The Migration Path to an All-IP Mobile Network

- **Goal: migrate wireless mobile access and backbone networks to IP**
 - Support the anticipated explosive growth of the wireless Internet
 - **merging of services for wireline and wireless networks**
 - **merging of wireless voice and data networks**
 - Reduced product and operational costs of IP infrastructure
 - **increased efficiency of packet-based networks for combining voice and data**
- **Technical Challenges: beyond those associated with non-mobile wired IP nets**
 - Transport:
 - **quality of service: loss, delay, jitter, and disconnection --- particularly during handoffs**
 - **real-time mobility management**
 - **support for wireless specific services**
 - Signaling and Control:
 - **network reliability approaching that of PSTN when dealing with failures of mobility management systems**
 - **transparent personal and device mobility**
 - **Internet call control**

Next-Generation Wireless Networks: Architectural Principles

- **Embrace internet technologies and services: uniform adoption of IP technology, rapid service creation, and global alignment/standardization**
- **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
- **Open Interfaces**
 - APIs
 - RAN (radio access net) internal interfaces, core network interfaces: SW radios
- **Independence from wireless access technology (2G/3G, W-CDMA/cdma2000, 802.11?)**
 - End-to-end IP transport of traffic and control
- **Performance, Quality, Reliability: End-to-end QoS mechanisms**
- **Security: mutual authentication, confidentiality, and non-repudiation**
- **Distributed, scalable architecture**
 - Intelligence distributed in the network and end points
- **OA&M: Standardized, compatible network management interfaces**

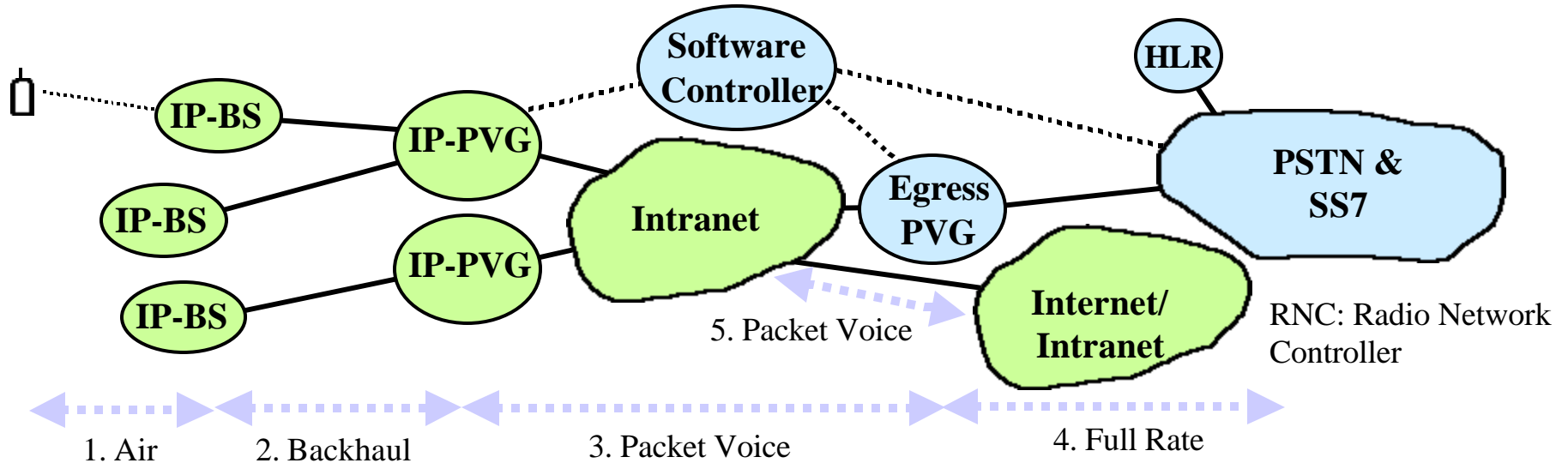
Evolution/Revolution: From Today's 2G Circuit Network



- Link 1: Air Interface
 - compressed voice (8Kbps) on “dedicated” (circuit)channel
 - data on packet channels (but carried on circuit)
- Link 2: Backhaul
 - compressed voice multiplexed on sub-rate circuits
- Link 3-4: Central Office
 - MSC performs *voice coding*, *soft handoff* functions
 - full rate voice switched at MSC to the PSTN
 - data split to mobile router

- - voice and data
- - packet data
- - circuit voice

All-IP Wireless Network



- Link 1: Air Interface

- compressed voice (8Kbps) on “dedicated” channel or packet-over-air
- data on packet channels

- Link 2: Backhaul

- aggregated, compressed IP voice multiplexed with data
- core network uses IP Mobility instead of tunneling
- IP-PVG performs *soft handoff* function

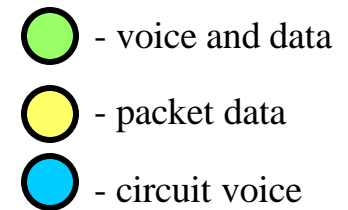
- Link 3: Packet Voice

- Internet voice session to Egress PVG
- Egress PVG performs voice coding

- Link 4

- full rate voice switched at Egress PVG to the PSTN

- Link 5: Packet voice or data to Internet



All IP Wireless Network Architecture

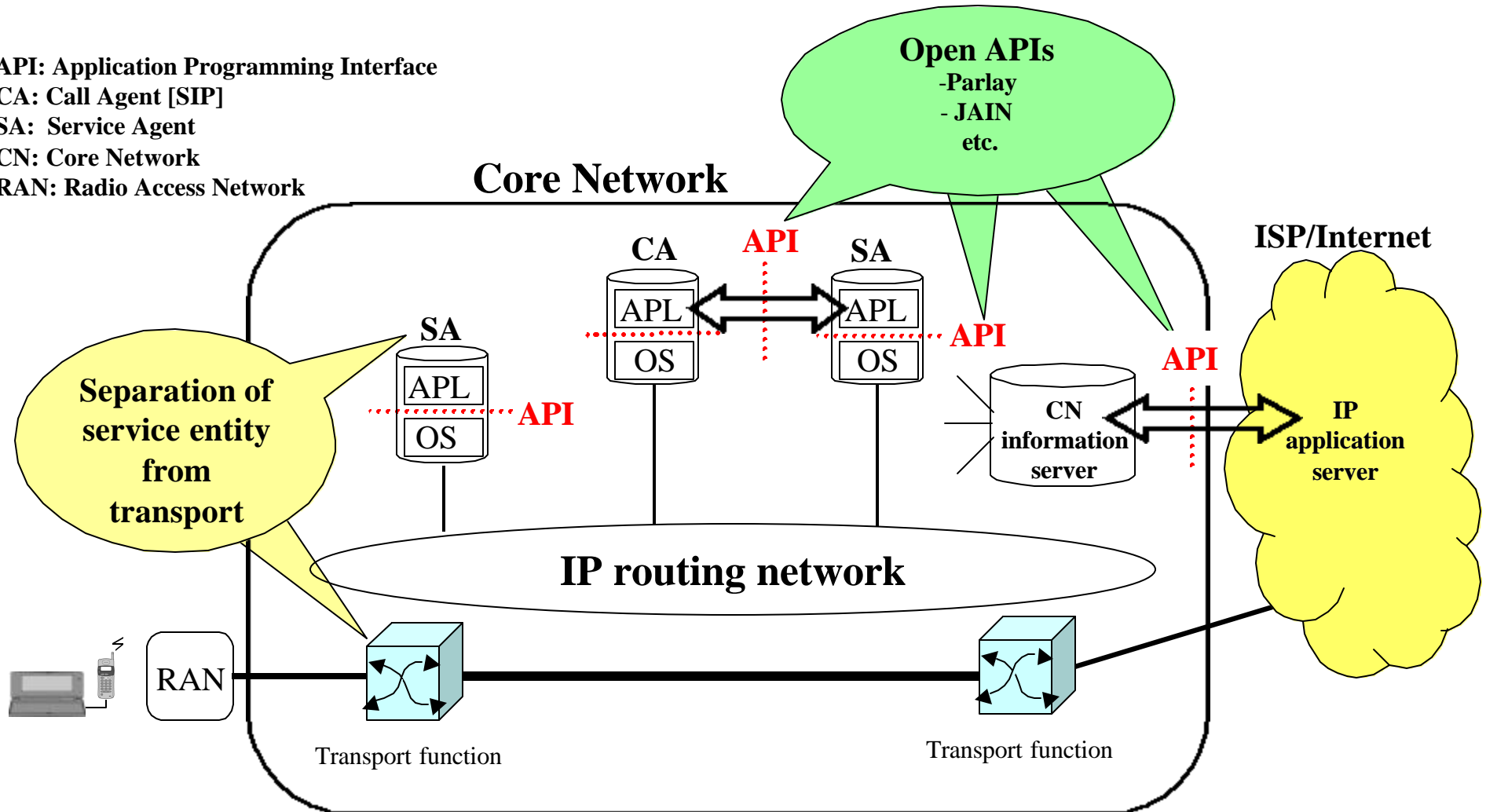
API: Application Programming Interface

CA: Call Agent [SIP]

SA: Service Agent

CN: Core Network

RAN: Radio Access Network

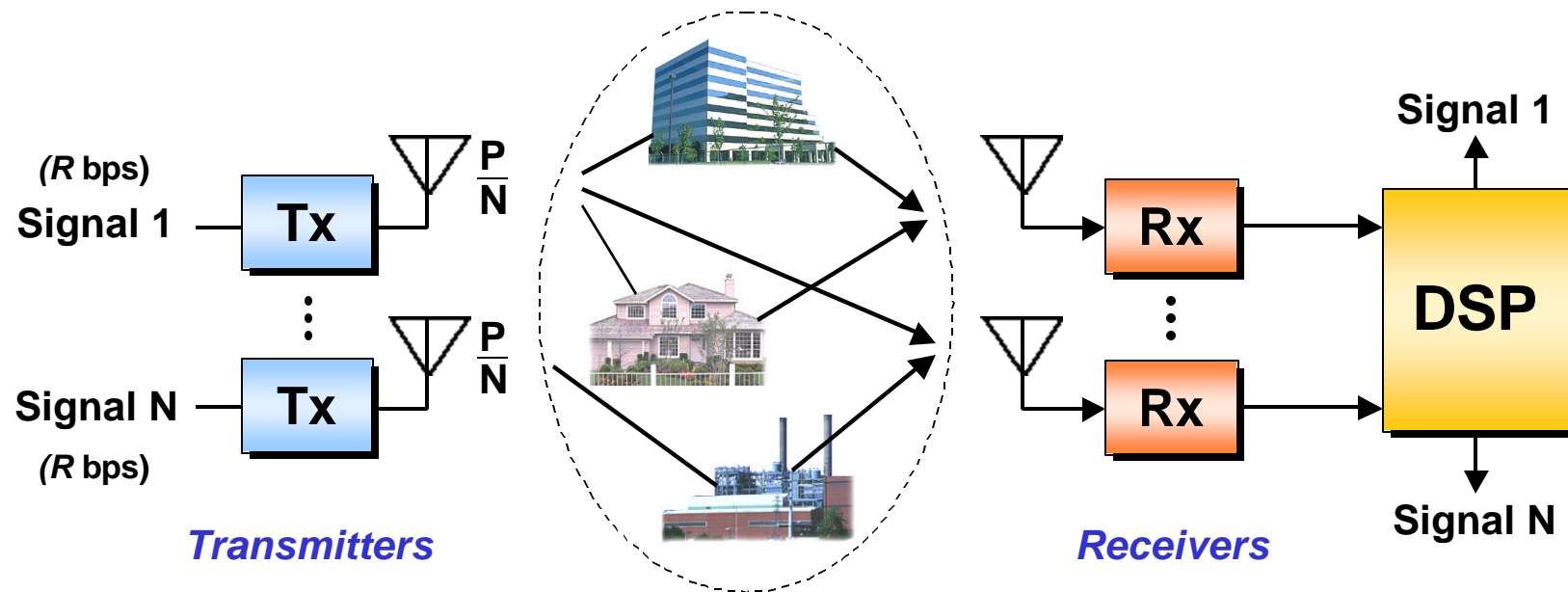


Goal: An open mobile wireless internet architecture that enables seamless integration of mobile telephony and internet services, that meet the needs of both network operators/Internet service providers and end users, and is independent of the access technology (2G/3G, cdma2000/W-CDMA, **802.11**(?) ...)

Next-Generation Wireless Networks: The Major Technical Challenges

- **Achieving the Bandwidth, Bit Error Rate and Packet Loss Requirements for Multimedia Services**
- ***Handoff Service Disruption [Loss and Delay]***
- **Resource Control to achieve Quality of Service [QoS]**
- **Operation/Evolution of Heterogeneous Networks and Equipment**
- ***Wireless Optimized Protocols***
- **Security**
- ***Reliable and Scalable Mobility Management***

MIMO/Smart Antenna Research

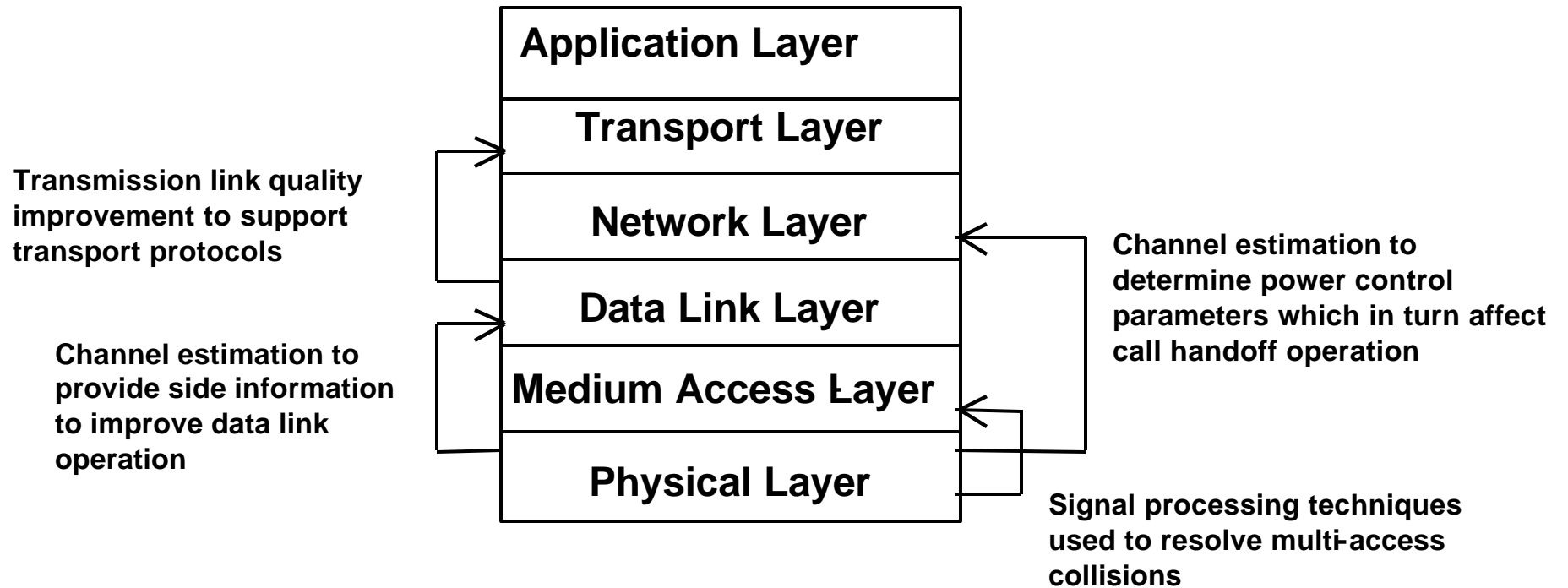


- Scattering scrambles the signals -- Each receiver has a different combination of signals
- DSP algorithm de-scrambles the received signal to reproduce original signals
- Capacity increases linearly with number of antennas with no increase in total power
- Useful in urban areas and in-building wireless

Research areas

- Couple with newer modulation [eg, OFDM]
- Explore with TDD [time division duplex], so antennas can only located at base and simplify terminal
- Use as MAC assist

Integrated Cross-Layer Research



***NeighborCasting*: Low-Latency Handoffs in Wireless IP Networks**

- **Mobile IP (RFC 2002): Defines Layer 3 handoff schemes**
 - Most-likely standard for mobility support for IP ---designed for data
 - Provides internetworking framework for wireless networks
- **Mobile IP can have large latency**
 - Large handoff latency -> Potentially large packet loss and media stream delay/jitter
- **Fast Handoffs are needed to support**
 - Real-time (isochronous/voice) applications (UDP)--- quality degrades due to packet loss and delay
 - TCP Flow Control (for data)---throughput degrades due to packet loss
- **How can we minimize service disruption for isochronous traffic during a handoff?**
 - Fast Handoff: reduce latency
 - Hierarchical Mobility Management: reduce signaling to home agent
 - Context Transfer (exchange state between between FAs): fast re-establishment of service parameters
- ***NeighborCasting*: Our approach (builds upon Mobile IP)**
 - Start data forwarding procedure right after L2 handoff decision
 - Multicast data to neighboring Foreign Agents (FAs) from old FA until L3 handoff completed
 - Dynamic, distributed neighbor FA information collection

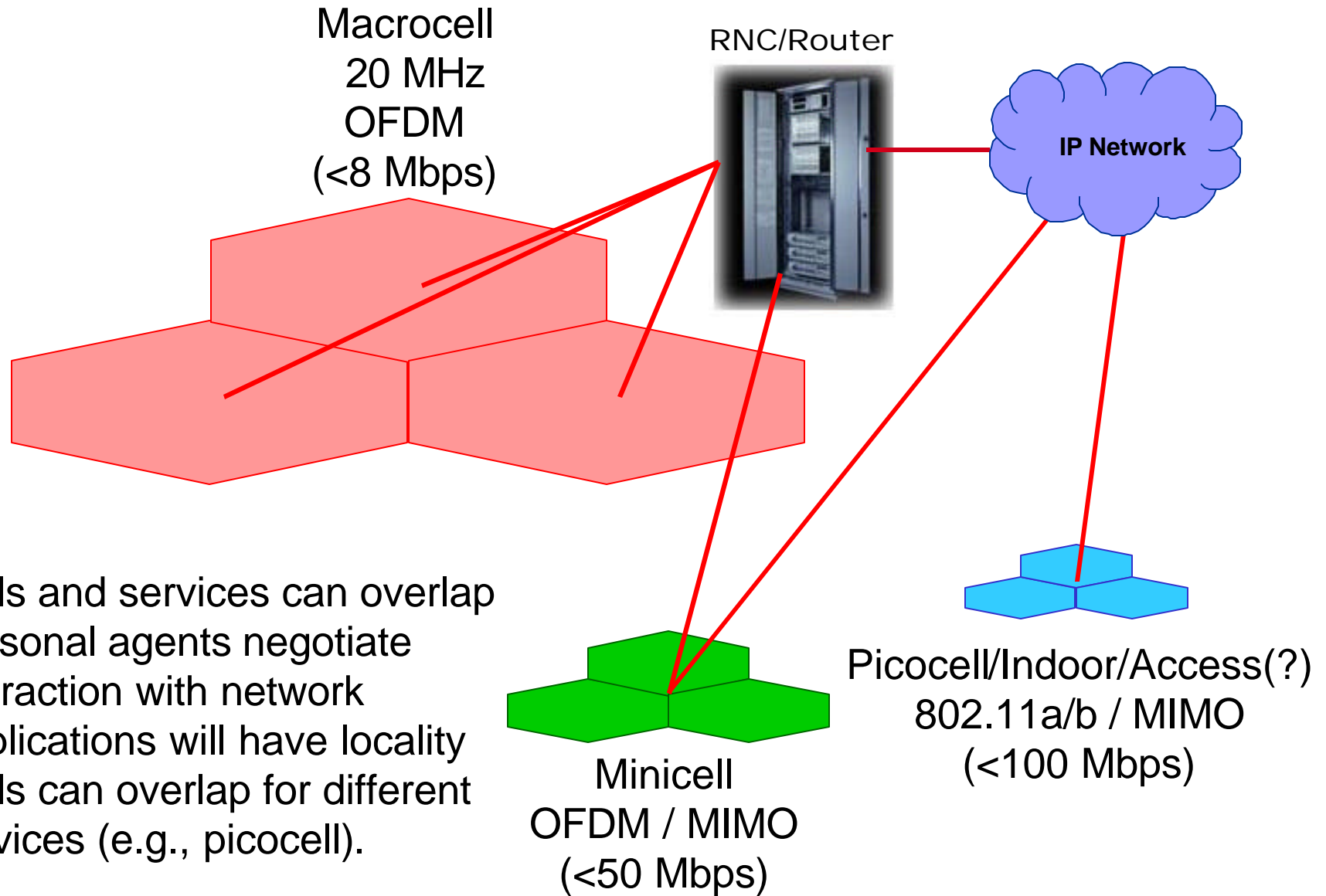
4G: Current Assumptions

- **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 [eg, scale to refrigerator, PC/TV exchanging info with a camera,]
- **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 [ie, 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 (at this point in time)

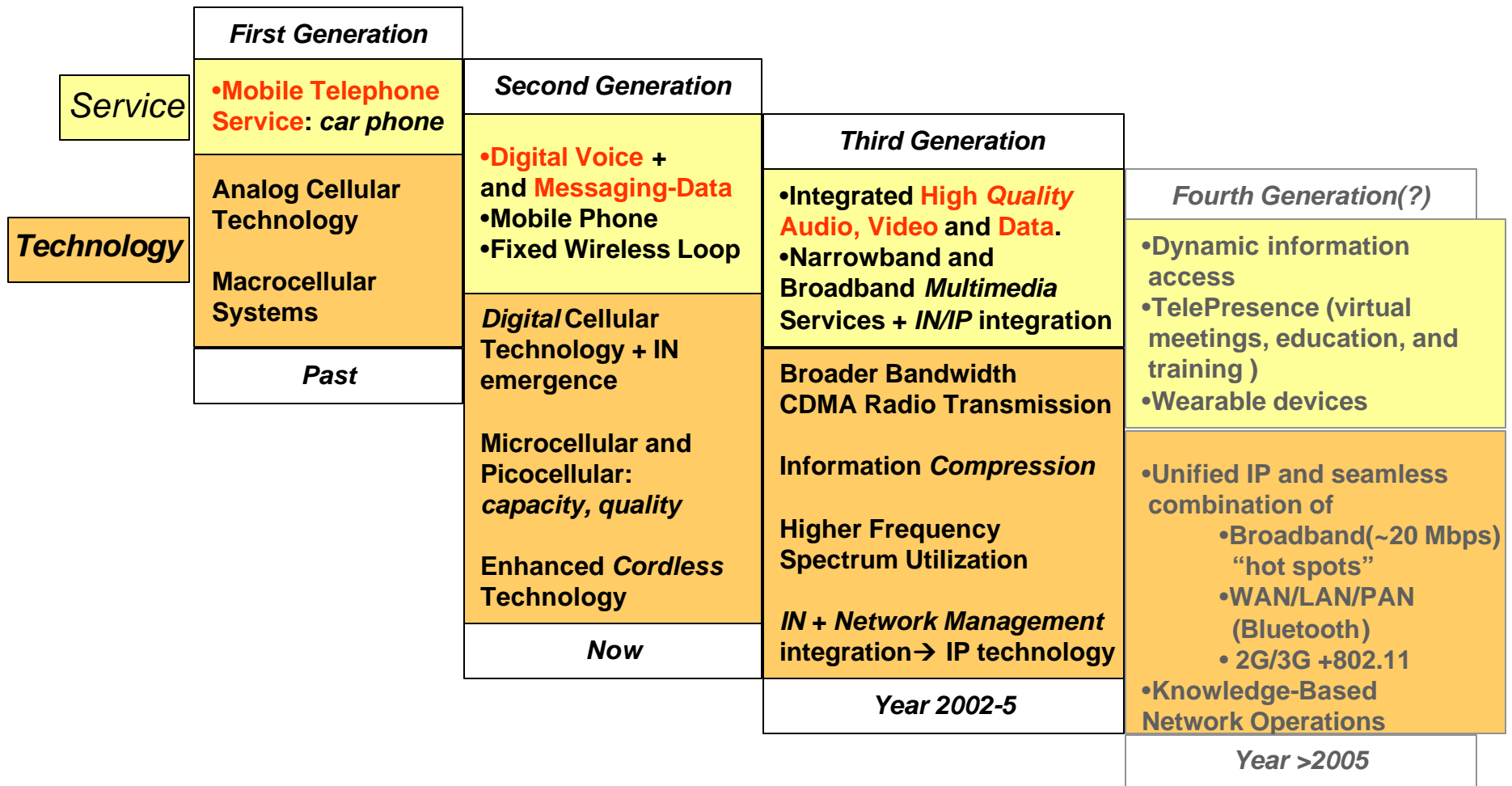
- **Terminal and service adaptability to various standards, infrastructures, bandwidths.** Requires rethinking of which layer is responsible for different functions [eg, security]. Big opportunity for SW radios and embedded network processors.
- **Unlicensed public operation:** how can multiple operators 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.

Example System coverage in 4G



- Cells and services can overlap
- Personal agents negotiate interaction with network
- Applications will have locality
- Cells can overlap for different services (e.g., picocell).

Wireless Network and Service Evolution



Evolution driven by merging of three areas:

Wireless communications + **Internet** + Digital Audio/Video