The Bay Area Research Wireless Access Network: Towards a Wireless Overlay Internetworking Architecture

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Subcontractor: Hughes Malibu Research Laboratories
Presentation Outline

• Retreat Purpose and Agenda
• Project Objectives, Motivation, and Approach
• Project and Testbed Status
• Technology Developments
• Review Project Plan and Directions
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Retreat Goals & Technology Transfer

UC Berkeley Project Team

People
Project Status
Work in Progress
Prototype Technology

Early Access to Technology
Promising Directions
Reality Check
Feedback

Industrial Collaborators
Government Sponsors
Friends
The UC Berkeley/Hughes Team

• Networking
  – Hari Balakrishnan (Reliable Transport)
  – Todd Hodes (Wide Area Roaming)
  – Daniel Jiang (Link Resource Mgr)
  – John Loffeld (System Support)
  – Ken Lutz (Network Infrastructure)
  – Giao Nguyen (Mobility Traces)
  – Venkat Padmanabhan (Mobile Routing)
  – Keith Sklower (System Suppor)
  – Mark Stemm (Vertical Handoff)

• Applications
  – Elan Amir (Collab Applications)
  – Yatin Chawathe (Proxy Resource Management)
  – Armando Fox (Proxy Architecture)
  – Steve Gribble (Mobile Applications)
  – Tao Ye (Mobile Applications)

• Admin Support
  – Terry Lessard Smith
  – Bob Miller
  – Patric Bodin

• Hughes Malibu Research Laboratory
  – Son Dao
  – Yongguang Zhang
  – Dante Vitteli
BARWAN Sponsors and Participants

• DARPA GloMo Program
  – DARPA PM, CECOM Agent, US Army
  – SRI Program Coordinator

• California MICRO Program
  – Hughes Aircraft
  – Daimler Benz
  – PCSI
  – GTE

• Other Support
  – Metricom
  – IBM
  – Xerox Fuji

• Friends
  – National Semiconductor, Ericsson
  – Stanford, UCSC, UCSF
Retreat Schedule

• Tuesday, June 18:
  – 12:00 Check-in and Lunch
  – 1:00 PM Project Overview, Randy Katz
  – 3:00 PM Break
  – 6:00 PM Dinner
  – 7:30 PM Posters and Technology Demos
    » UCB, UC Santa Cruz, and Stanford Research Groups
    » Refreshments will be served
  – 9:00 PM Gaming Strategies and Brewing Benchmarks
Retreat Schedule

• Wednesday, June 19:
  – 7:30 AM Breakfast
  – 8:30 AM System Architecture Walkthrough I, Todd Hodes and Steve Gribble
  – 10:00 AM Break
  – 10:30 AM System Architecture Walkthrough II, Todd Hodes and Steve Gribble
  – Noon Lunch
  – 1:30 PM Break
Retreat Schedule

• Wednesday, June 19:
  – 4:00 PM Research Highlights
    » Network Performance Measurement: Elan Amir, Venkat Padmanabhan
    » TCP Performance Over Lossy Links: Hari Balakrishnan
    » Vertical Handoff: Mark Stemm
    » GloMop and Applications Architecture: Armando Fox, Steve Gribble
  – 6:00 PM Dinner
  – 7:30 PM The View from Government and Industry
    » Open Collaboration Architectures: Steve McCanne
    » The View from DARPA: Kevin Mills
    » The View from CECOM: Rob Ruth
    » The View from Industrial Labs: Barry Leiner
  – 9:00 PM Gaming Strategies and Brewing Benchmarks
Retreat Schedule

• Thursday, June 20:
  – 7:30 AM Breakfast
  – 8:30 AM Six Month Planning: Eric Brewer
  – 10:00 AM Break & Room Checkout
  – 10:30 AM Industry and Visitor Feedback
  – Noon Lunch
  – 1:00 PM Depart for Home
Presentation Outline

• Retreat Purpose and Agenda
• **Project Objectives, Motivation, and Approach**
• Project and Testbed Status
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• Review Project Plan and Directions
Access is the Killer App

• Objectives
  – Given widely varying display, computing, and hybrid/asymmetric communications capabilities:
    » Provide access to the same capabilities as your desktop environment while on the move
    » Be connected whenever possible via the “best” available network
    » Support graceful application adaptation to the available bandwidth and latency

• Key Technical Strategies
  – Wireless Overlay Internetworking Architecture
  – Network- and Type-Aware Applications Building Blocks
Wireless Overlay Concept

- In-Building
- Campus-Area Packet Relay
- Metropolitan-Area
- Regional-Area
- Theatre of Operations
- Rear Echelons
- Bases, Depots, Ranges
- Command Centers
- Training Centers
Asymmetric, Heterogeneous, and Hybrid Access

- Command Post
- Disaster Relief
- Remote Clinic
- Organization w/poor Internet connectivity

Local Subnet

High Bandwidth

Low Bandwidth
Client-PROXY-Server Architecture

• Proxy
  – Mediates between wireless and wireline environment
  – Ideally executes at “well-connected” boundary of internetwork
  – Manages caches and chooses transport data representations on-the-fly
  – Trade transcoding time against communications time
Bandwidth Adaptive Application Interfaces

Application Support:
- Subtype specific modules
- Transmission constraints

Network Management:
- Routing & handoff
- Choose subnet based on application constraints, network capabilities

Connection Monitor:
- Determines network perf.
- Collects statistics for representation/subnet choices

Applications can be proxy and/or mobile aware, but need not be
# Overlay Network Challenge

<table>
<thead>
<tr>
<th>Type of Network</th>
<th>Bandwidth</th>
<th>Latency</th>
<th>Mobility</th>
<th>Typ Video Performance</th>
<th>Typ Audio Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-Building</td>
<td>&gt;&gt; 1 Mbps</td>
<td>&lt; 10 ms</td>
<td>Pedestrian</td>
<td>2-Way ’ractive Full Frame Rate (Comp)</td>
<td>High Quality 16-bit Samples 22 Khz Rate</td>
</tr>
<tr>
<td></td>
<td>Comm’l RF: 2 Mbps</td>
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<tr>
<td></td>
<td>Research IR: 50 Mbps</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Campus-Area Packet Relay</td>
<td>≈ 64 Kbps</td>
<td>≈ 100 ms</td>
<td>Pedestrian</td>
<td>Med. Quality Slow Scan</td>
<td>Med. Quality Reduced Rate</td>
</tr>
<tr>
<td>Network</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wide-Area</td>
<td>19.2 Kbps</td>
<td>&gt; 100 ms</td>
<td>Vehicular</td>
<td>Freeze Frame</td>
<td>Asynchronous &quot;Voice Mail&quot;</td>
</tr>
<tr>
<td>Regional-Area (LEO/DBS/VSAT)</td>
<td>4.8 kbps–10+ Mbps (asymmetric)</td>
<td>&gt; 100 ms</td>
<td>Vehicular Stationary</td>
<td>Seconds/Frame Freeze Frame</td>
<td>Asynchronous &quot;Voice Mail&quot;</td>
</tr>
</tbody>
</table>

Latency as critical as bandwidth in wireless networks
Wide diversity of network performance parameters
Competing infrastructure providers
Pedestrian vs. vehicular mobility
Application Support Challenge

<table>
<thead>
<tr>
<th>Device</th>
<th>Bandwidth, bits/sec</th>
<th>CPU</th>
<th>Mem/Disk</th>
<th>Screen size</th>
<th>Bits/pixel</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-end PC</td>
<td>Ethernet (10Mbits), ISDN (128K)</td>
<td>120 Mhz Pentium</td>
<td>16/2G</td>
<td>1280x1024</td>
<td>16-24, color</td>
</tr>
<tr>
<td>Low-end PC</td>
<td>ISDN (128K)</td>
<td>75-100 Mhz Pentium</td>
<td>8/500</td>
<td>1024x768</td>
<td>8-16, color</td>
</tr>
<tr>
<td>High-end notebook</td>
<td>Cellular (9600) or wireline (28.8K) modem</td>
<td>50-66 Mhz 486</td>
<td></td>
<td>800x600</td>
<td>8, color</td>
</tr>
<tr>
<td>Low-end notebook</td>
<td>(28.8K) modem</td>
<td></td>
<td></td>
<td>640x480</td>
<td>4, gray</td>
</tr>
<tr>
<td>PDA</td>
<td>2400-14.4K modem</td>
<td>20 Mhz RISC or x86</td>
<td>2/0</td>
<td>320x200</td>
<td>1–2, gray</td>
</tr>
</tbody>
</table>

Client variation spans an order of magnitude
Collaboration Heterogeneity

- **PC**
  - 8 bit frame buffer
  - 75 MHz Pentium (2.31 SpecInt95)
  - No compression hardware

- **Internet (MBone)**

- **Private Network**
  - PC’s
  - Workstations
  - Laptops

- **High-end Workstation**
  - UltraSparc2 (6.41 SpecInt95)
  - Hardware Compression
  - 24 bit frame buffer

- **Pen-based Computer**
  - Gray scale LCD display
  - Low power processor
  - Limited I/O bandwidth
  - No multicast support

- 1.54 Mbps
- 128 kbps
- 10 Mb/s
Architectural Issues

• Dynamic resource allocation and adaptation
  – Proxies: adapt representation and degree of compression to available bandwidth and latency
    » Scheduling data streams for a given client
    » Discovery versus notification from the network
    » Proxy transcoder load balancing
  – Network: meet bandwidth guarantees for classes of users and types of data
    » Scheduling data streams for clients sharing the same bandwidth constrained (wireless) link
    » Load balancing across overlay networks

• Leverage existing Internet standards
  – Mobile IP, Service location protocols, HTTP, POP, etc.
  – But allow architecture-aware applications to obtain enhanced functionality
The Daedalus/GloMop Architecture

mobile host

GloMop

NCM

Handoff controller

CBQ agent

base stations

beacond

snoop

decapd

proxy host

Proxy

NCM

domain services

Authentication

Metering & Credit

Subnet manager

Mobility database

subnet services

Foreign agent

Resource Mgmt

corresponding host

content server

PTM

Distillers

delivery class abstraction
Daedalus Network Components

- mobile host
  - GloMop
  - NCM
  - CBQ agent
  - Handoff controller
  - base stations
    - beacond
    - CBQ
    - snoop
    - decapd

- proxy host
  - Proxy
  - NCM
  - PTM
  - Distillers
  - delivery class abstraction

- domain services
  - Authentication
  - Metering & Credit
  - Subnet manager
  - Mobility database
  - Foreign agent
  - Resource Mgmt

- subnet services
  - Abstract

- corresponding host
  - content server
GloMop Application Support Components

- mobile host
  - GloMop
    - NCM
      - Handoff controller
        - CBQ agent
  - base stations
    - beacond
    - snoop
    - decapd

- proxy host
  - Proxy
    - NCM
      - KDC / TGS
      - Metering & Credit
      - Subnet manager
      - Mobility database
      - Foreign agent
        - SLP server
  - Distillers
    - PTM

- domain services
  - content server

- subnet services
  - corresponding host
    - delivery class abstraction
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Project Strategy

Architectural Design
Scaled Implementations

√ Early Prototypes
√ Proof of Concepts
√ Measurements & Evaluation
Project Plan and Status

Project Start: 15 Aug 95
*(Start + 10 Months)*

- Early Proof of Concept Implementations
- Establishment of BARWAN Testbed
- Functionality
  - Demonstrate Seamless Roaming over Local and Wide Area
  - OOTW/LE Spin Off
  - Measure Alternative Overlay Network Performance

- Scalability
  - Demonstrate Ability to Scale to Large Communities of Mobile Users
  - NOWs
    - Wireless Overlays
    - Enhanced Net Performance
  - Extend with Emerging Technologies
Achievements—January 1996

• Establishment of heterogeneous wide-area and local area wireless access technology testbed (“BARWAN”)

• “Proof of concept” prototypes of proxies for web/image, video, postscript, maps
  – Leveraged in UCB InfoPad and UCLA WAMIS Projects

• Prototype bandwidth adaptive applications
  – PDA MIME mail, Internet conferencing/collaboration tools

• Prototype implementations of reliable transport and mobile handoff mechanisms
  – Algorithms leveraged in UCB InfoPad Project

• Development of industrial collaborations for eventual technology transfer
Achievements—June 1996

• Enhancement of BARWAN Testbed
  – Successful integration of Metricom WAP, Unix DBS Driver, Infrared
  – Implementation and evaluation of vertical handoff
  – Transfer of software to SRI for evaluation in OOTW/LE testbed

• Proxy Development
  – Demonstration of Internet Video over DBS, Metricom packet radio
  – Demonstration of rapid proxy adaptation across vertical handoffs

• Reliable Transport
  – Deployment of Snoop Agent in UCSC Reinas Wide Area Testbed
  – Dramatic improvement in performance for wide-area sensor network

• New Industrial Collaborations
  – PCSI, Daimler Benz join BARWAN consortium
  – Geoworks for proxy software technology transfer
  – Serious discussions with Ericsson and Nokia
Local Area Wireless Testbed
Soda Hall, UC Berkeley

Scalable, High Bandwidth Low Latency Switches

Organized Fiber Physical Links

Wireless Transceivers

Computing / Interactive “Light” workstations

Interactive Media Access workstations

Dedicated Computing Resources
~100 “dark” workstations + mass store, special servers

- Cooperative Wireless Overlay Networks
  - In-building IR and RF subnets share same base stations
  - Support low latency vertical handoffs
Wide-Area Wireless Testbed

Non-Cooperating Wide-Area Wireless Networks: no control of base stations

- Metricom PR Network
- DirecPC DBS Service
  - Cellular Modems
  - Cellular Digital Packet Data
  - **Wireless Cable Modems**
  - **GSM General Packet Radio Service**
BARWAN Testbed

Internet

Gateway

Metricom "WAP"

Gateway

Soda Hall

DirecPC Basestation

Hughes DBS Basestation

Internet Gateway

Soda Hall

BARWAN Testbed

Circuit Switched Cellular & Cellular Digital Packet Data

+ Ethernet

Metricom Wide Area

WLAN RF
IBM IR

Base Station

Gateway

Metricom "WAP"
BARWAN Testbed

- Metricom Packet Radio
- WaveLAN PCMCIA Card
- CDPD Modem
- IR PCMCIA Card
- IBM ThinkPad 755x BDSI OS 2.1
BARWAN Testbed Extensions

Reinas Env. Monitoring Network
Monterey Bay

Profs. Patrick Mantey, Darrell Long

Tetherless Access Long Haul Links
WaveLAN Point-to-Point Links

Snoop deployment along the WaveLAN links—significant improvement in TCP performance observed
BARWAN Testbed Extensions

Wireless Cable Modem
10 Mbps downlink

ITFS Transmitter
Grizzly Peak

Soda Hall
Dwinelle Hall

Asymmetric bandwidth with hybrid connectivity
BARWAN Testbed Extensions

- PDA + Modem + Digital Cell Phone
- PCS 1900
- PacBell Mobile Services deployment in Bay Area
- Fall 1996

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

Internet

Internet Gateway

Proxy Server

BSS

MSC

PSTN

Cellular Infrastructure
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Mobile Computing Challenges

Low Data Rate
High Latency
Unreliability
Mobility

Adaptability
Overlay Routing: Mobile IP + Multi-homed Hosts

Choice of routing path based on:
- Bandwidth
- Latency
- Coverage
- Load
- P(Retranmission)
- Cost

Vertical Handoff
Low Latency Handoff

Use hints about terminal trajectory to form MC groups

Multicast packets to “regional” base stations to smooth hand-offs for R/T streams

Minimize location update traffic to home agent and mobility aware CHs
Reliable Mobile Transport: Snoop Packet Filter

Local retransmissions
TCP acks
Nack lost packets
Retransmit

TCP-aware agent at BS
End-to-end semantics unchanged

Cache unacknowledged packets at BS (costs extra “soft” state)
Perform local retransmissions based on duplicate acks & time outs

Base station explicitly NACKs lost packets from MH using Selective Ack (SACK) mechanism
Video Stream Proxy: Video Gateway

Heterogeneous Video Conferencing Environments
RTP knowledgeable; multicast-to-unicast routing

High Bandwidth Audio/Video Stream
1 - 2 mbps

Layered DCT

128 kbps
256 kbps

Infopad VQ

JPEG Decoder
LDCT Encoder
H.261 Decoder
H.261 Encoder
Nv Decoder
Ipadvq Encoder

Infopad VQ
Web Proxy: On-Demand Distillation

- Lossy compression that preserves semantic content
- Each *transcoder* is datatype-specific, and not just images:
  Postscript to HTML
  Compressed HTML
  Progressive Map Refinement
- Distillation works in real time on desktop PCs
PDA Applications

• Integrate PDA “islands” with desktop/wireline world via Internet standards
• Proxy Mail: Virtual folders, MIME images, graceful disconnection
• Proxy architecture for authentication, white board
Major Recent Research Activities

• Overlay Networks
  – Vertical Handoffs (research highlight and demonstration)
  – TCP Performance over Lossy Links (research highlight)
  – Measurement of Metricom, DBS Performance (research highlights)
  – Trace Collection and Analysis (poster)

• Application Support
  – Web Proxy Architecture Enhancements (research highlight)
  – Proxy Support for End-to-end Security (research highlight)
  – Proxy Transcoder Manager (poster)
  – Video Gateway plus video over Direct Broadcast Satellite and Metricom wide area networks (demonstration)
Lake Tahoe Demonstration

Galaxy IV Satellite

Hughes Van

DBS IR
WaveLAN
Cellular Modem

Video Source

SLIP Connection

Soda Hall
U.C. Berkeley

Internet

Maryland

Vertical H/O
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Reliable Transport Performance in Wide-Area Wireless Networks

Problem: Short acks disturb data flow

Yields highly variable RTT estimates

Problem: Contention for acks on the reverse channel
Challenges in Asymmetric Connections

• Reverse channel bandwidth or contention limits connection throughput
  – Forward to reverse bandwidth as large as 1000:1
  – DBS, cable modems, Cellular Digital Packet Data, etc.
  – Some possible approaches:
    » End-to-end rate regulation to regulate burstiness
    » Delayed acknowledgements (ack compression) at the receiver
    » Split connections at bottleneck gateway
      E.g., Caching at cable head end or DBS Earth Station

• Large Bandwidth-Delay Products
  – B/W: >100 kbps to mbps, RTT: 250-500 ms
  – Some possible approaches:
    » Multiple losses in a large window (SACKs)
    » Congestion losses in wired network decrease window size and link utilization
“Remote Collaboration by Proxy”

Resource Manager

Resource Locator

Proxy

Inter-User Link Resource Allocation

Intra-User Resource Allocation
Six Month Plan

• Complete measurement and evaluation of wide-area wireless networks, including Reinas Testbed

• Complete the basic architectural design
  – Functional components, interfaces, protocols
  – Resource (bandwidth, compute cycles) allocation mechanisms and policies for real-time streams as well as image formats

• Commence design for scalability
  – Network Scaling
    » Bandwidth allocation within subnet
    » Load balancing across overlays
    » Hierarchical Foreign Agents in Mobile/Overlay IP
  – Application Support Scaling
    » Scalable processing techniques for proxies
    » Caching strategies for Web access
## Research Plan as Proposed

<table>
<thead>
<tr>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>T1: Overlay Internetwork Management Services</strong></td>
<td>Measure &amp; Eval Ovly Nets</td>
<td>Design for Wide-Area Ovly</td>
</tr>
<tr>
<td></td>
<td>Design for In-Building Ovly</td>
<td>Demo In-Building Ovly Net</td>
</tr>
<tr>
<td><strong>T2: Mobile Application Support Services</strong></td>
<td>Design API &amp; Appl Toolkit</td>
<td>Demo API for In-Building</td>
</tr>
<tr>
<td></td>
<td>Develop Simple Collab Apps</td>
<td>Demo Scaled Apps Perf</td>
</tr>
<tr>
<td><strong>O1: Wide-Area Deployment and Demonstration</strong></td>
<td>Accelerate Design for Wide-Area Ovly Integration</td>
<td>Demo Wide-Area Overlay Design for Multiple Ovlys</td>
</tr>
<tr>
<td><strong>O2: Pilot Application Demonstrations</strong></td>
<td>Deploy In-Build Net@UCSF Eval Med Image Apps Reqs</td>
<td>Design Libr Nav &amp; Med Image Distr Apps using API</td>
</tr>
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# DARPA GloMo Program Goals

<table>
<thead>
<tr>
<th>DARPA GloMo</th>
<th>Daedalus/BARWAN Program</th>
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</thead>
<tbody>
<tr>
<td><strong>FY 96</strong></td>
<td></td>
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<tr>
<td>Adaptive Mobile Internet Services</td>
<td>Measure/eval overlay networking tech</td>
</tr>
<tr>
<td>Location Transparent Computing</td>
<td>Design overlay network architecture</td>
</tr>
<tr>
<td><strong>FY 97</strong></td>
<td></td>
</tr>
<tr>
<td>Demo B/W Adaptive MM Node</td>
<td>Design proxy architecture, API, toolkit</td>
</tr>
<tr>
<td>Demo Advanced Mobile Networking</td>
<td>Prototype proxies for image, video, maps</td>
</tr>
<tr>
<td><strong>FY 98</strong></td>
<td></td>
</tr>
<tr>
<td>Demo Multimedia Conferencing</td>
<td>Design Scalable Proxies/Proxy Trans Mgr</td>
</tr>
<tr>
<td>Demo Continuous Mobility</td>
<td>Arch for “Remote Collaboration by Proxy”</td>
</tr>
<tr>
<td></td>
<td>Overlay IP and Vertical Handoff</td>
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<tr>
<td></td>
<td>Reliable transport for hetero/asym nets</td>
</tr>
<tr>
<td></td>
<td>Demo scalable processing for proxies</td>
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<tr>
<td></td>
<td>Demo seamless roaming over in-building, wide-area wireless overlays</td>
</tr>
</tbody>
</table>
Industrial/University Partnerships

• Research Access to Wireless Network
  – Metricom (Ricochet), GTE MobileNet (CDPD), Hughes Network Systems (DirecPC), \textit{PacTel} (PCS)—\textit{help from Ericsson, Nokia}?

• Research Collaborations
  – Daimler Benz (Vehicular/logistical applications)
  – Fuji Xerox PA Labs (Mobile applications and networks)
  – Hughes (Reliable transport over satellite links)
  – IBM (Mobile routing)
  – Metricom (Reliable transport over wide-area PR network)
  – PCSI (Reliable transport over CDPD, proxy architecture)

  – CMU (Mobile trace collection and analysis)
  – UCSC Reinas (Wide area point-to-point wireless network)
Technology Transfer Activities

• Proxy Software
  – Non-exclusive software licenses in negotiation with Wink Communications (set-top boxes) and Geoworks (PDA/smart phone)
  – Video Gateway distribution to CERN

• Snoop TCP Software
  – Distribution to some DoD sites (ship-to-ship reliable communications links)
  – UCSC Reinas Testbed

• Software transferred to SRI for OOTW/LE Testbed evaluation
Summary and Conclusions

• Objective: a complete network and application support architecture for access across lossy links from a wide variety of end devices

• Access is the killer app
  – Seamless connectivity through wireless overlays
  – Adaptivity through proxy services

• Dealing with heterogeneity, asymmetry, adaptation
  – Overlay IP routing based on Mobile IP
  – Asymmetric bandwidth in satellites, cable modems, cellular systems: new transport protocol techniques
  – High loss links: achieving high bandwidth utilization through local intelligent retransmission
  – Adapt representations to the quality of the end device and its network connectivity: proxies for audio/video streams and imageful web documents