Is Wireless (Data) Dead?

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Heilmeier's Vision

"People and their machines should be able to **access** information and communicate with each other **easily** and **securely**, in any medium or combination of media -- voice, data, image, video, or multimedia -- **any time**, **anywhere**, in a **timely**, **cost-effective** way." G. Heilmeier, 1992

- Access
  - Internet connectivity
- Anytime, Anywhere
  - Wide-Area Coverage
  - Scalable Processing
  - Highly Available Operation
- Easily
  - Transparent Access
  - Localized Service
- Securely
  - Global Authentication
- Any Medium
  - Multimedia: AV/Graphics
- Timely
  - Performance
- Cost Effective
  - Heterogeneous Support via Proxies

Marconi's Vision

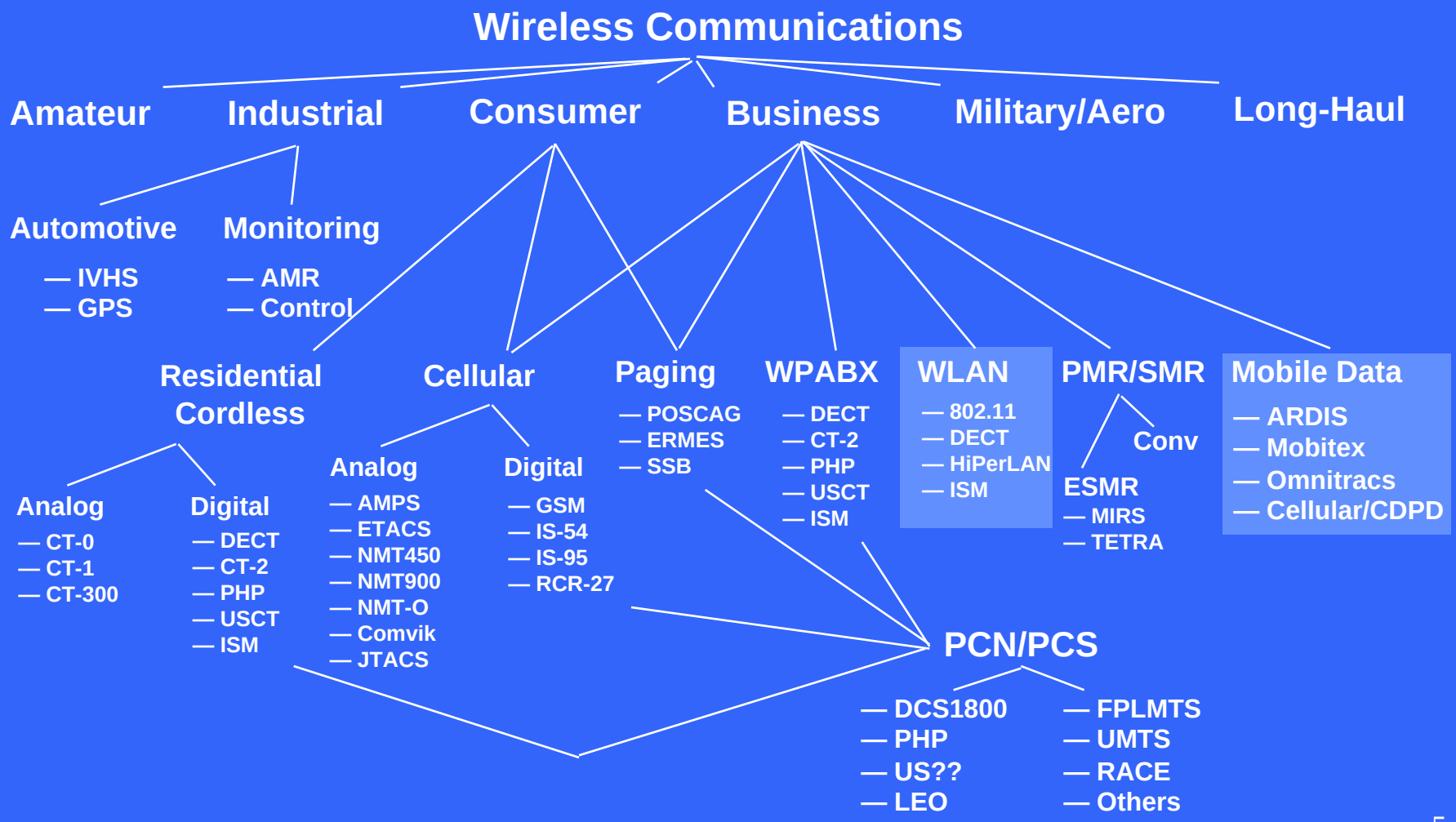
"It is dangerous to put limits on wireless."

Guglielmo Marconi (1932)

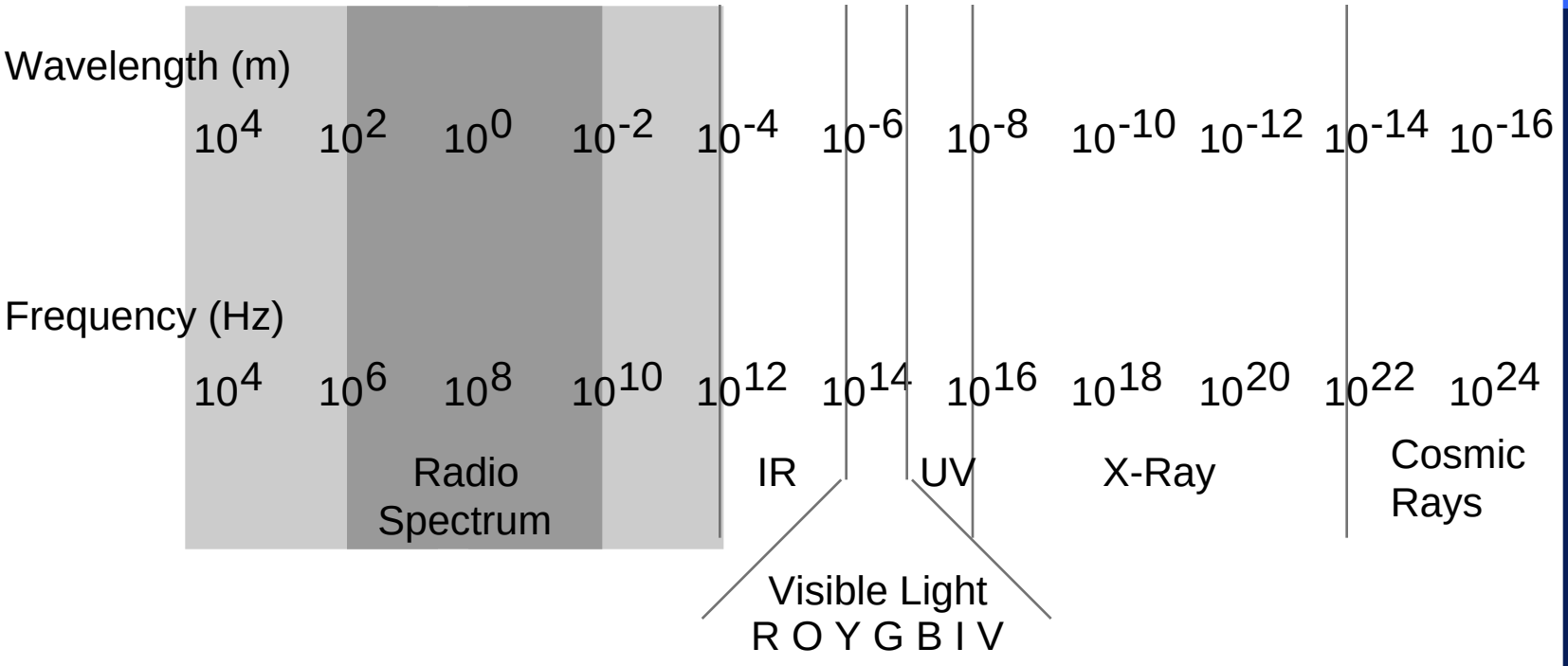
Presentation Outline

- Wireless Definitions and Trends
- Wireless Telephony
- Quo Vadis Wireless Data?
- Access is the Killer App!
- Summary and Conclusions

The Wireless Universe



Radio Basics



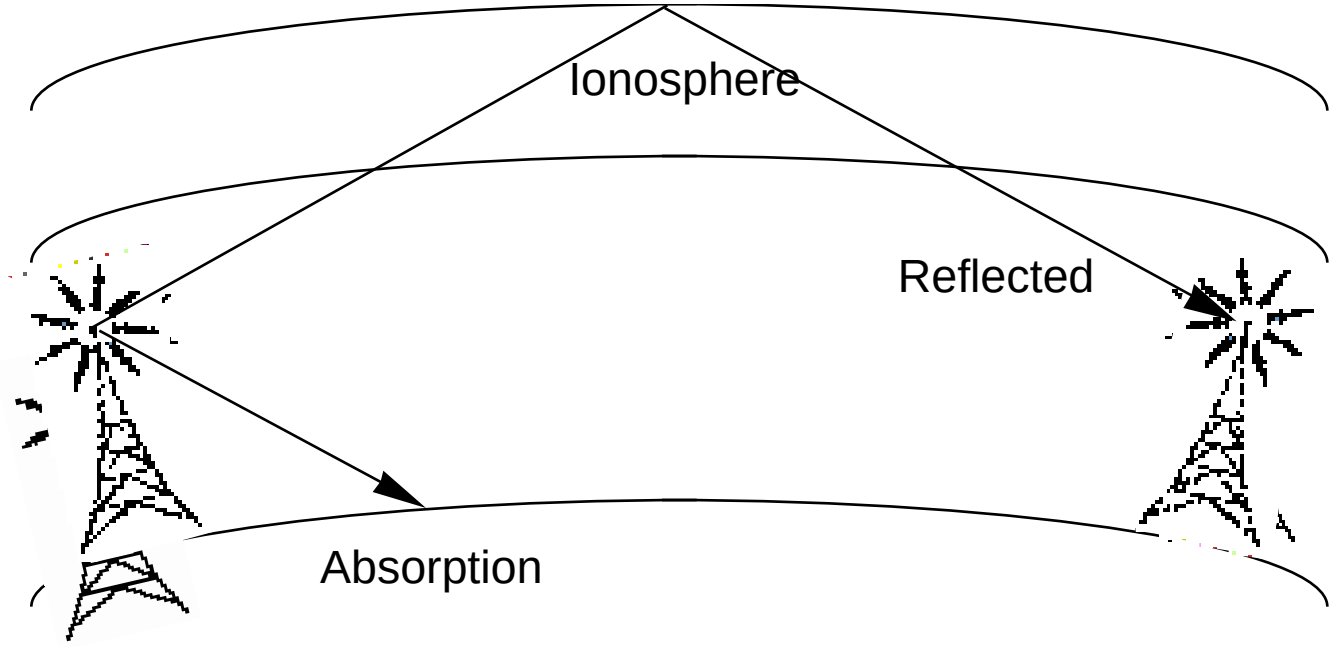
Speed of Light = $\lambda * f = 3 \times 10^8$

AM Radio	1 MHz	300 m	≈1000 ft
FM Radio, TV	100 MHz	3 m	≈10 ft
Cell Phone	1 GHz	30 cm	≈1 ft
Satellite	10 GHz	3 cm	≈1 in

< 30 KHz	VLF
30 - 300 KHz	LF
300 KHz - 3 MHz	MF
3 - 30 MHz	HF
30 - 300 MHz	VHF
300 MHz - 3 GHz	UHF
3 - 30 GHz	SHF
> 30 GHz	EHF

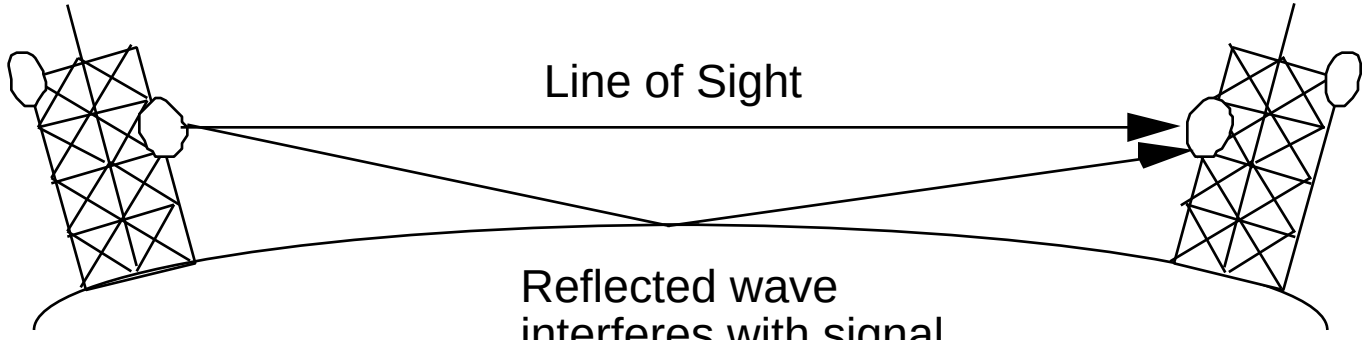
Radio Basics

HF Transmission

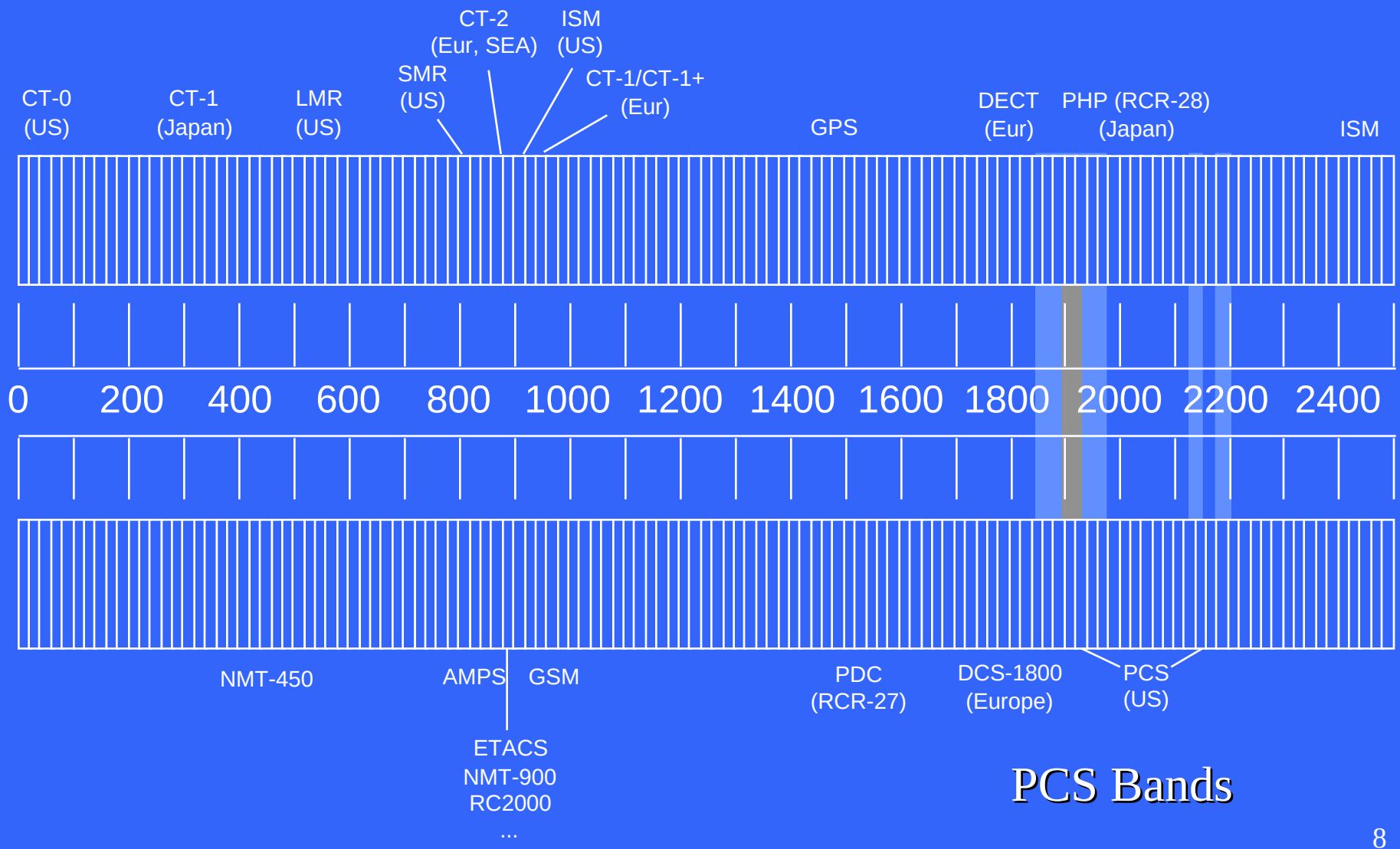


Directional Antenna

VHF Transmission



Wireless Spectrum



PCS Bands

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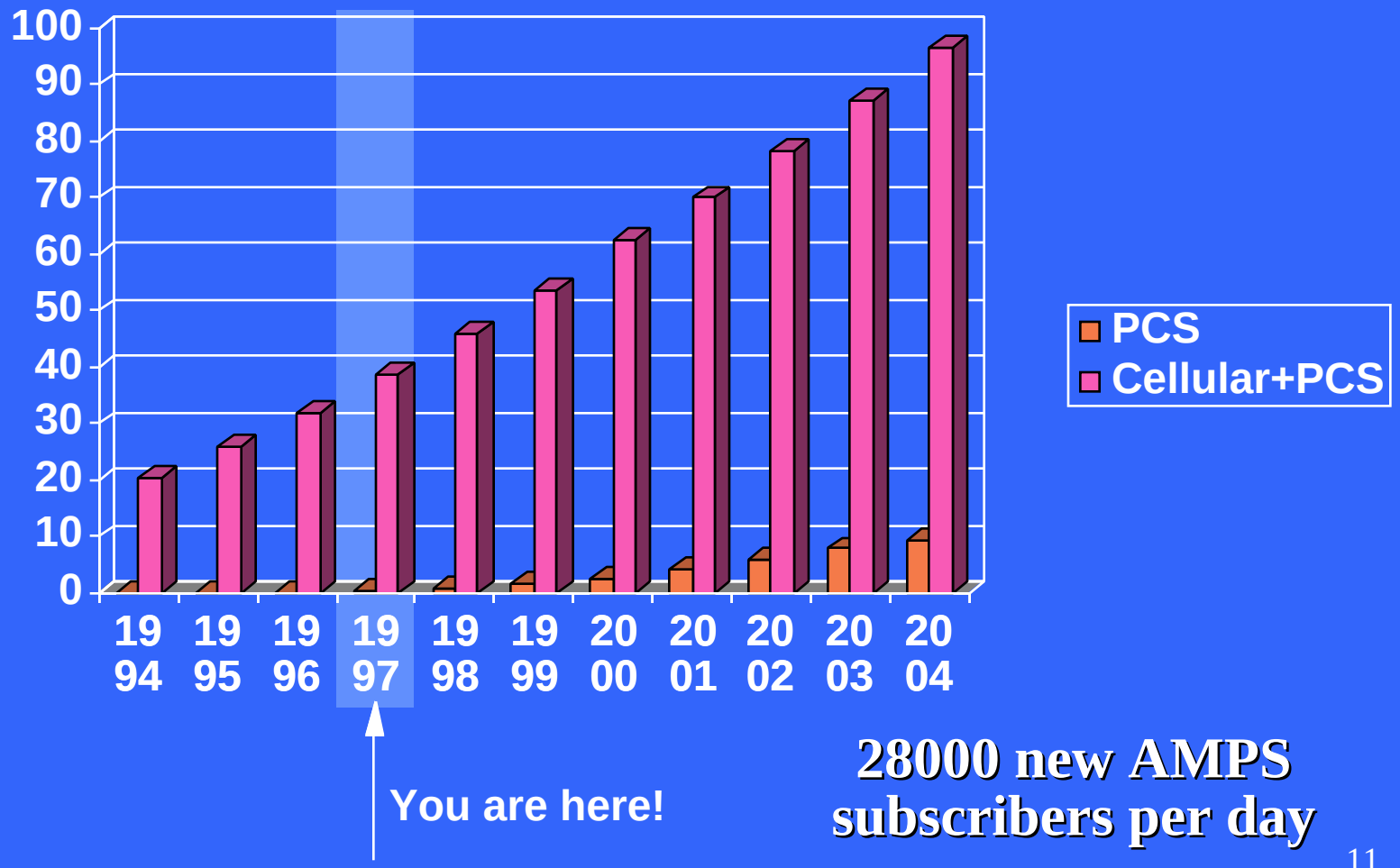
Wireless Telephony not Dead!

- Exploding Cellular Voice Services
  - Approximately 40 million subscribers in US
  - Roughly half of the world's cellular users
  - Similar number of paging subscribers in US

  - $7 billion in primary PCS license auctions
  - $10.2 billion in secondary PCS auctions

Proliferation of Wireless Telephony

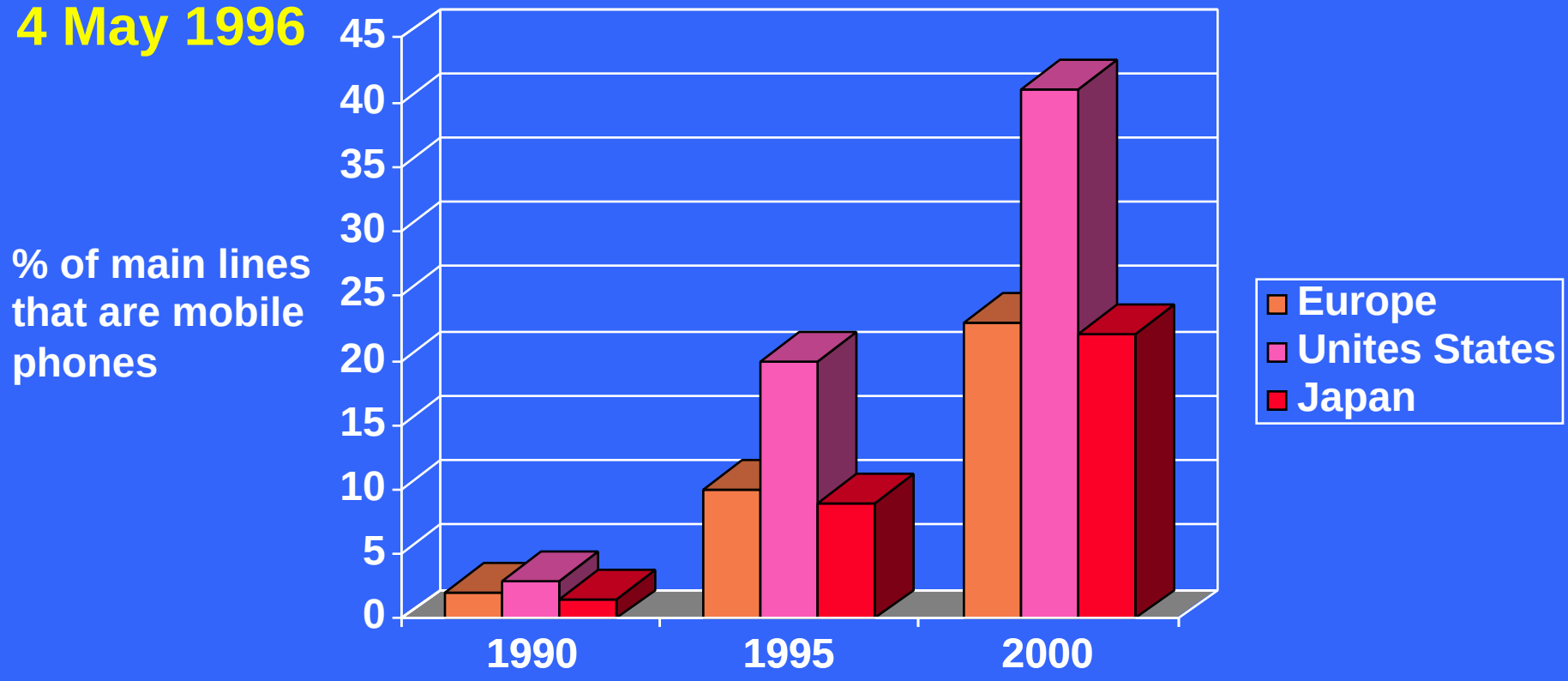
Yankee Group Forecast



28000 new AMPS subscribers per day

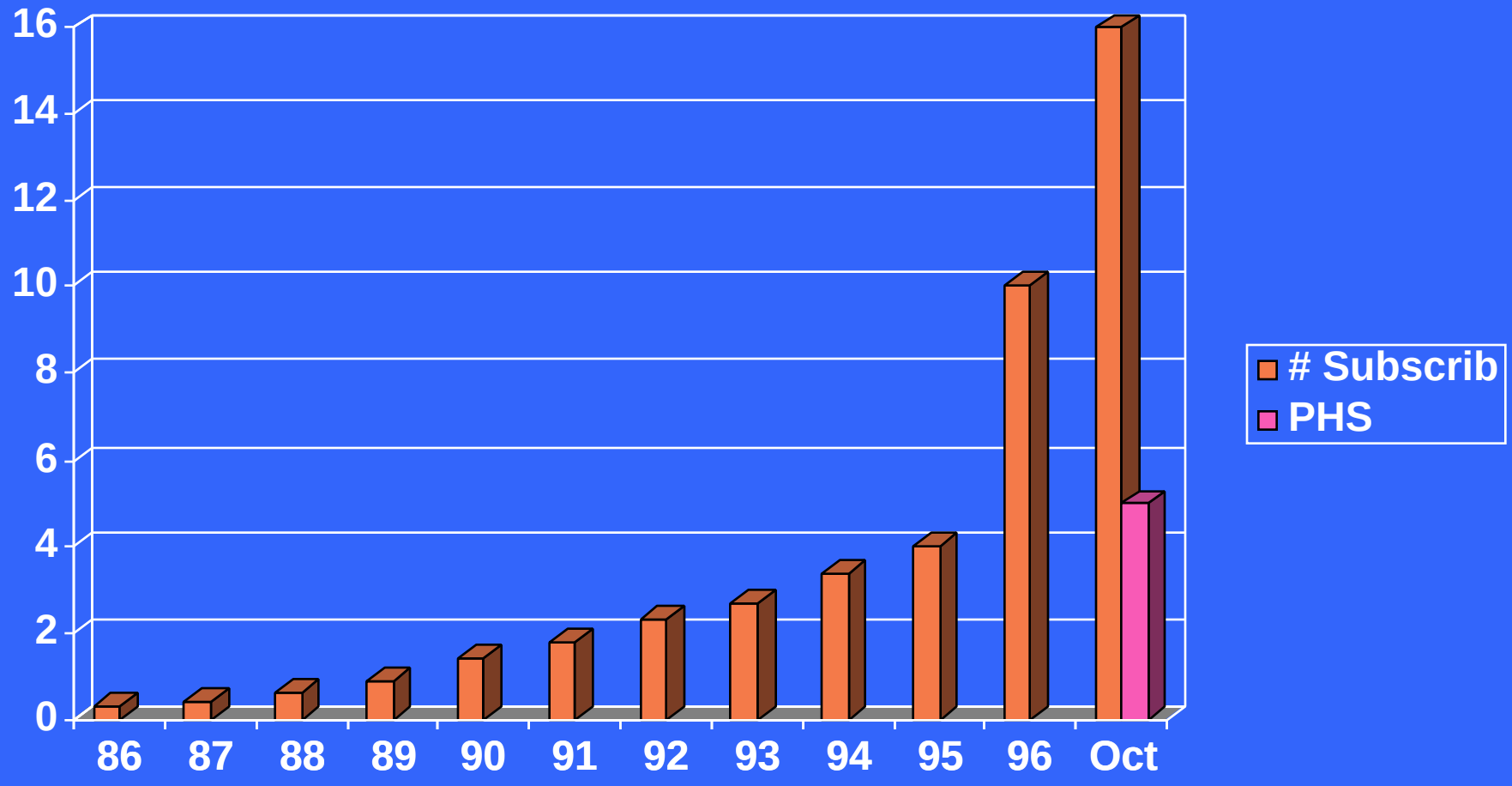
Cellular Phone Growth

Economist
4 May 1996



Year 2000: Mobile phones will reach 42% of fixed-line subscribers

Japan Unplugged



Number of mobile phone subscribers in Japan, in March of each year — N.Y. Times, 20 January 1997

The Lessons of the Japanese Cellular Phone System

- Unexpectedly Rapid Growth
  - 1995: ten years to 5.4 million subscribers
  - March 1996: 10 million
  - October 1996: 21 million
- Why?
  - Rapidly declining prices for cell phones & services
  - Deregulation of Japanese cellular telephone market
  - Recent introduction of personal communication services: portable handiphone system

PCS = "Pretty Crazy Situation"?

Proposal	Mobility	Supporters
CDMA (IS-95)	High	Qualcomm, AT&T, Motorola, ALPS, GSIC, Samsung, Sony, US West, Sprint Bell Atlantic, Time Warner
PCS1900	High	Pac Bell, Nokia, MCI, Siemens, Kycom
IS-54	High	AT&T, McCaw
Omnipoint	High/Low	Omnipoint, Rockwell
WACS	Low	Bellcore, Motorola, Panasonic, US West, Sprint, Bell Atlantic, Time Warner
DECT	Low	Ericsson
PHS	Low	NEC, Panasonic, Hitachi, Toshiba, PCSI
5 MHz CDMA	Low	Interdigital, Oki

- PCS Primeco (Nynex/Bell Atlantic/US West/Airtouch): CDMA
- Wirelessco (Sprint, Comcast, Cox, TCI): CDMA
- AT&T Wireless: TDMA
- Other RBOCs (e.g., PBMS): PCS 1900 (Upbanded GSM)

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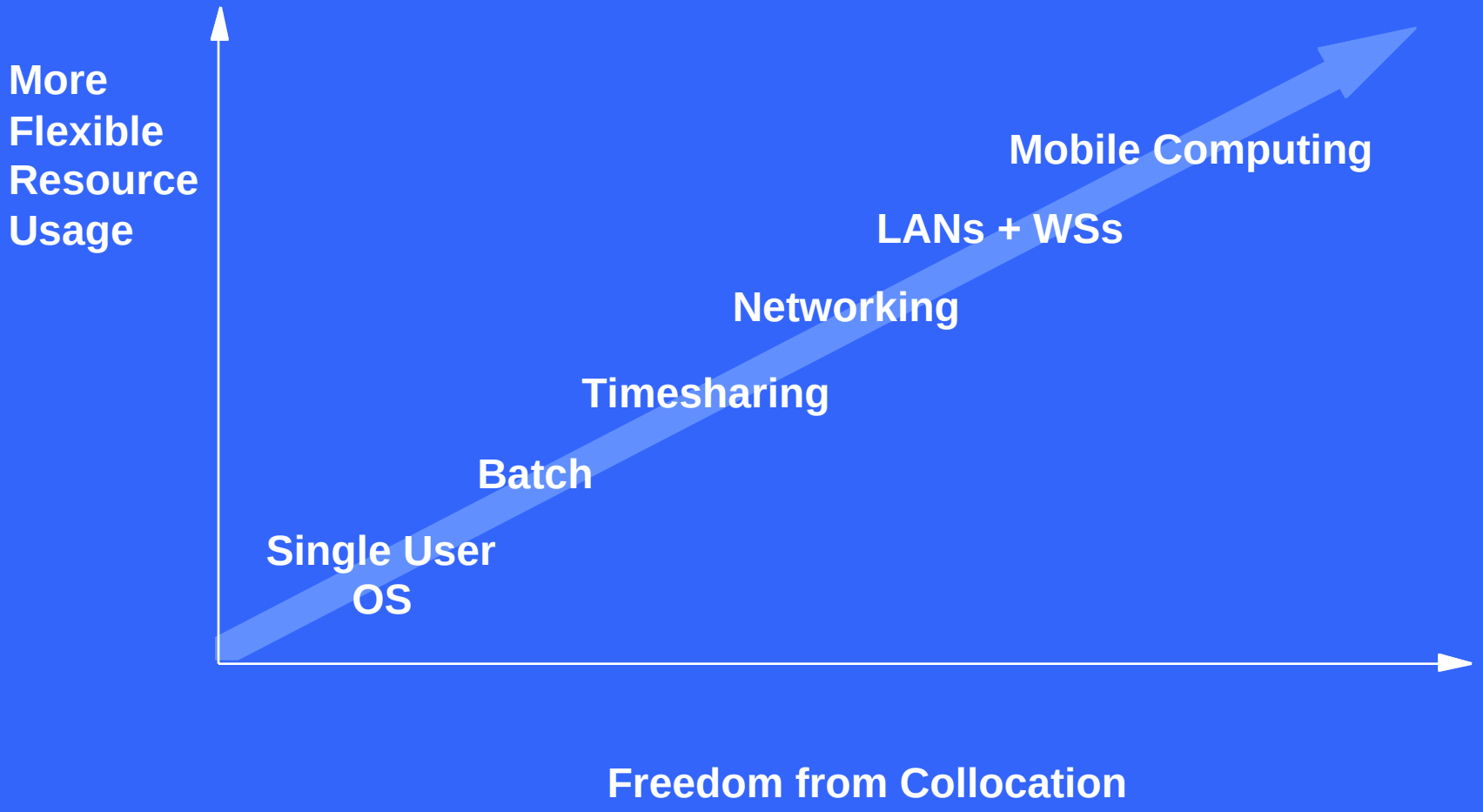
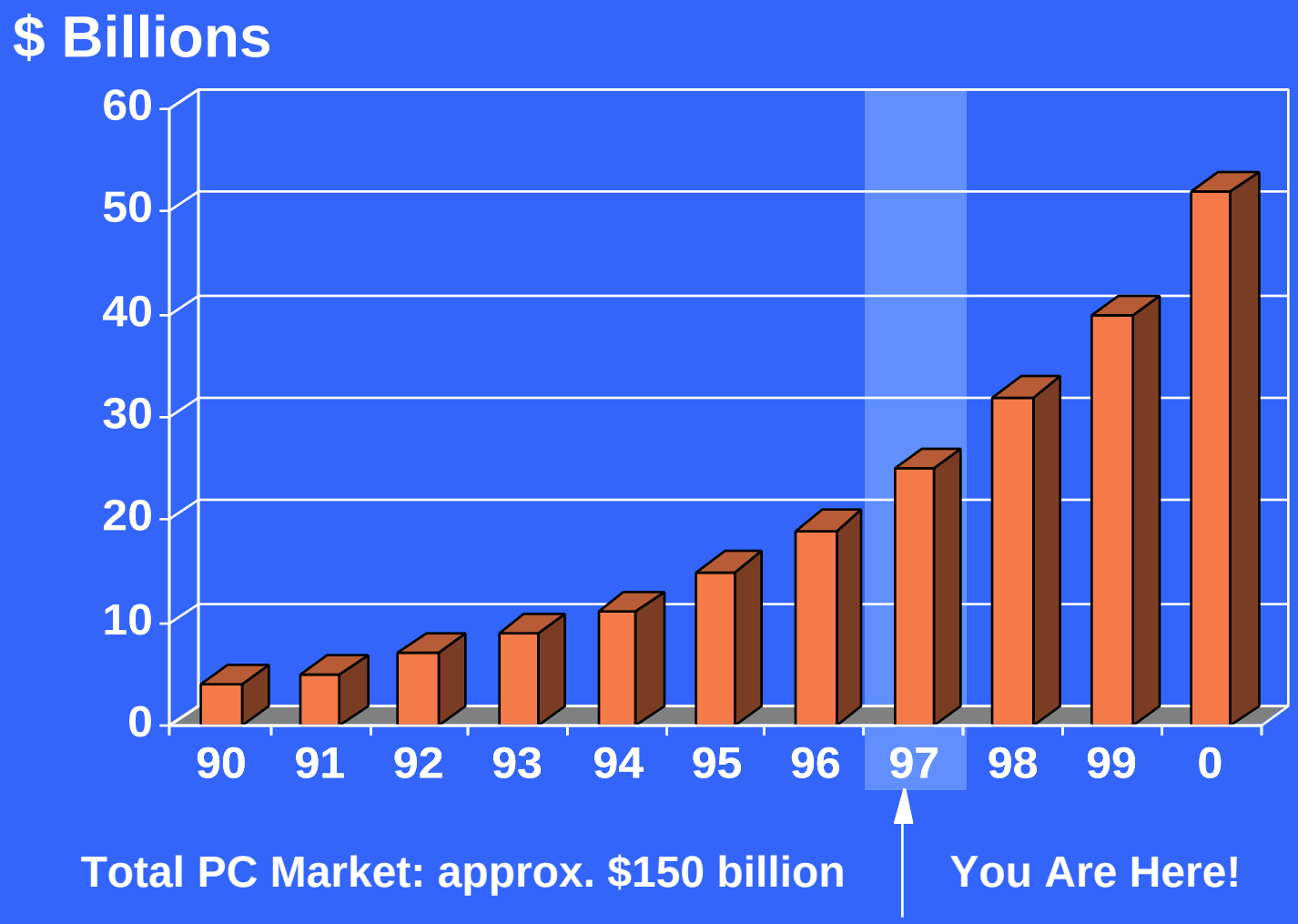
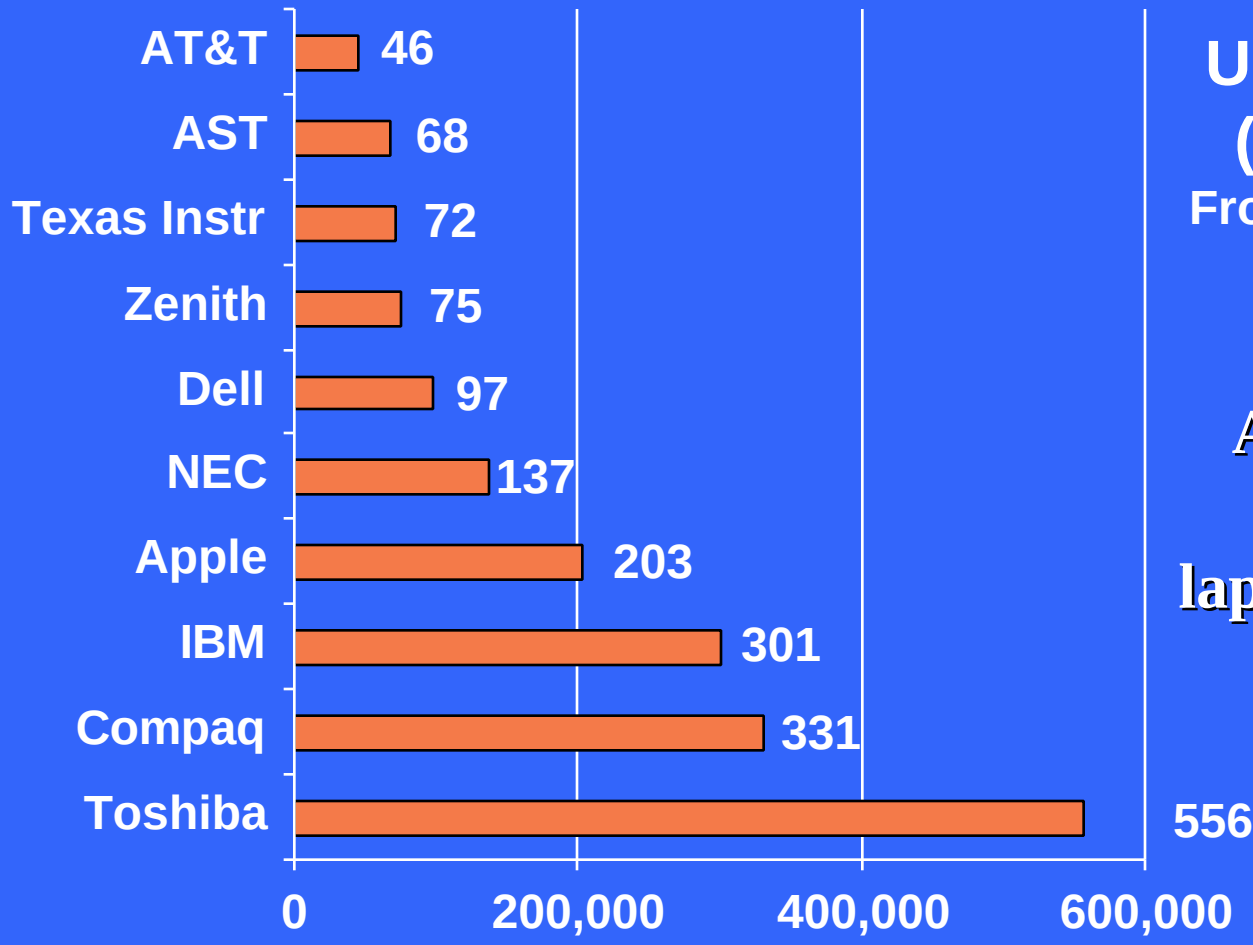
Mobile Computing is the *Natural Evolution* of Computing



Global Markets for Portable Computers



Laptop Sales, Jan-Sept 1995



Unit Sales (Top 10)
From NYTimes 17 Jan 96

Approx. 20% of units are laptop computers

A Short History of Wireless Data

- Wireless LANs
  - late 1970s
    - » IBM Research--IR for factory apps (<<1 mbps)
    - » HP--RF for 100 kbps to distributed terminals
    - » Motorola--1.7 GHz prototype LAN extention
  - 1985: ISM bands opened for low power SS
    - » Evolves into the PCMCIA formfactor interface
  - Recent Developments
    - » 1990: Motorola--18 GHz Altair LAN extension
    - » 1990: IEEE 802.11 Committee Formed
    - » 1992: Winforum Committee Formed
    - » 1992: European ETSI HiperLAN Effort
    - » 1993: Licensed and Unlicensed PCS Bands
    - » 1995: 60 GHz spectrum allocation

A Short History of Wireless Data

- Wide Area Data
  - Ardis
    - » 1983: IBM + Motorola; IBM sells out in 1994
    - » 1994: 35,000 users, 1300 base stations. 45 million msgs per month, 19.2 kbps
  - RAM Mobile Data/Mobitex
    - » Bell South/Ericsson/Motorola
    - » 1986: deployed in Sweden
    - » 1989: 840 base stations, 40 switching centers, in 100 metro areas, 6300 US cities and towns, 8000 kbps, nationwide roaming
    - » 1994: 12,000 subscribers in US

A Short History of Wireless Data

- Wide Area Data
  - CDPD
    - » 1991: CDPD patents filed by 3 IBMers (Miller, Moore, Pate, IBM Boca Raton)
    - » 1993: Initial CDPD specifications, carriers plus IBM. McCaw, IBM, PCSI
    - » 1995: Deployment of CDPD infrastructure
    - » 19.2 kbps, make use of idle channels in analog cellular system via "channel hopping"; TCP/IP compliant with support for mobile-IP like mobility routing
    - » Not viewed as a marketing success (yet): where are the subscribers? how pervasive is the coverage?

Some Observations

- Wireless Data Services
  - Have been around for more than 10 years
  - Messaging Systems
    - » EMBARC, MobileComm, SkyTel
    - » low speed (100s bps), short message, two-way available
  - Wide-Area Data Networks
    - » 100,000 subscribers in US??
    - » RadioMail: Internet E-mail gateway: a few thousand subscribers?
  - Wireless Local Area Networks
    - » Large number of manufacturers yet small sales volumes
    - » Approximately 1.2 million units sold to date

Technical and Economic Challenges

- Pricing
  - $/airtime, $/data transfer, flat rate?
  - Transmitted packets or received packets?
  - Artifact provider vs. pipe provider vs. service provider
- Performance
  - 20 kbps but not quite fast enough for “multimedia”
  - Coverage, non-interoperability
- Killer App
  - Vertical application vs. email, paging, web access
- Formfactor
  - Laptops vs. PDAs vs. Smart Phones

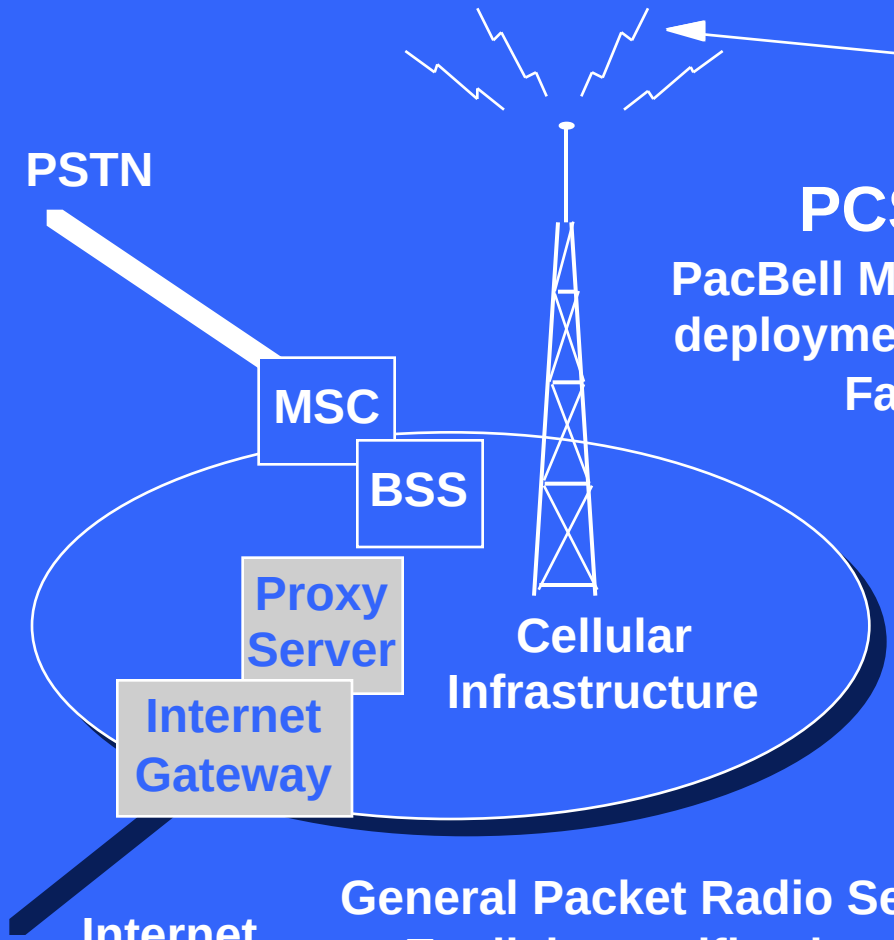
Promising Developments

- Converging Platforms
  - Smart phones: cellular phone + built-in pager/PDA
    - » e.g., Nokia/Geoworks “Internet” Phone
    - » e.g., IP-addressable two-way pagers for Narrowband PCS
- PCS Licenses
  - Room for *all* of those cellular service providers?
  - Possible packet data services?
- Emerging Industry Standards
  - CDPD, IEEE 802.11, WINFORUM
  - Better interoperation or co-existance in the future
  - 60 GHz allocation

Promising Developments

- 60 GHz Allocation
  - FCC opens 5 GHz of spectrum at 59-64 GHz
  - Oxygen absorption leads to rapid fall off in signal strength: makes allocation perfect for (very) high bandwidth WLAN
  - MM Wave Communications Working Group is defining sharing etiquette
  - Many technical challenges remain: multipath, antenna arrays
  - Many economic challenges remain: high volume production and reduced costs

Promising Developments: GPRS



PCS 1900

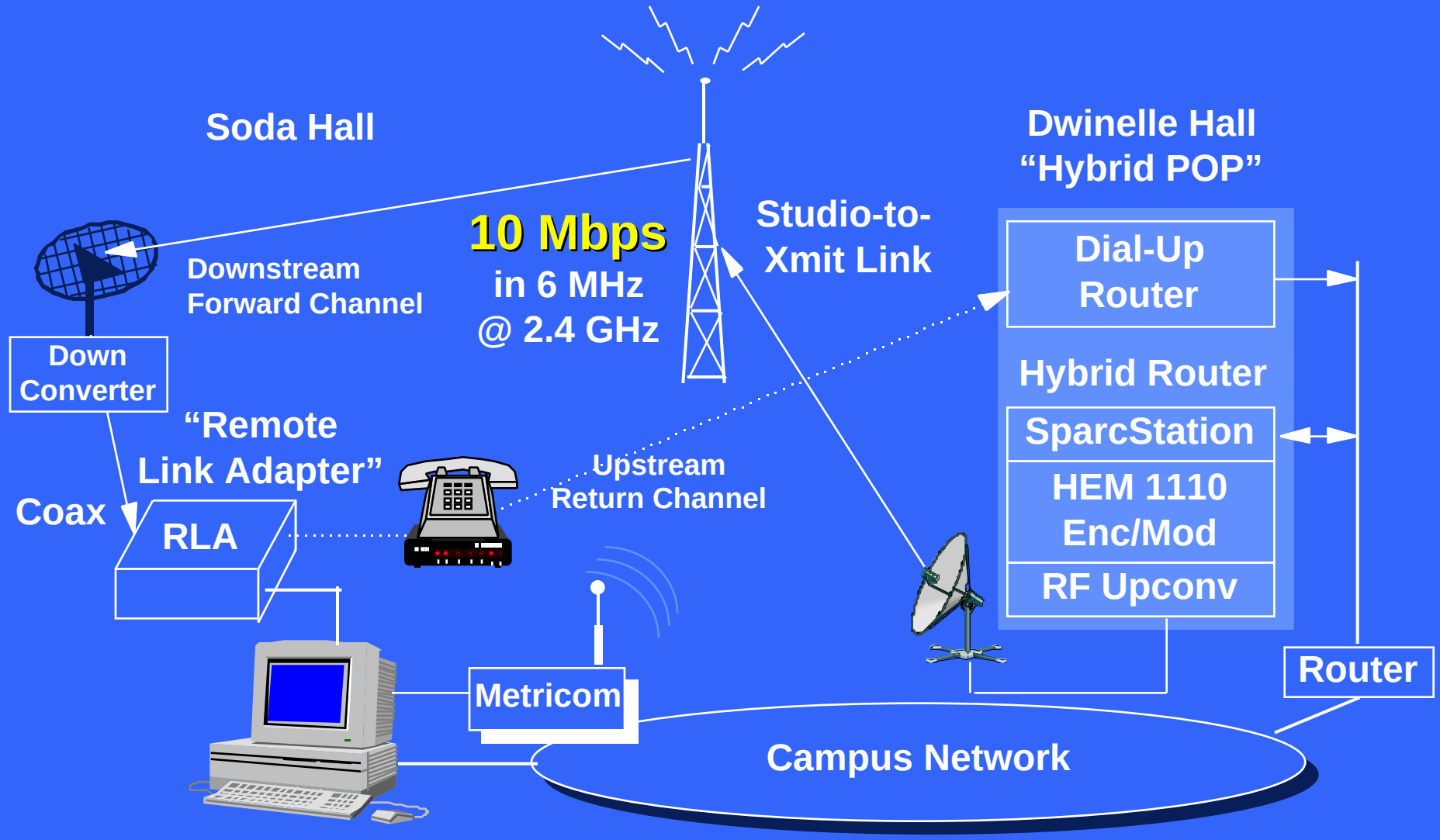
PacBell Mobile Services deployment in Bay Area Fall 1996

PDA + Modem + Digital Cell Phone

Nokia
Ericsson
Hewlett Packard
Geoworks Software

General Packet Radio Service (GPRS) of GSM System
Explicit specification for proxy support services

Promising Developments: Wireless Cable



Wireless ATM

- Uttered in same phrase as mobile multimedia
- Switched scalable bandwidth is good thing
- But ...
  - QoS guarantees incompatible with radio channels: still need to write applications that can adapt
  - Mobility presents problems for ATM's connection orientation: connection tear-down and rebuild
  - No mechanisms for shared media: implications for costs of the wireless network

What Every Happened to Ubiquitous Computing?

- Computers are getting more ubiquitous
  - Multiple computers in my office
  - Have you been to an airport lately?
  - Echelon style in-building controls: chip in a light socket
- But it is information, in the form of the web, that has become ubiquitous, not the computer!
  - 47 million Americans on the Internet at end of 1996
  - 12 million more than at start of 1996: 34% increase

Wirless Data Success Story: UPS

- 60,000 widely dispersed mobile units communicating with a central DB server
- Competitive need for real-time package tracking
- “TotalTrack”: UPS + 100 cellular carriers
  - Cellular modems, bulk service from an alliance of cellular service providers, interfaced to UPSnet, UPS’ own packet switched network
  - Integrated billing, roaming, redundancy
  - ARDIS & RAM rejected due to insufficient coverage

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Access is the Killer App

- Killer Capabilities
  - Access to your desktop environment while on the move
  - Be connected whenever possible via the “best” available network
  - Support the application’s graceful adaptation to the available bandwidth and latency
- Technical Strategies
  - Continuous Connectivity: Wireless Overlays
  - Proxies: Network- and Type-Aware Applications Building Blocks

Overlay Network Challenge

Type of Network	Bandwidth	Latency	Mobility	Typ Video Performance	Typ Audio Performance
In-Building	>> 1 Mbps Comm'l RF: 2 Mbps Research IR: 50 Mbps	< 3 ms	Pedestrian	2-Way 'ractive Full Frame Rate (Comp)	High Quality 16-bit Samples 22 KHz Rate
Campus-Area Packet Relay Network	≈ 64 Kbps	≈ 100 ms	Pedestrian	Med. Quality Slow Scan	Med. Quality Reduced Rate
Metro-Area (Wireless Cable)	10-30 mbps (one way, LOS)	< 10 ms	Stationary	2-Way 'ractive Full Frame Rate (Compressed)	High Quality 16-bit Samples 22 KHz Rate
Wide-Area	19.2 Kbps	> 100 ms	Vehicular	Freeze Frame	Asynchronous "Voice Mail"
Regional-Area (LEO/DBS/VSAT)	4.8 kbps–10+ Mbps (asymmetric)	> 100 ms	Vehicular Stationary	Seconds/Frame Freeze Frame	Asynchronous "Voice Mail"

Latency as critical as bandwidth in wireless networks

Wide diversity of network performance parameters

Competing infrastructure providers

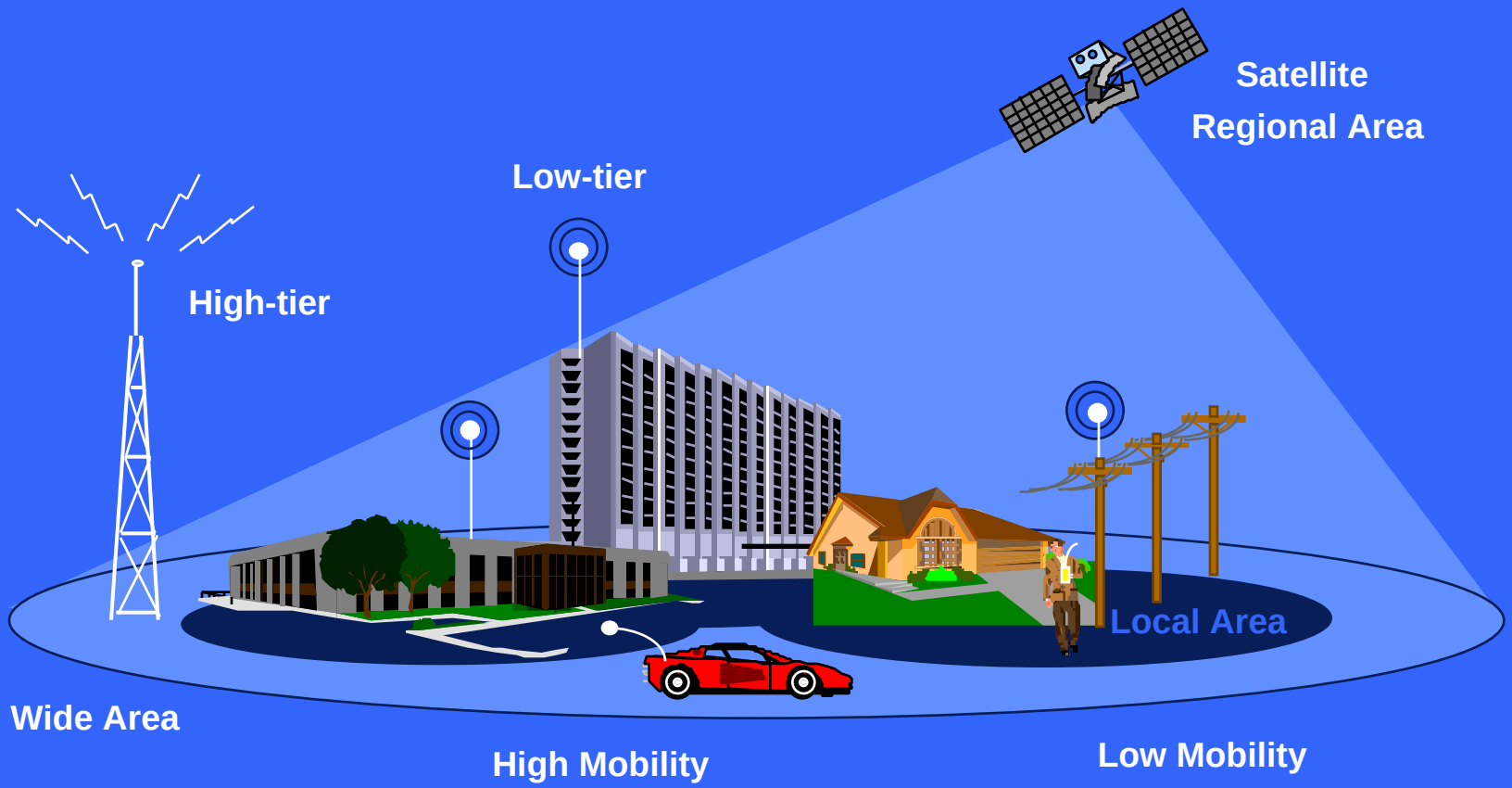
Pedestrian vs. vehicular mobility

Application Support Challenge

Device	Bandwidth, bits/sec	CPU	Mem/ Disk	Screen size	Bits/ pixel
High-end PC	Ethernet (10Mbits), ISDN (128K)	266 Mhz Pentium Pro	64/4G	1280x1024	16-24, color
Low-end PC		150 Mhz Pentium	16/1G	1024x768	8-16, color
High-end notebook	Cellular (9600) or wireline (28.8K) modem			800x600	8, color
Low-end notebook		100 Mhz 486		640x480	4, gray
PDA	2400-14.4K modem	20+ Mhz RISC or x86	2/0	320x200	1–2, gray

Client variation spans an order of magnitude

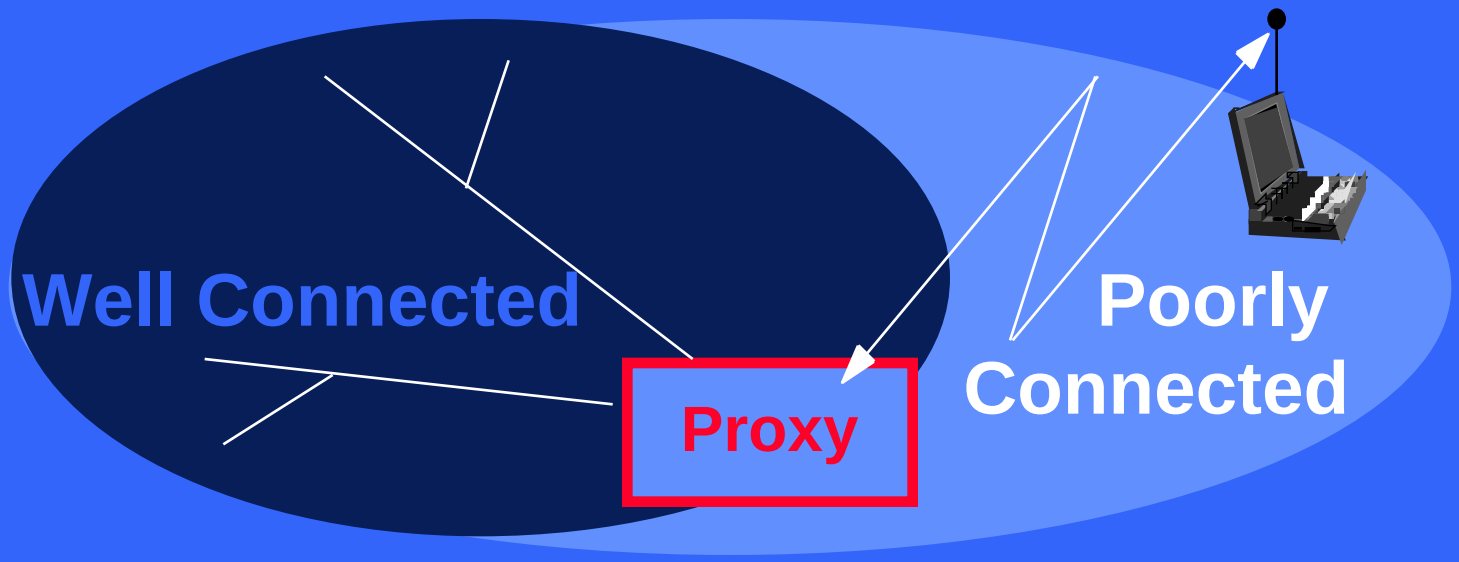
Wireless Overlay Networks



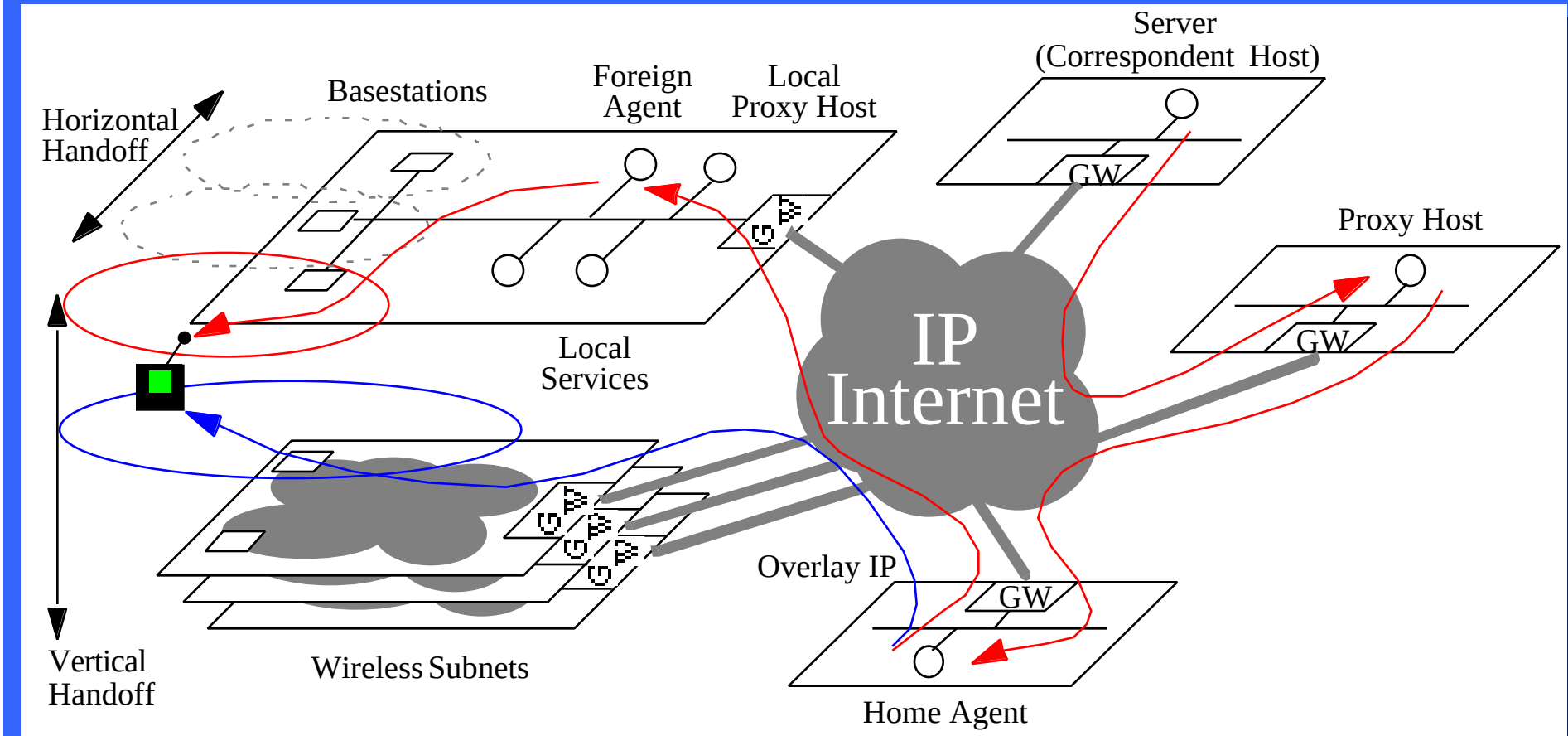
- Wireless internetwork: stacked networks providing wide area coverage and the best possible bandwidth and latency

Proxy Architecture

- Proxy
  - Mediates between wireless and wireline environment
  - Ideally executes at “well-connected” boundary
  - Manages caches & chooses representations on-the-fly
  - Trade transcoding time against communications time

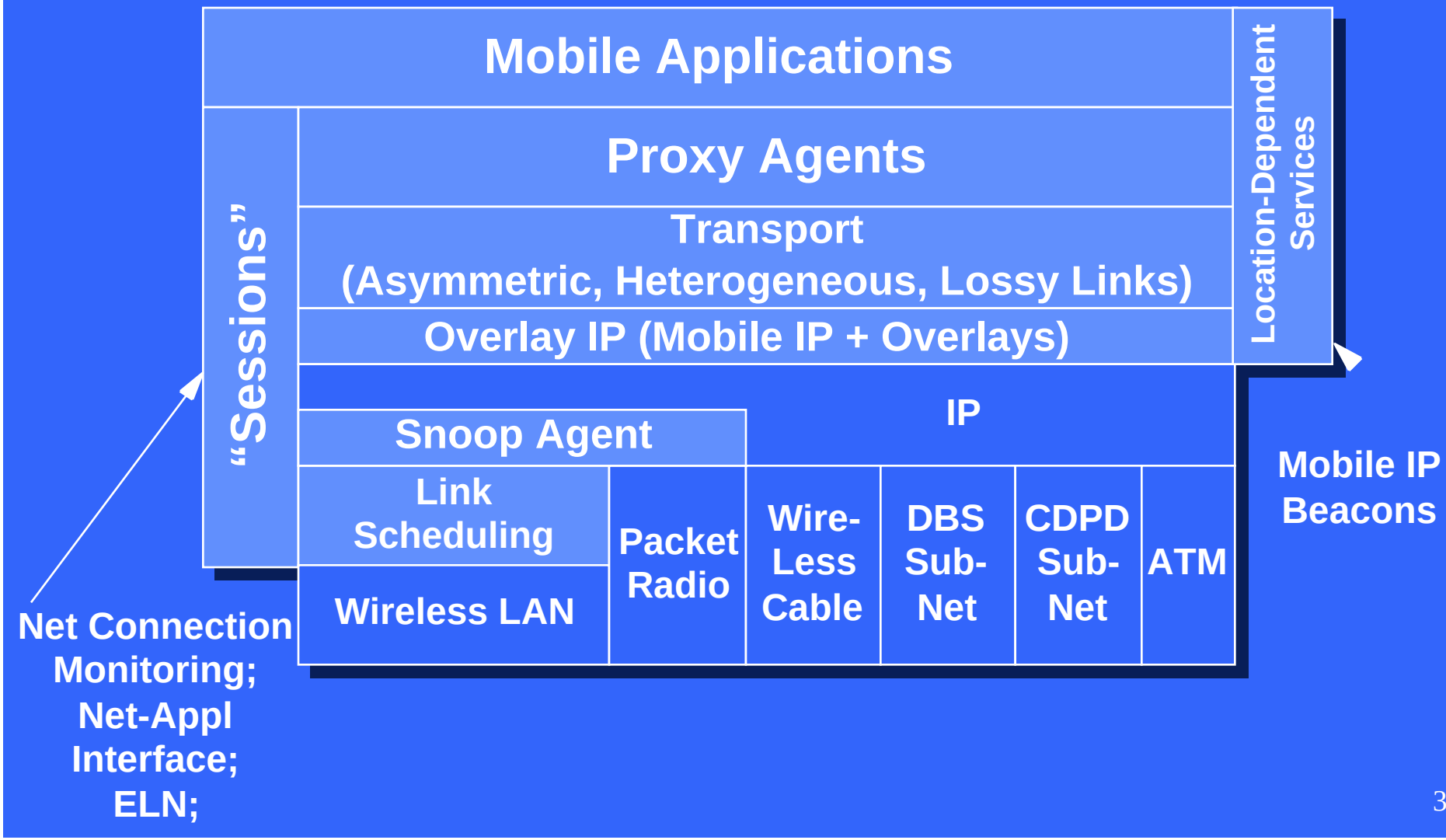


BARWAN Architecture



- Overlay IP extends Mobile IP
- Proxy/Forwarding Agent Interaction
- “Vertical” Handoffs between subnetworks

BARWAN Architecture



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Summary

- Wireless data is *not* dead
  - Very successful vertical applications like UPS
  - Wide-Area: ISP model vs. “pipe” provider, GPRS
  - Local-Area: Higher b/w, 802.11 standards, etiquette
- Access is the killer app
  - Connectivity through wireless overlays
  - Adaptivity through proxy services
- IP “Dial Tone”
  - IP to the pager, phone, PDA, laptop, etc.
  - Internet service integration
    - » A phone is not a workstation: limited b/w, storage, display

Conclusions

- Promising Developments:
  - Overlays and Proxies
  - New spectrum allocations for serious bandwidth
- Many of these ideas apply equally well in today's heterogeneous network environments
  - Asymmetries in satellites and cable modem links
  - Transport over high bandwidth-delay networks
  - High loss links: bandwidth achieved?
  - Adapt representations to the quality of the end device and its network connectivity