Wireless Mobile Communication: *From Circuits to Packets*

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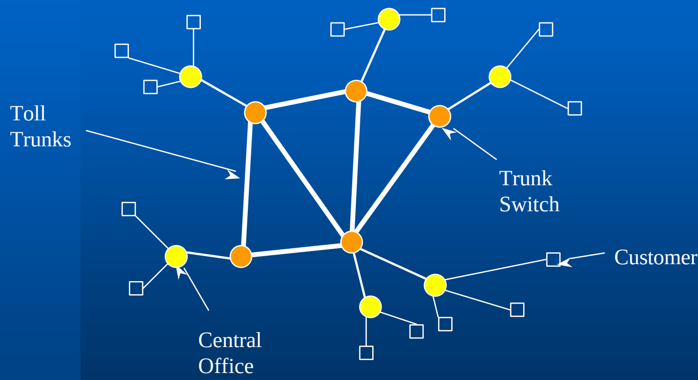
A Brief Historical Perspective

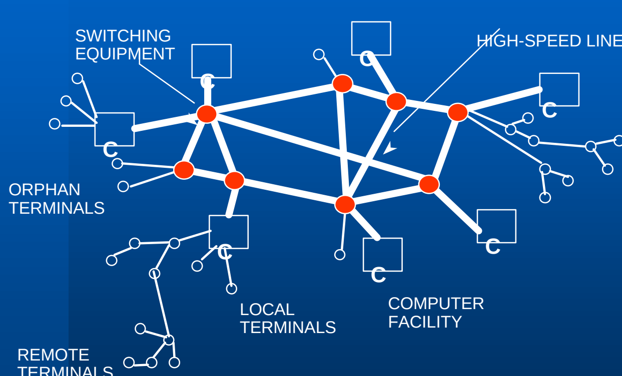
The Telephone Network



1878

Circuit Switching
64 Kbps circuits

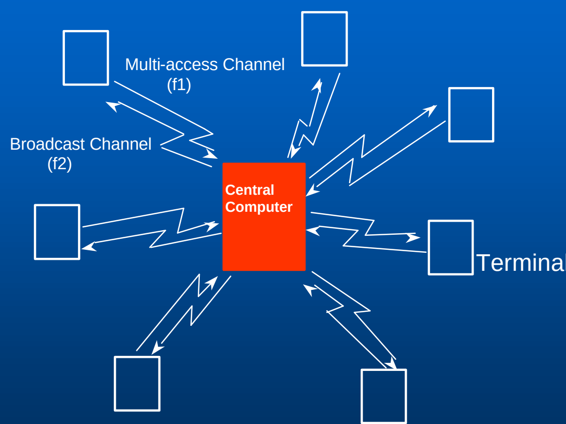
The ARPANet



1969

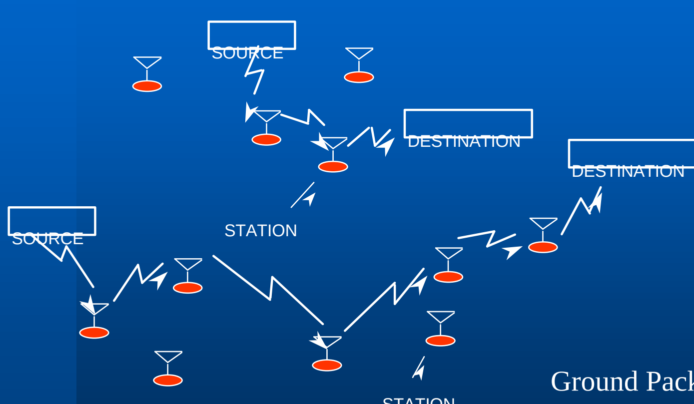
Packet Switching
Statistical multiplexing

The ALOHA System



1970

Packet Radio Network



Ground Packet
Radio System
(GPRS)

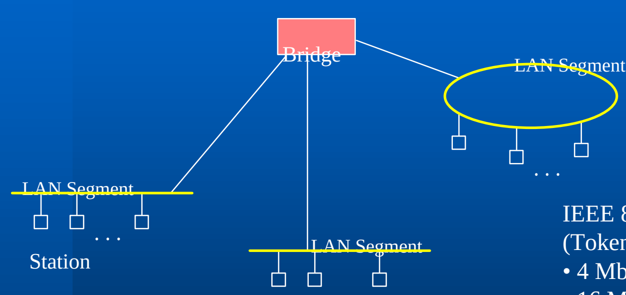
1973

Public Data Networks

- X.25
  - Packet switching
  - Virtual circuits
  - Approved by CCITT in 1976

1976

Local Area Networks

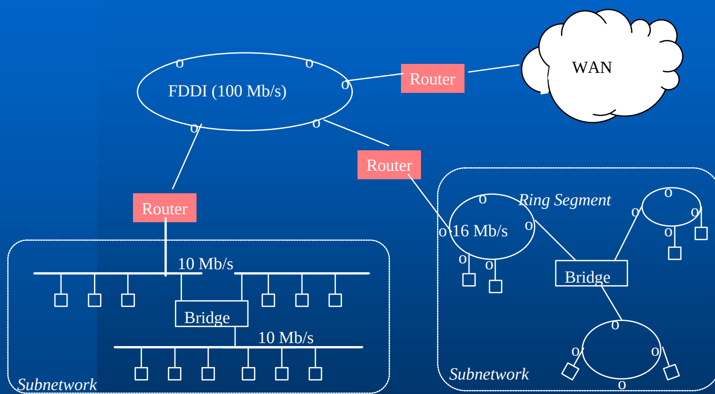


IEEE 802.3 (Ethernet)
• 10 Mb/s

IEEE 802.5
(Token Ring)
• 4 Mb/s
• 16 Mb/s

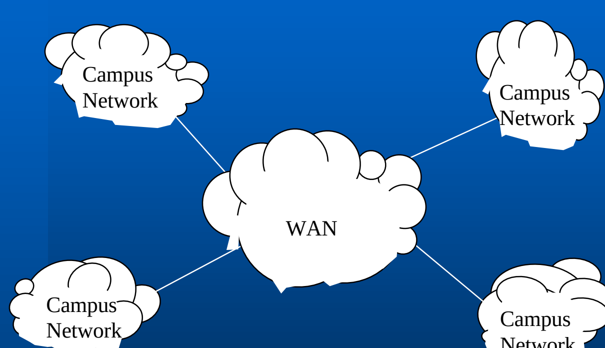
1980

Campus Network



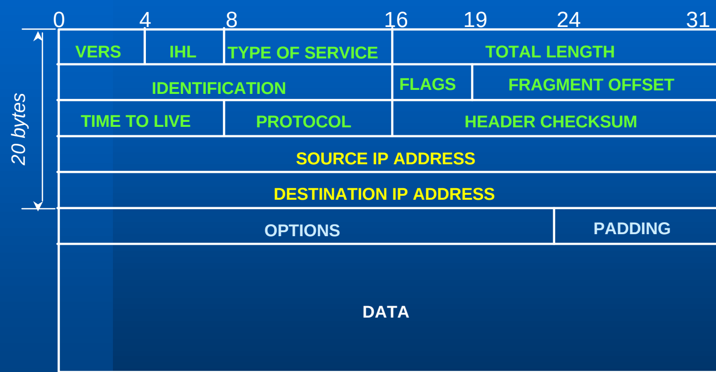
Mid 1980's

A Global Data Network



Mid 1980's

The Internet Protocol (IP)



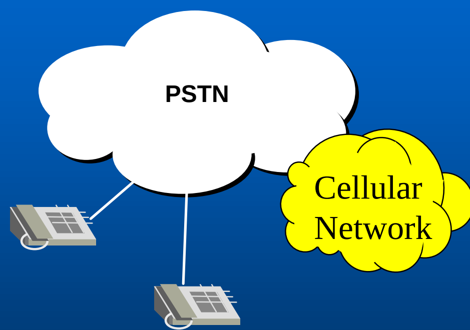
1975

Datagram format

Data Network Applications

- Resource sharing
- Remote login
- Electronic mail
- News
- File transfer

Wireless Voice Networks



Wireless voice communication
Full mobility management solution

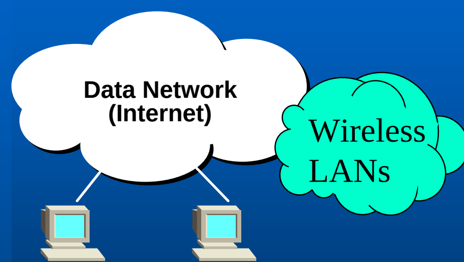
1990

A Growth Spurt

- **Data traffic growth (50-300% per year)**
  - **Making the Internet Public**
  - **Advent of the World Wide Web**

1995-present

Wireless Data Networks

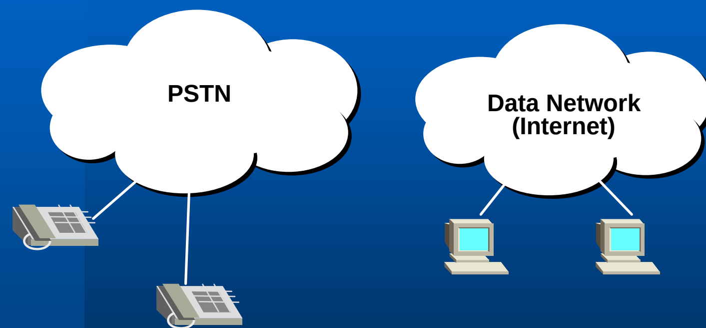


Wireless data communication
No mobility management

1997+

Toward a Converged Network

One Network for Each Type of Traffic



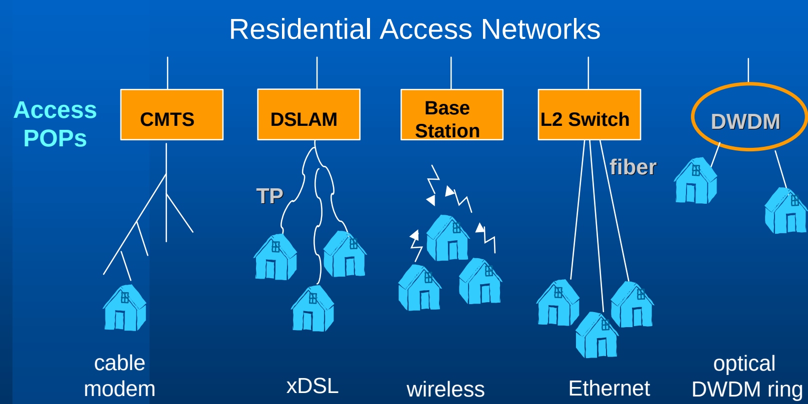
1995-present

Toward a Converged Network

Forces at work:

- **Ubiquity of the internet (50M users in 4 years)**
- **Deregulation of telecommunications industry**
- **Market readiness for new communications services and applications**
- **Advances in technology:**
  - **Semiconductors, photonics, wireless**

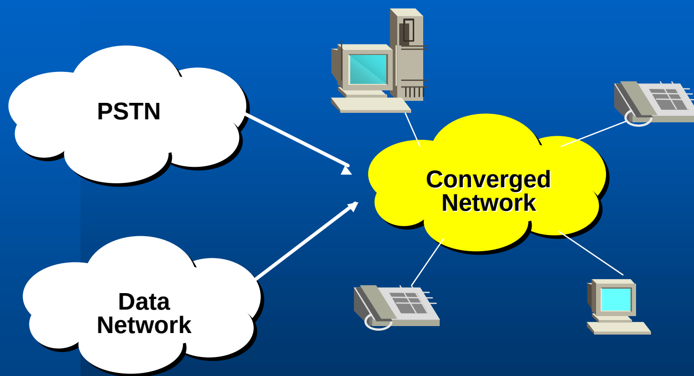
Access Network Technologies



New Applications

- News
- Collaboration
- Distance Learning
- Home shopping
- Karaoke
- Pay-per-View
- Medical diagnostics
- Training
- Investment
- Video Conferencing
- Corporate Communication
- Banking
- Telephony
- Factory Floor Reference

Shift



Converged Network

- *Packet-based*
  - Statistical multiplexing efficiency for data traffic
  - Flexibility to meet varying requirements of new applications
  - Open client-server paradigm in management, control, and services
- *IP-based*
  - Ubiquity of IP
  - Advances in associated protocols

New Applications

New Applications

- Communication among people
- News and entertainment
- Education and training
- Information retrieval
- Commerce
- Corporate communication
- Health care
- Advertising, publishing
- Factory floor reference

...

Communication Among People

- Voice communication (voip, IP telephony)
  - Ubiquity of the internet
  - Alternative to telcos
  - Integration with other applications
  - New functionality
    - Conferencing (made easier)
    - Storage (record, play-back, index, edit, integrate…)

Communication Among People

- Video Conferencing
  - A picture is worth a thousand word
    - *facial expressions, gestures, reactions…*
  - Same advantages as with voice communication
  - Insertion of video clips
  - Fly-on-the-wall
  - Quality
- Collaboration
  - shared white board
    - *more frequent meetings*

News and Entertainment

- News in all its forms (paper, audio, video, web, combination; Live and stored)
  - Selectivity (on-line, by profile…)
  - Accessibility without frontiers
  - Urgent notification
  - Linkage among various sources
  - Archival material

News and Entertainment

- Movies and TV programming
  - Movie-on-demand (pay-per-view)
    - *Large selection*
    - *Full VCR functionality*
  - Live broadcasts (sports, weddings, …)
    - *Wider audience*
- Interactive games

Education and Training

- Distance learning
  - Distance independence
- Asynchronous learning
  - Time independence
- Flexible curriculum
- Flexible pace
- Monitoring

Business Applications

- Information kiosks
- Corporate communication
- Factory floor reference
- Banking
- Home shopping
- E-commerce
- Publishing
- Etc...

Medical Applications

- Medical imaging
- Tele-surgery!
- Health education

New Traffic Types

- Voice
  - Stream oriented
  - Delay sensitive
- Video
  - Stream oriented
  - High bandwidth (1 - 20 Mb/s)
- Images
  - High data volume

Characteristics and Requirements

Types of traffic	Traffic Pattern	Bandwidth Requirement	Latency Requirement
Voice			
Telephony	Stream-oriented symmetric	6-64 Kb/s	100-150 ms. (interactive communications)
Video			
Video conferencing	Stream-oriented @ symmetric	1-2 Mb/s	100-150 ms.
Entertainment (Movie-on-demand)	asymmetric	20 Mb/s (HDTV)	minutes (near VoD)
VOD applications	asymmetric	4-6 Mb/s (MPEG2)	seconds
Data			
Web browsing	Random & bursty	10 mb/s (peak)	< 1 sec. (interactive, time sensitive)
E-commerce	asymmetric	1 Mb/s (average)	
Other (email, file transfer)	unpredictable		No real-time requirement

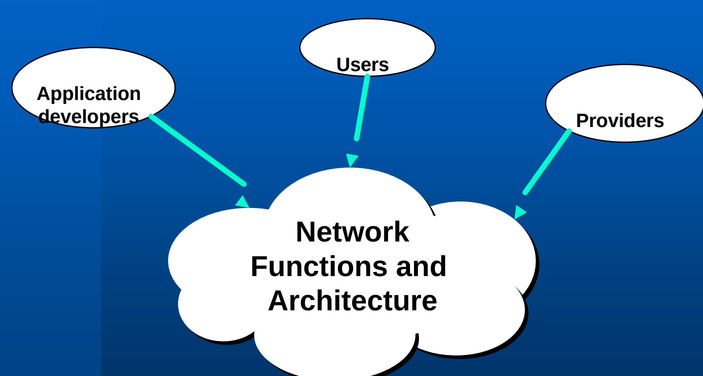
New Networking Requirements

- Bandwidth
- Latency
- Multicasting
- Integrated services
- Roaming
  - Nomadic access
  - Seamless handover

"Enable high performance data communications for mobile workforce, whether on company premises, in the field or at home" (Paul Henry)

Service-oriented Internet

Sources of Requirements



Users Requirements

- High quality of service
  - Support effectively new types of traffic (voice, video)
    - *Low latency*
    - *Good quality*
  - Differentiated services
  - High network availability and reliability
  - Simplicity in using network
  - Low cost
  - Security and privacy
- Mobility

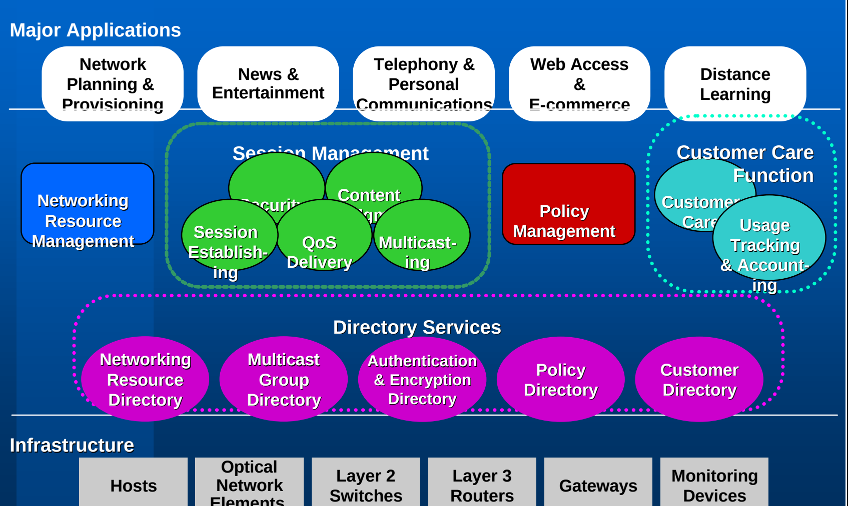
Service Provider Requirements

- Ease of network configuration and resource allocation
- Customer care management
- Usage tracking and accounting
- Policy management
- Flexible network solutions
  - To meet evolution and growth

Application Developer Requirements

- Rapid development
- Open architecture
- Isolation from network details
- Standard common service-oriented support functions
- Ease of integration with other applications

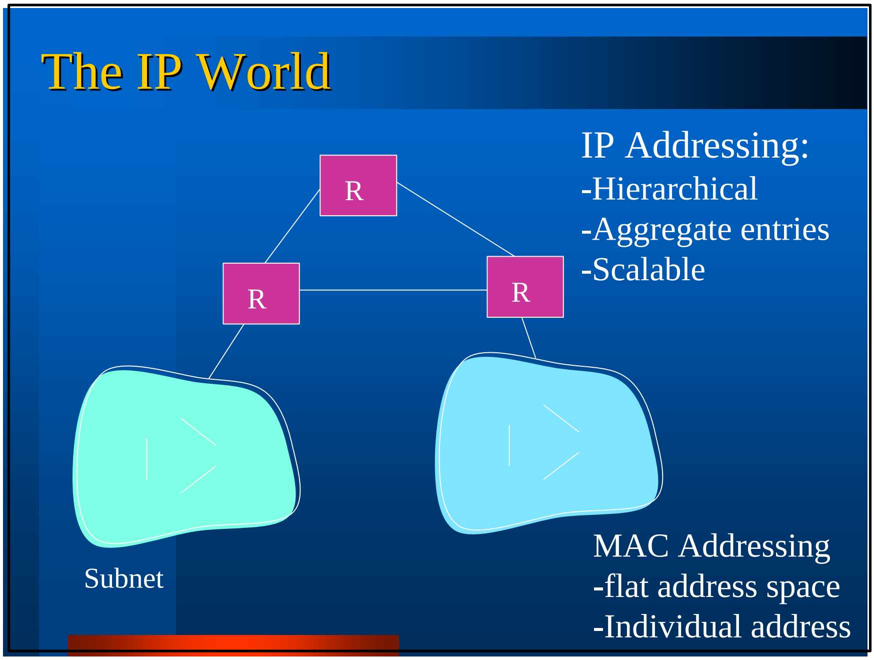
A Three-level Logical Architecture

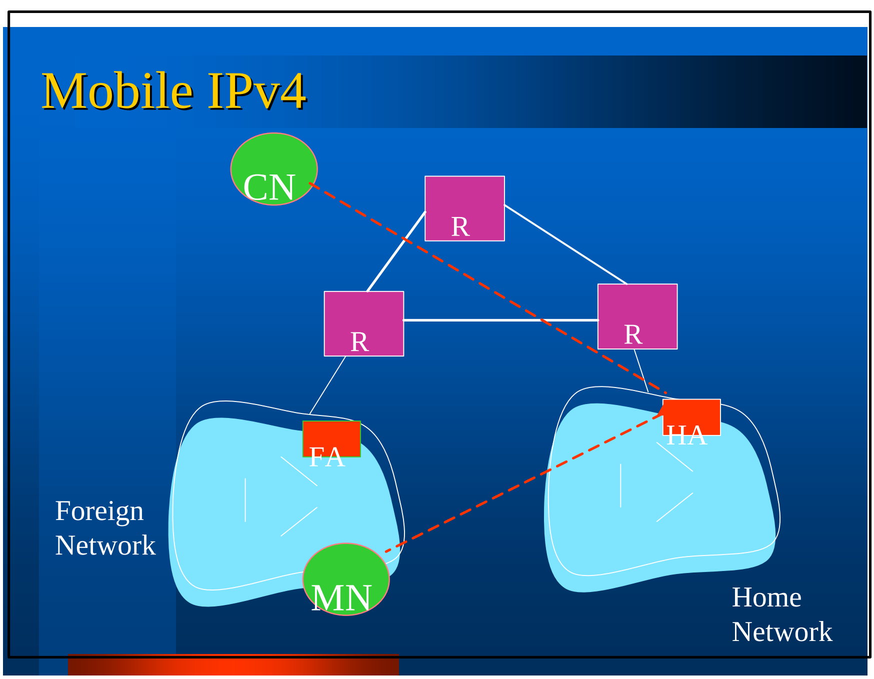


Wireless Mobile Data Communication

Two Independent Efforts

- **The internet world:**
  - *Mobile IP*
- **The cellular voice network world:**
  - *General packet radio service (GPRS)*


The IP World
IP Addressing:
-Hierarchical
-Aggregate entries
-Scalable
R
R
R
Subnet
MAC Addressing
-flat address space
-Individual address


Mobile IPv4
CN
R
R
R
FA
HA
Foreign Network
MN
Home Network

Problems With Mobile Ipv4

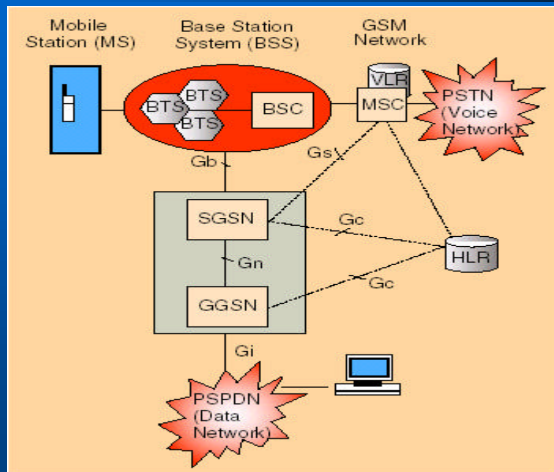
- Triangular routing
  – Route optimization?
- Deployment problem:
  – Availability of FA in foreign networks
  – Hampered by use of private ipv4 addresses and network address translators
- Ingress filtering
- Mechanisms for authentication and authorization are specific to mobile ipv4
  – Separate protocol for registrations (using UDP)

Mobile Ipv6

- Mobility signaling and security features integrated as header extensions
- Address auto-configuration:
  – ***Stateful*** using dhcpv6
  – ***Stateless*** (no need for FA), using router advertisement and router solicitation ICMP messages, and combining foreign network prefix with MH interface identifier
- Built-in route optimization
  – Biding updates sent to HA and CN (biding requests and biding acknowledgements)

General Packet Radio Service

Link
Layer
Mobility



1. Attach
2. Activate PDP Context

Source: A. Samjani, "General Packet Radio Service [GPRS]", IEEE Potentials,Volume: 21 , Issue: 2, April-May 2002 Pages:12 - 15

Integration, Not Convergence

Wireless LANs and Cellular Data

"The Wireless LANs standardization and R&D activities worldwide, combined with the recent successful deployment of WLANs in numerous hotspots, justify the fact that WLAN technology will play a key role in the wireless data transmission"

Source:A. Salkintzis, C. Fors, R. Pazhyannur, Motorola, "WLAN-GPRS integration for next generation mobile data networks", IEEE Wireless Communications,Volume: 9 , Issue: 5 , Oct. 2002, Pages:112 - 124

Wireless LANs and Cellular

"A cellular data network can provide relatively low-speed data service over a large coverage area. On the other hand, WLAN provides high-speed data service over a geographically small area. An integrated network combines the strengths of each."

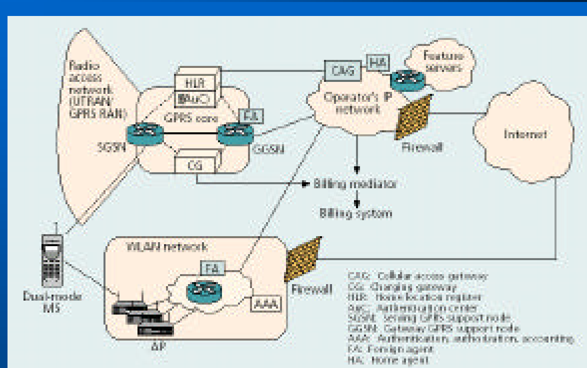
Source:A. Salkintzis, C. Fors, R. Pazhyannur, Motorola, "WLAN-GPRS integration for next generation mobile data networks", IEEE Wireless Communications,Volume: 9 , Issue: 5 , Oct. 2002, Pages:112 - 124

Wireless LANs and Cellular

"Public WLANs can hardly be seen as competing with true mobile data systems. However, they can be deployed as a complementary service to GPRS/UMTS, owing essentially to their bandwidth/cost ratio."

Source:Public Wireless LAN for Mobile Operators, WLANs beyond the entrerprise, Technology White paper by Alcatel

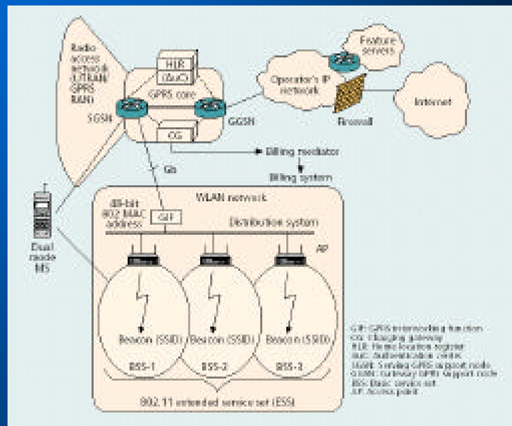
WLAN-GPRS Integration (Loose Coupling)



WLAN deployed as an access network complementary to the GPRS Network. Uses only subscriber databases in GPRS.

Source: A. Salkintzis, C. Fors, R. Pazhyannur, Motorola, "WLAN-GPRS integration for next-generation mobile data networks", IEEE Wireless Communications,Volume: 9 , Issue: 5 , Oct. 2002, Pages:112 - 124

WLAN-GPRS Integration (Tight Coupling)



WLAN Connected to GPRS core network as a radio access network

Source: A. Salkintzis, C. Fors, R. Pazhyannur, Motorola, "WLAN-GPRS integration for next-generation mobile data networks", IEEE Wireless Communications,Volume: 9 , Issue: 5 , Oct. 2002, Pages:112 - 124

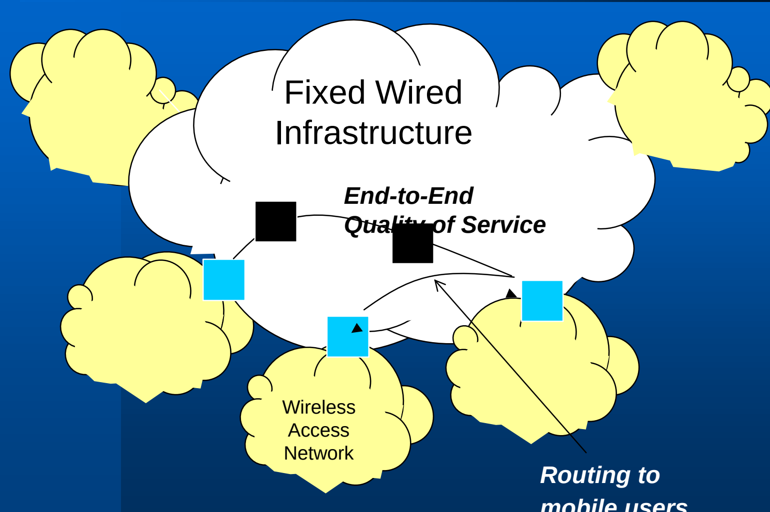
WLAN-GPRS Integration

"Typically, no user intervention would be required to perform the switchover from WLAN to GPRS. Moreover, the user would not perceive this handover. When the user moves back into the coverage of a WLAN system, the flow would be handed back to the WLAN network"

Source: A. Salkintzis, C. Fors, R. Pazhyannur, Motorola, "WLAN-GPRS integration for next-generation mobile data networks", IEEE Wireless Communications,Volume: 9 , Issue: 5 , Oct. 2002, Pages:112 - 124

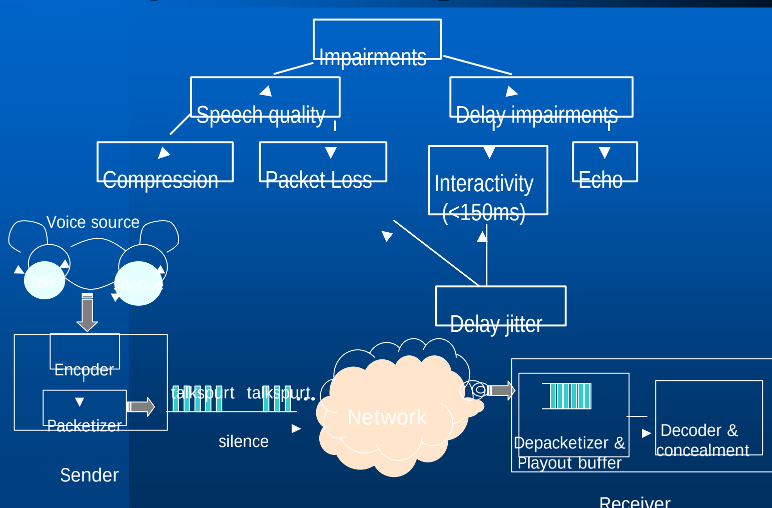
Will Convergence Ever Happen?

Internet Evolution



Is the Internet Ready for VoIP?

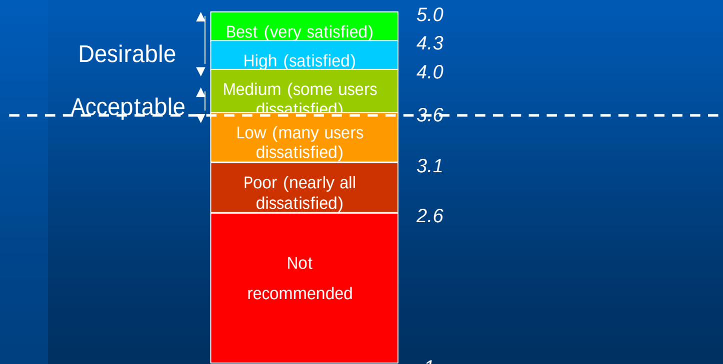
VoIP System and Impairments



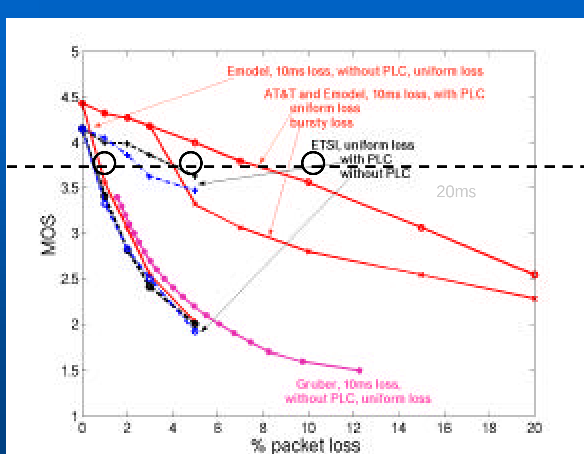
VoIP Quality Measure

Mean Opinion Score (MOS)

Speech Transmission Quality according to user satisfaction

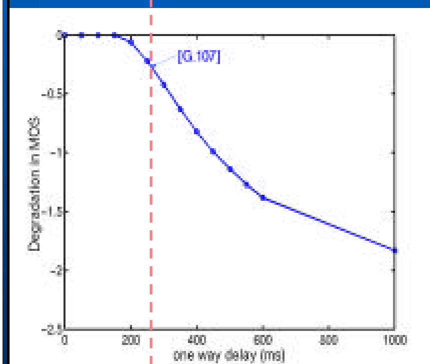


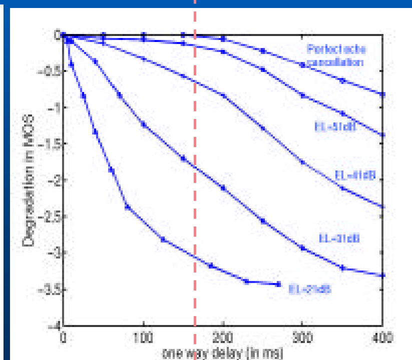
Loss Impairment for G.711



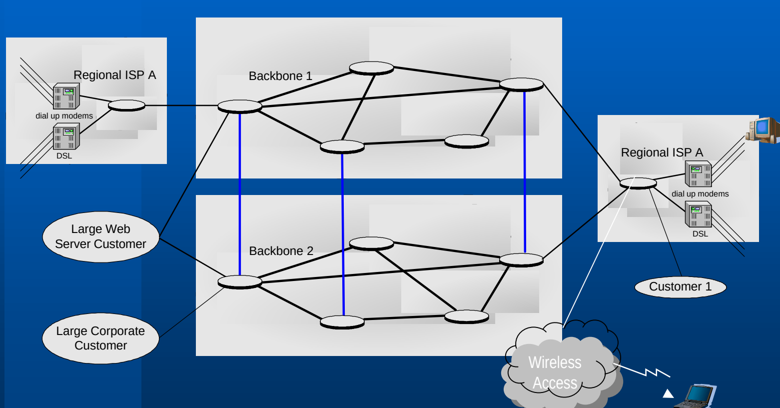
Delay Impairments

- **Interactivity impairment:**
  - Depends on "task" and total delay
- **Echo impairment:**
  - Depends on echo cancellation and total delay



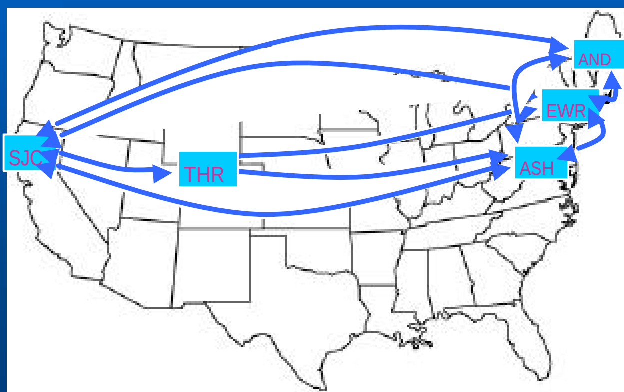


Assessment of Backbone networks



Internet Backbone Measurements

- Probe based measurements (RouteScience).
- Backbone networks of 7 major ISPs.



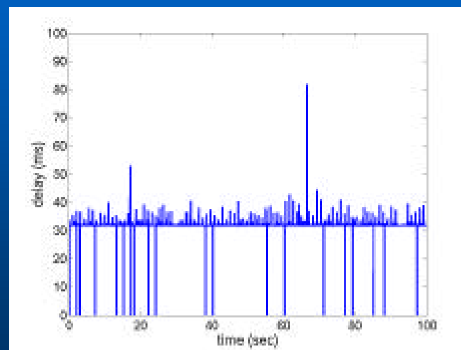
Packet Loss Characteristics

- Rare sporadic single packet loss
- Repetitive single packet loss
- “Clips”: consecutive packets lost
  - 19-25 packets lost
  - Long clips (outages)
    - Duration: 10s of seconds - 2 minutes
    - Usually preceeding changes in the fixed part of the delay
    - Often happen simultaneously on more than one path of a provider

Example of Repetitive Single Loss

- 4 paths of an ISP
- 48 hours period
- 1 packet lost every 5 sec on average (0.2% loss)

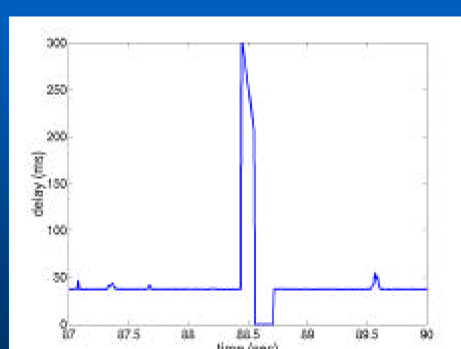
EWR-P3-SJC, Thu 7:20 (UTC)



Example of a Clip

230 ms clip

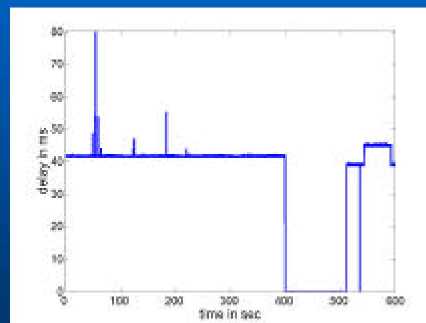
EWR-P2-SJC, Thu, 13:50



Example of Outage

Outage of 112 sec

ASH-P7-SJC, Wed, 4:00



- change in fixed delay
- reverse path: outage 166sec
- next day same time, both paths

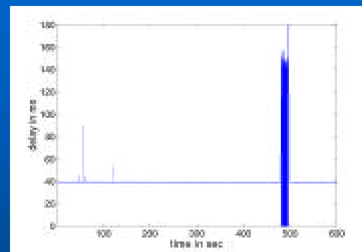
Packet Loss Characteristics

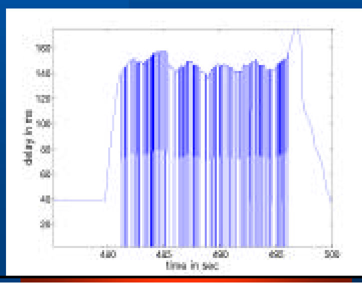
- **Clustered packet loss**
  - **High loss rates (10-80%) for up to 30 sec**
  - **Synchronized with similar events on other paths**
  - **Precede or follow changes in delay**

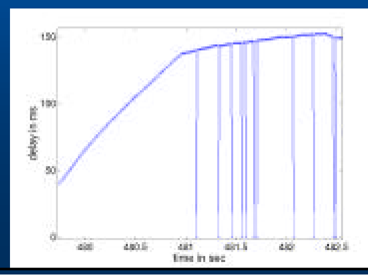
Example of clustered packet loss

EWR-P6-SJC, Wed 3:20 (UTC)

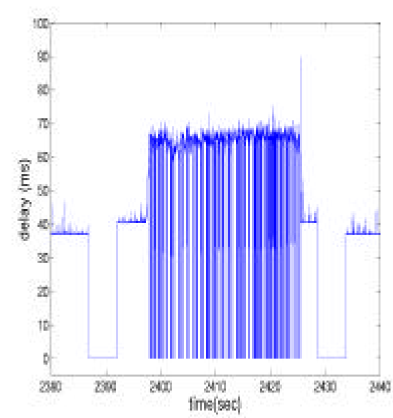
- 9.4% loss: 141 single packets in 15 sec
- Accompanying increase in delay
- Synchronized with events on 3 other paths of the same provider

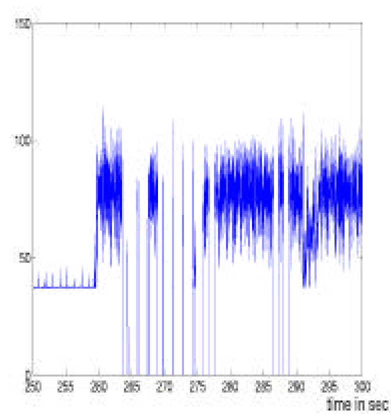






More Complex Loss Events





EWR-P2-SJC Wed 06/27/01 3:30

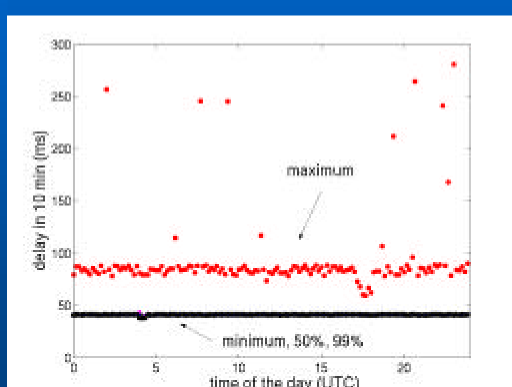
EWR-P2-SJC Thu 06/28/01 20:10

Packet Delay Characteristics

- Low delay variability
- High delay variability
- Mixed behavior

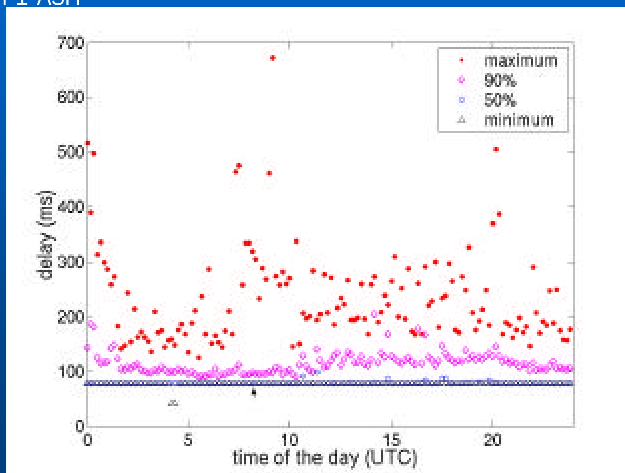
Example 1: Low Delay Variability

- SJC-P7-ASH Wed 6/27/01



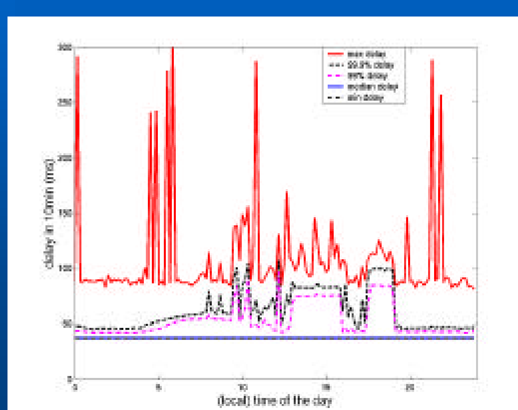
Example 2: High Delay Variability

- THR-P1-ASH



Example 3: Mixed Behavior

- SJC-P2-ASH Thursday 06/28/01

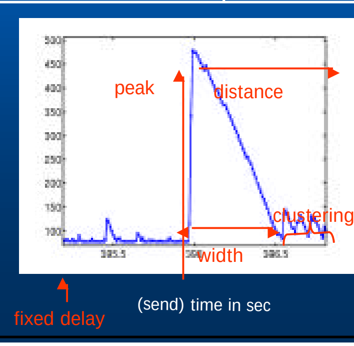


Delay Components

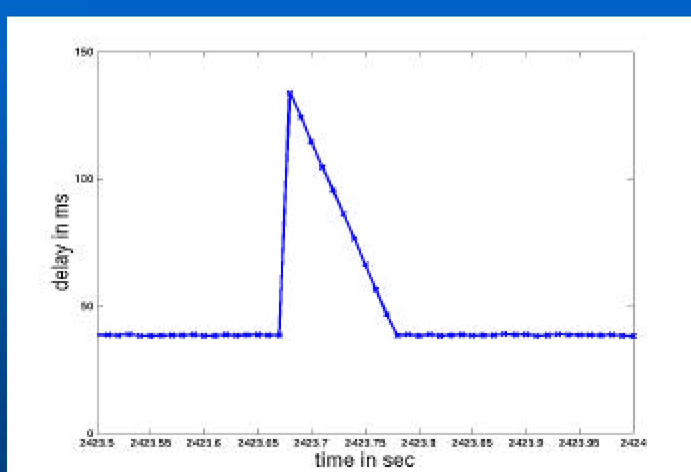
- **Fixed delay:**

Path connecting sites:	Fixed Delay
In the east coast only	3.3 - 12 ms
From/to Colorado	28 – 78 ms
Coast-to-coast	31 - 47 ms

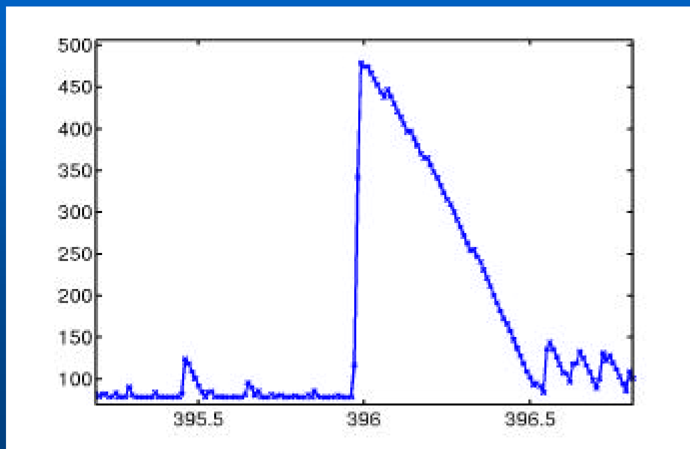
- Delay variability:
  - Mostly in the form of spikes
    - less frequently congestion
  - There are consistent patterns per provider/path/time



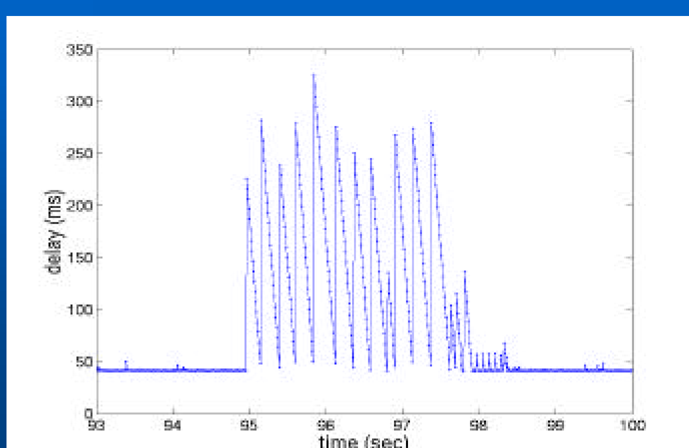
Simple Spike From P7 (A)



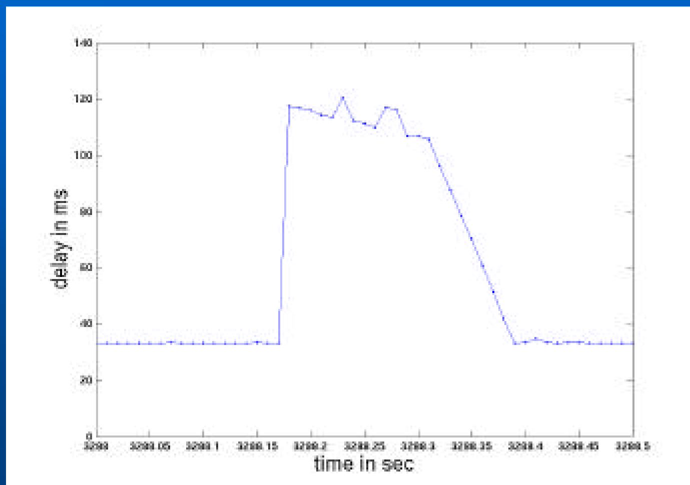
High Spike From P1 (B)



Cluster of Spikes From P4 (C)

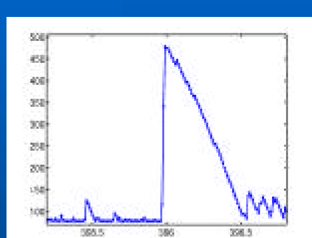


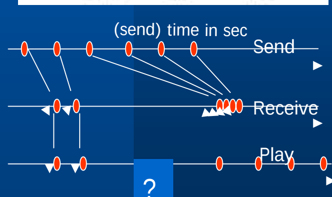
Non Triangular Spike From P5 (D)



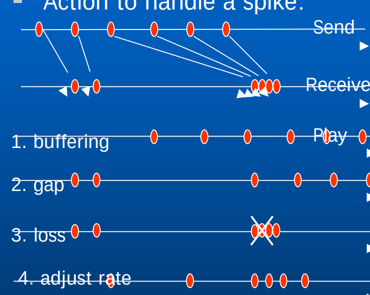
Effect of Delay Jitter

- A spike means that packets arrive bunched-up





- Action to handle a spike:



- Playout scheduling

For more information

- A. Markopoulou, F. A. Tobagi and M. Karam, "Assessment of VoIP quality over Internet backbones," Proceedings of the IEEE INFOCOM 2002, New York, June 2002.
- F. A. Tobagi, A. P. Markopoulou and M. J. Karam, "Is the Internet Ready for VoIP?" Proceedings of the 2002 Tyrrhenian International Workshop on Digital Communications – IWDC 2002, Capri, Italy, September 2002.
- A. P. Markopoulou, F. A. Tobagi and M. J. Karam, "Assessing the Quality of Voice Communication over Internet Backbones," *IEEE/ACM Transactions on Networking*, Vol.11, No. 5, Ocotber 2003, pp. 747-760.

VoIP Over 802.11 Wireless LANs

VoIP Performance

- Capacity of a voice-only 802.11 network:
  - Maximum number of simultaneous voice calls that can be supported -

    For a given MOS requirement
- Distribution of voice quality across users taking into account channel conditions (frequency selective fading)

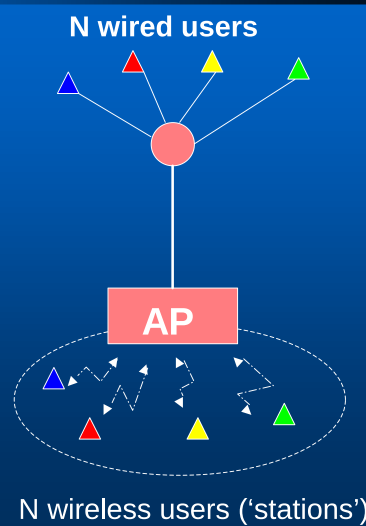
802.11 Key Features

- CSMA/CA
  - "Listen before you talk"
- No collision detection
  - Frames are positively acknowledged
- Collisions and errors in transmissions
  - Retransmissions
  - Random delay
  - Packet may eventually be dropped

Network Scenario

Single Basic Service Set (BSS)

802.11(b) at 11 Mb/s



An Upper Bound on Capacity

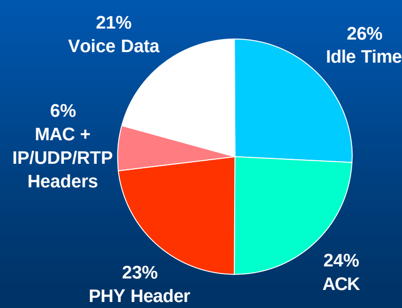
Analysis assuming no collisions and no errors

Encoder (data rate)	Voice Data Per Frame		
	10ms	30ms	50ms
G.711 (64kbps)	6	18	26
G.729 (8kbps)	7	22	35

- ***Don’t get 8x capacity using 1/8 rate!***
- ***For maximum capacity, use G.729 with 50ms voice per packet***

Where Does the Time Go?

G.711 (64kbps), N = 18, 30ms speech/packet



How Tight Is the Upper Bound?

- **Simulation with no errors**

	Voice Data per frame		
	10ms	30ms	50ms
G.711	6 (6)	17 (18)	25 (26)
G.729	7 (7)	21 (22)	34 (35)

Simulation (analysis)

- **Effect of collisions is very low…**

… for this scenario!

Observations

- Access Point is a bottleneck
  - Frames dropped in AP downlink queue
- Very few collisions occur
  - Typically, probability of collision for any given transmission ~ 3% at AP
- Failure is sudden
  - quality at (Nmax + 1) is very poor

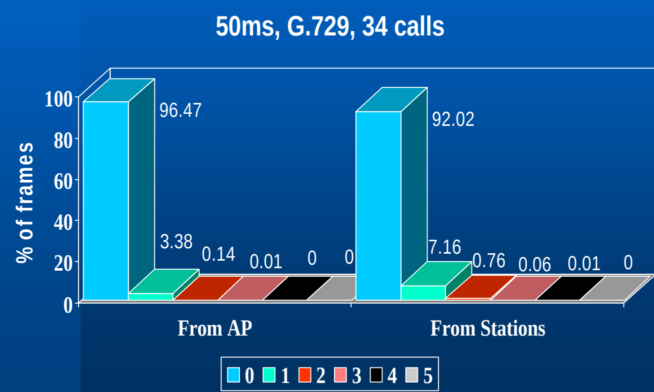
How many collisions does a frame incur?

	G.711			G.729		
Voice Data per frame (ms)	10	30	50	10	30	50
Capacity	6	17	25	7	21	34
AP	1.6	2.8	3.9	2.7	3.5	3.7
Stations	2.0	5.3	8.7	3.2	6.1	8.9

Probability of transmission colliding (%)

Retransmissions

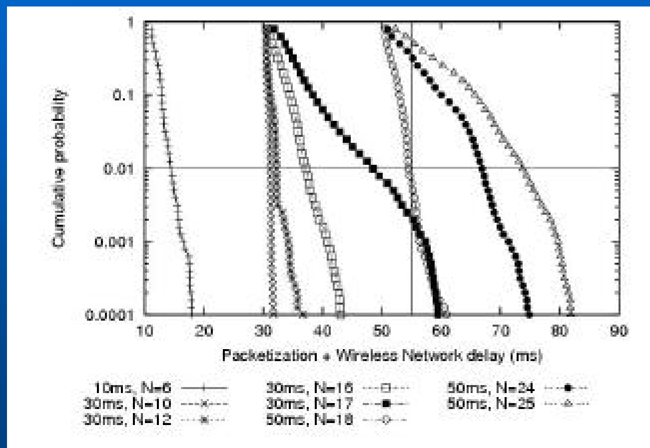
- How many packets incur *x* collisions?



Capacity with Delay Constraints

- Target MOS; e.g., 3.6, 4.0
- Playout deadline:
  – 150ms causes no degradation in MOS [source: ITU E-model]
- Maximum acceptable loss rate
  – e.g. for G.711, 10ms packets, MOS 3.6, maximum acceptable loss rate is 4.9% [source: ETSI TR 101 329-6 v.2.1.1, 2002]
- Delay budget for wireless network + packetization

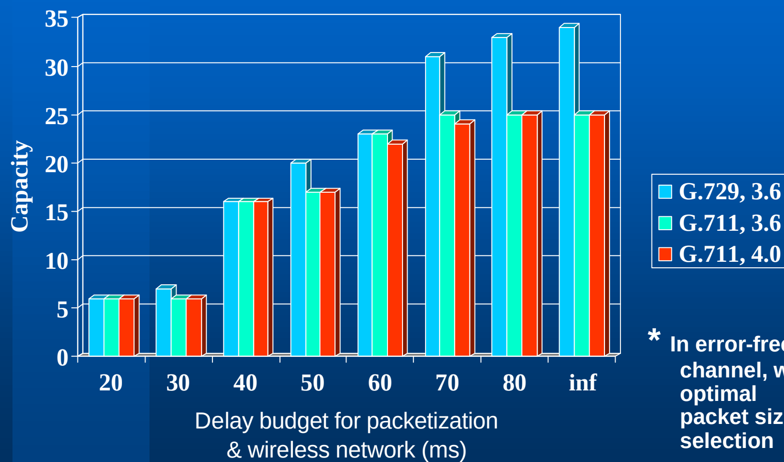
Delay CCDF – G.711



Tradeoffs & Limitations

- **Packet Size:**
  - **Larger packets increase capacity, but have high packetization delay cost**
  - **Harder to conceal loss of longer packets**
- **G.729 vs. G.711:**
  - **G.729 requires 5ms look-ahead at encoder**
  - **G.711 has lower capacity with no delay constraints**
  - **G.729 has lower intrinsic quality (3.65 vs 4.15 for G.711)**

Delay-constrained Capacity*



* In error-free channel, with optimal packet size selection

Observations

- Capacity highly sensitive to delay budget
  - May be worth increasing delay budget, sacrificing MOS for higher capacity
  - Wireless Network Delay is low for N < capacity
- Very similar results for G.729/G.711
- Low sensitivity to MOS requirement
- Optimal packet size can be obtained considering packetization delay only

Capacity with Delay Constraints

- What happens if we consider frame errors?

Channel Errors - Intuition

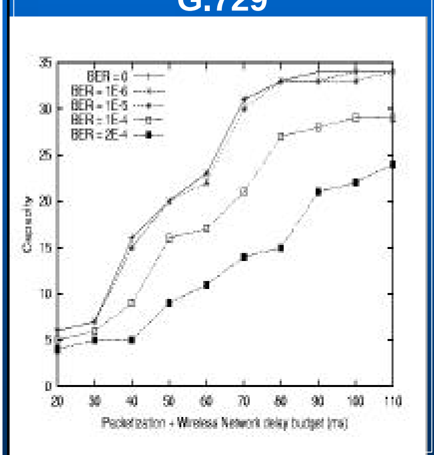
- Channel errors decrease capacity and increase delay:
  - More retransmissions require more time on the medium
  - Each packet requires (on average) more transmissions

Channel Errors – Approach

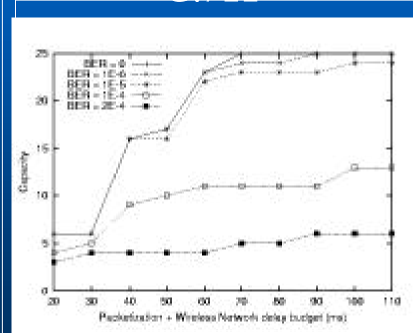
- **Constant BER model**
  - **All stations + AP experience equal channel conditions**
- **BER from 10^{-6} to 2×10^{-4}**
  - **Capacity for BER ³ 10^{-3} is 0**
- **PHY header assumed to be received correctly**
  - **Transmitted at 1Mbps**
- **All MAC frame errors are detected, but cannot be corrected**

Capacity for MOS = 3.6

G.729



G.711



For more information

- **David P. Hole and F. A. Tobagi, “Capacity of an IEEE 802.11b Wireless LAN Supporting VoIP,” Proceedings of the International Conference on Communications, ICC 2004, Paris, France, June 2004.**

http://mmnetworks.stanford.edu/papers/hole_icc04.pdf

VoIP Over IEEE 802.11a

System Parameters

- ETSI indoor channel A.
  - Typical office environment with non-line of sight NLOS.
  - RMS delay spread - 50 ns.
  - Maximum delay spread - 390 ns.
- Packet size – 154 bytes.

Average VoIP Quality Ignoring Fading

Average MOS in a non-fading Channel

	Data Rates - Mbps							
$\widetilde{SNR}$ dB	6	9	12	18	24	36	48	54
5	4.50	4.43	3.84	1.00	1.00	1.00	1.00	1.00
10	4.50	4.50	4.50	4.50	1.00	1.00	1.00	1.00
15	4.50	4.50	4.50	4.50	4.50	4.49	1.00	1.00
20	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.08
25	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50

Average VoIP Quality With Fading

Average MOS in a Fading Channel

	Data Rates - Mbps							
$\widetilde{SNR}$ dB	6	9	12	18	24	36	48	54
5	2.26	1.30	1.43	1.06	1.00	1.00	1.00	1.00
10	3.96	2.52	3.14	1.67	1.28	1.01	1.00	1.00
15	4.43	3.85	4.27	3.13	2.85	1.43	1.04	1.01
20	4.50	4.42	4.49	4.14	4.19	2.83	1.78	1.34
25	4.50	4.49	4.50	4.46	4.48	4.02	3.44	2.71

Call Quality Distribution (No Retransmissions)

Percentage of Calls with $MOS \leq MOS_t$

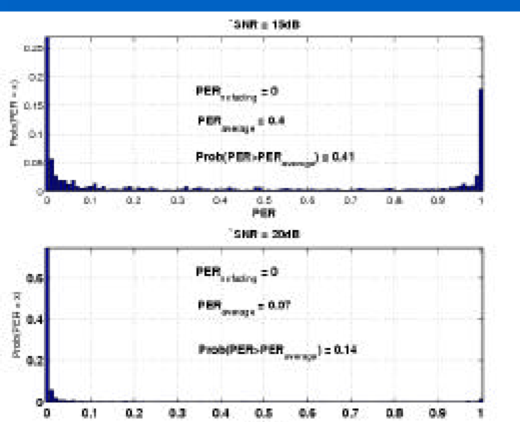
Data Rates Mbps	$\widetilde{SNR}$ dB	Dist. Meters	$MOS_t = 2.6$	$MOS_t = 3.6$	$MOS_t = 4.0$	$MOS_t = 4.3$	Ave. MOS
6	15	36	1.5	2.0	2.1	3.2	4.43
6	20	28	0	0	0	0.1	4.5
12	20	28	0.3	0.5	0.5	0.9	4.49
12	25	23	0	0	0	0	4.5
24	20	28	7.9	10.1	11.4	14.8	4.19
24	25	23	0.4	0.6	0.8	1.5	4.48
48	30	17	4.8	6.0	6.8	7.7	4.32
48	35	12	0.1	0.4	0.4	0.9	4.49
54	30	17	12.8	16.8	19.0	23.1	3.99
54	35	12	2.0	2.4	3.3	4.6	4.42

Call Quality Distribution (up to 3 Re-tx)

Percentage of Calls with $MOS \leq MOS_t$ with 3 Retransmissions

Data Rates Mbps	$\widetilde{SNR}$ dB	Dist. Meters	$MOS_t = 2.6$	$MOS_t = 3.6$	$MOS_t = 4.0$	$MOS_t = 4.3$	Ave. MOS
6	15	36	0.7	0.8	0.8	1.2	4.48
6	20	28	0	0	0	0.1	4.5
12	20	28	0	0	0.2	0.2	4.5
12	25	23	0	0	0	0	4.5
24	20	28	4.6	5.0	5.6	6.7	4.33
24	25	23	0.07	0.07	0.1	0.2	4.49
48	30	17	2.3	2.5	2.9	3.2	4.42
48	35	12	0	0	0	0	4.50
54	30	17	7.5	8.1	9.0	10.2	4.23
54	35	12	0.5	1.0	1.2	1.4	4.47

Packet Error Rate Distribution



Histograms of PER for 24Mbps at $\widetilde{SNR} = 15$ & 20 dB

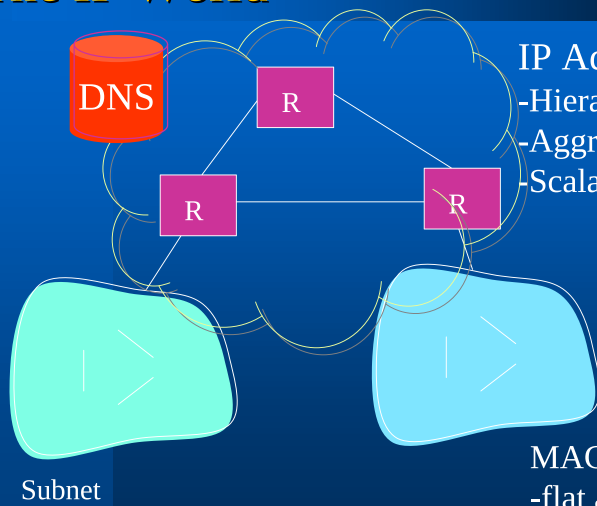
For more information

- Olufunmilola Awoniyi and F. A. Tobagi, "Effect of Fading on the Performance of VoIP in IEEE 802.11a WLANs," Proceedings of the International Conference on Communications, ICC 2004, Paris, France, June 2004.

http://mmnetworks.stanford.edu/papers/Awoniyi_icc04.pdf

Role of Layer 2 Technologies in Mobility Management

The IP World

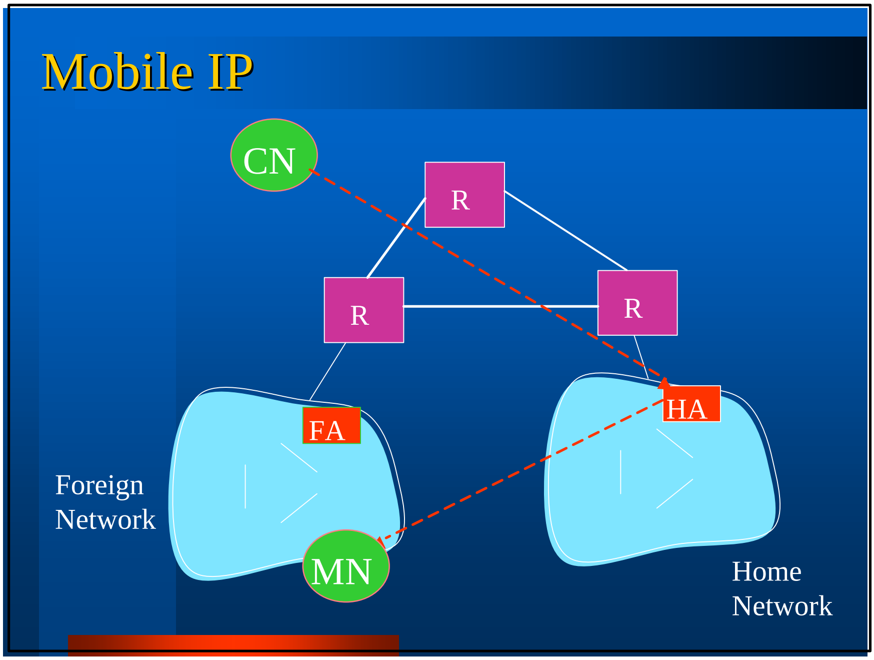


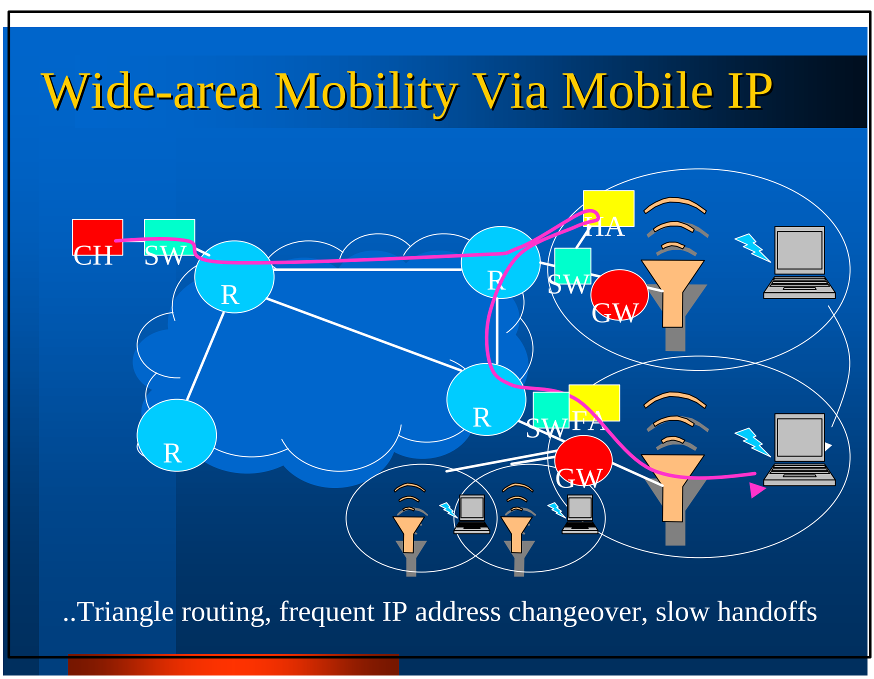
IP Addressing:
-Hierarchical
-Aggregate entries
-Scalable

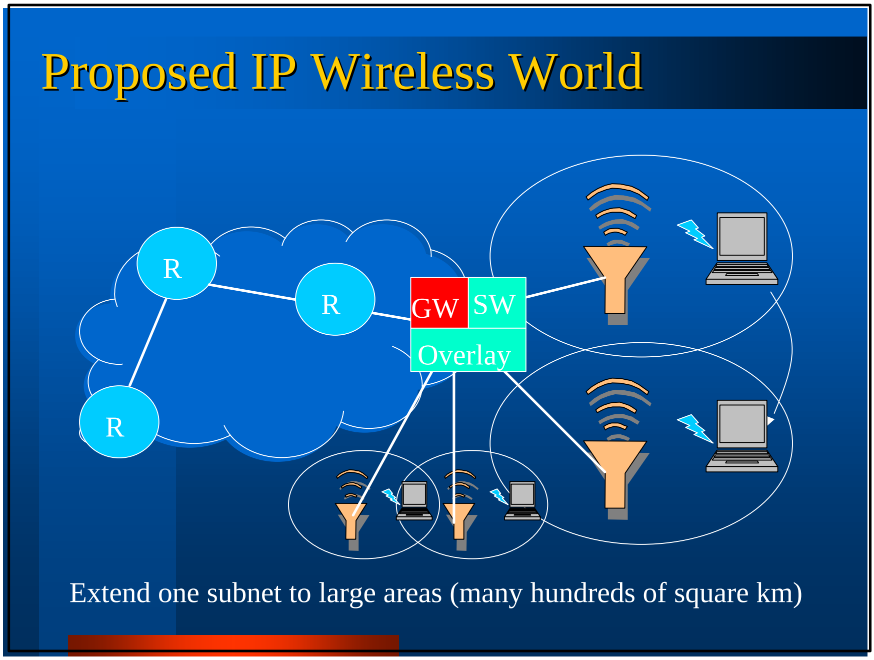
MAC Addressing
-flat address space
-Individual address

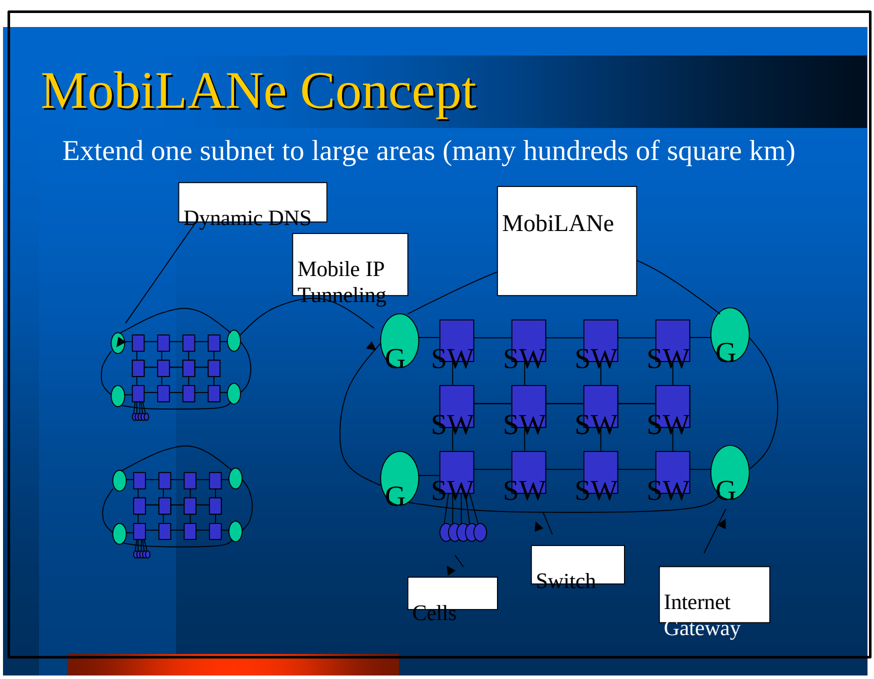
Tracking and Routing in the Internet

Directory (DNS)	Gives a fixed IP address	Persistent and Complete
Layer 3	Route to the user subnet	- Static - Scalability by address aggregation
Layer 2	Learns about user	Highly Dynamic


Mobile IP
CN
R
R
R
FA
HA
Foreign Network
MN
Home Network


Wide-area Mobility Via Mobile IP
CH
SW
R
R
R
R
HA
SW
GW
SW
FA
GW
..Triangle routing, frequent IP address changeover, slow handoffs


Proposed IP Wireless World
R
R
R
GW
SW
Overlay
Extend one subnet to large areas (many hundreds of square km)


MobiLANe Concept
Extend one subnet to large areas (many hundreds of square km)
Dynamic DNS
Mobile IP Tunneling
MobiLANe
G
SW
Cells
Switch
Internet Gateway

Issues

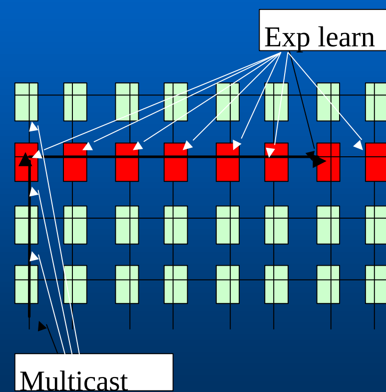
- What structure should the network have?
- What are appropriate protocols for user tracking and routing?
- What is the optimal size of the network?
- What is its reliability?

Tracking and Routing Issues

- Passive learning and flooding
  - Fast mobility => learning quickly obsolete => more flooding => not scalable to many users (bandwidth overload at switches and possibly links)
  - Tracking along spanning trees => slow updates for movement between certain sections of the tree
- Flat address space
  - Large, unstructured databases at nodes in the spanning tree (especially close to the root). Address distribution via multiple spanning trees helps, but only by a constant factor at best
  - Inherent tradeoff of memory technology (fast access => small size; Large size => slow access)

MobiLANe

- Instead, use <u>explicit learning</u> (GARP like protocol)
- Combine learning with <u>selective multicast</u> to reduce database size and improve worst-case updates
  - Concept similar to *m-regional matching* (Awerbuch-Peleg 1995) but made practical
- Use <u>cache hierarchies</u> to optimize lookups

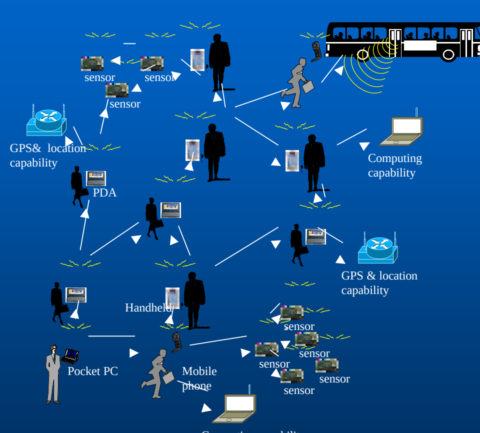


For more information

- C. Hristea and F. A. Tobagi, "IP Routing and Mobility," Proceedings of IWDC 2001, Taormina, Italy, September 2001, Springer Verlag LNCS, Vol. 2170.
- C. Hristea and F. Tobagi, "A network Infrastructure for IP Mobility Support in Metropolitan Areas," *Computer Networks*, Vol. 38, pp. 181-206, February 2002.
- C. Hristea and F. A. Tobagi, "Optimizing Mobility Support in Large Switched LANs," Proceedings of the IEEE International Conference on Communications, ICC 2003, Anchorage, Alaska, May 2003.

Ad Hoc Networks

A Scenario

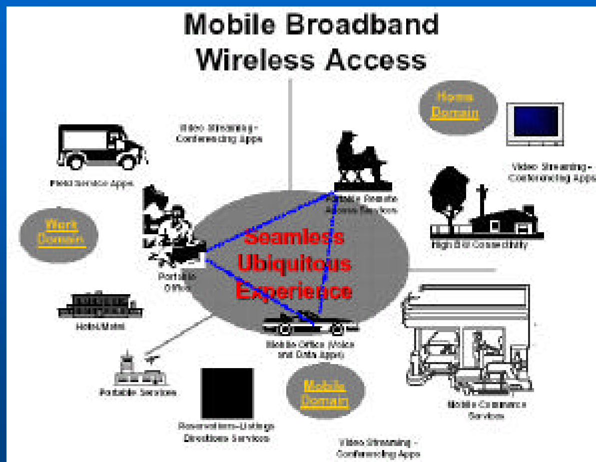


Source: A. Helmy, USC, "Service Provisioning in Large-scale Infrastructure-less Wireless Networks"

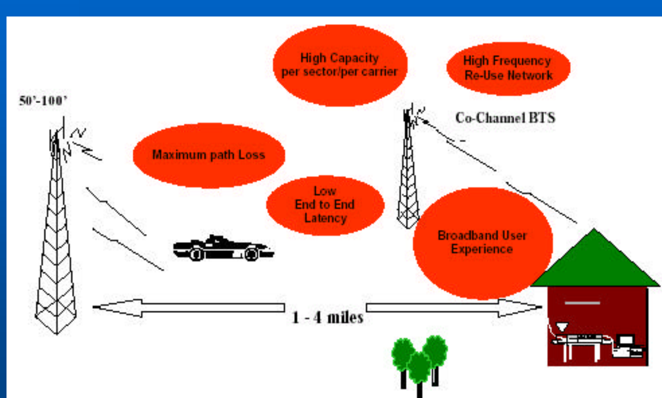
Ad Hoc Networks

- Made its debut for applications in military tactical operations (Packet Radio Network, Survivable Radio Network, etc.)
- Made possible by the use of packet switching
- Easy deployable
- Wider area coverage without the need for infrastructure
- Many applications scenarios

IEEE 802.20



Source: IEEE 802.20 Requirements Document – Ver. 9, November 5, 2003



Source: IEEE 802.20 Requirements Document – Ver. 9, November 5, 2003

- The 802.20 Air-Interface (AI) shall be optimized for high-speed IP-based data services operating on a distinct data-optimized RF channel.
- The AI all shall support interoperability between an IP Core Network and IP enabled mobile terminals and applications shall conform to open standards and protocols.
- The MBWA will support VoIP services. QoS will provide latency, jitter, and packet loss required to enable the use of industry standard Codec's.
- The 802.20 systems must be designed to provide ubiquitous mobile broadband wireless access in a cellular architecture.
- allowance for indoor penetration in a dense urban, urban, suburban and rural environment.

Source: IEEE 802.20 Requirements Document – Ver. 9, November 5, 2003