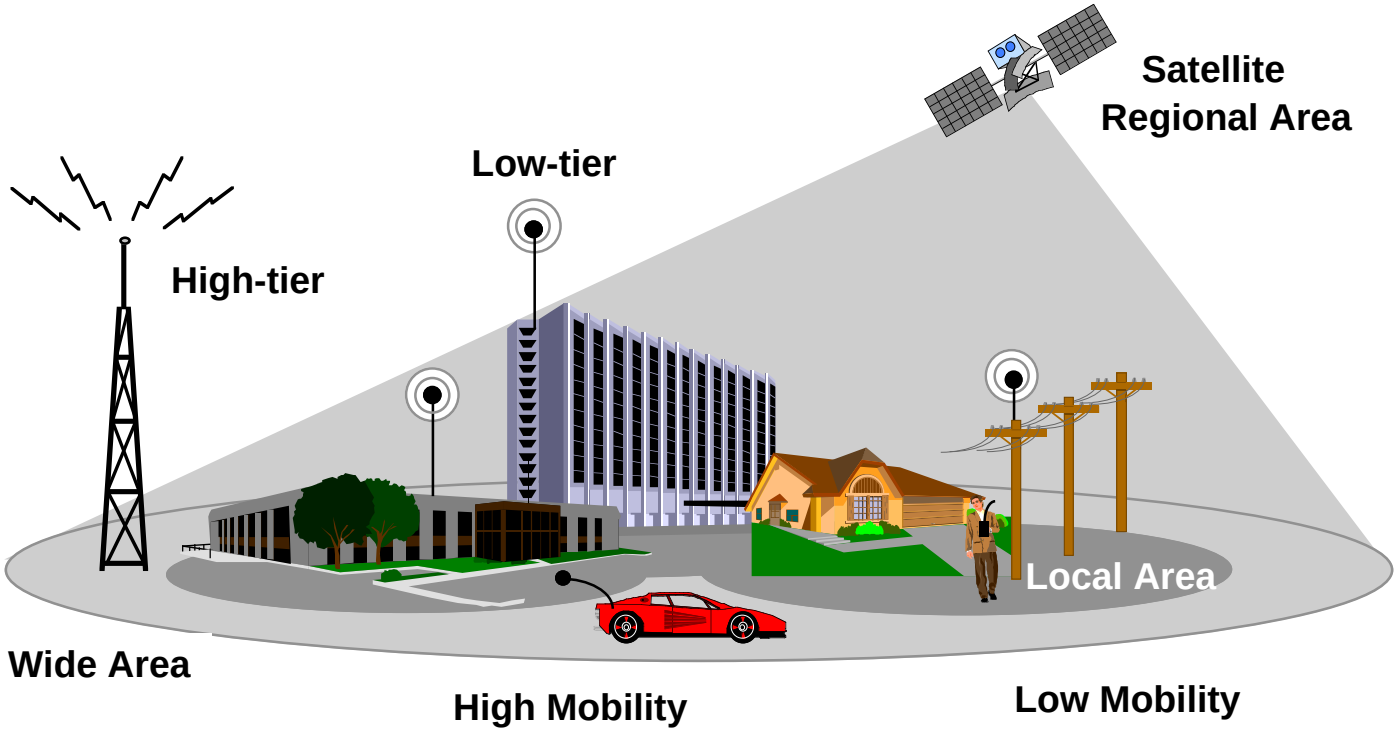
The Bay Area Research Wireless Access Network: Towards a Wireless Overlay Internetworking Architecture



Randy H. Katz and Eric A. Brewer

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University of California, Berkeley, CA 94720-1776

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 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**

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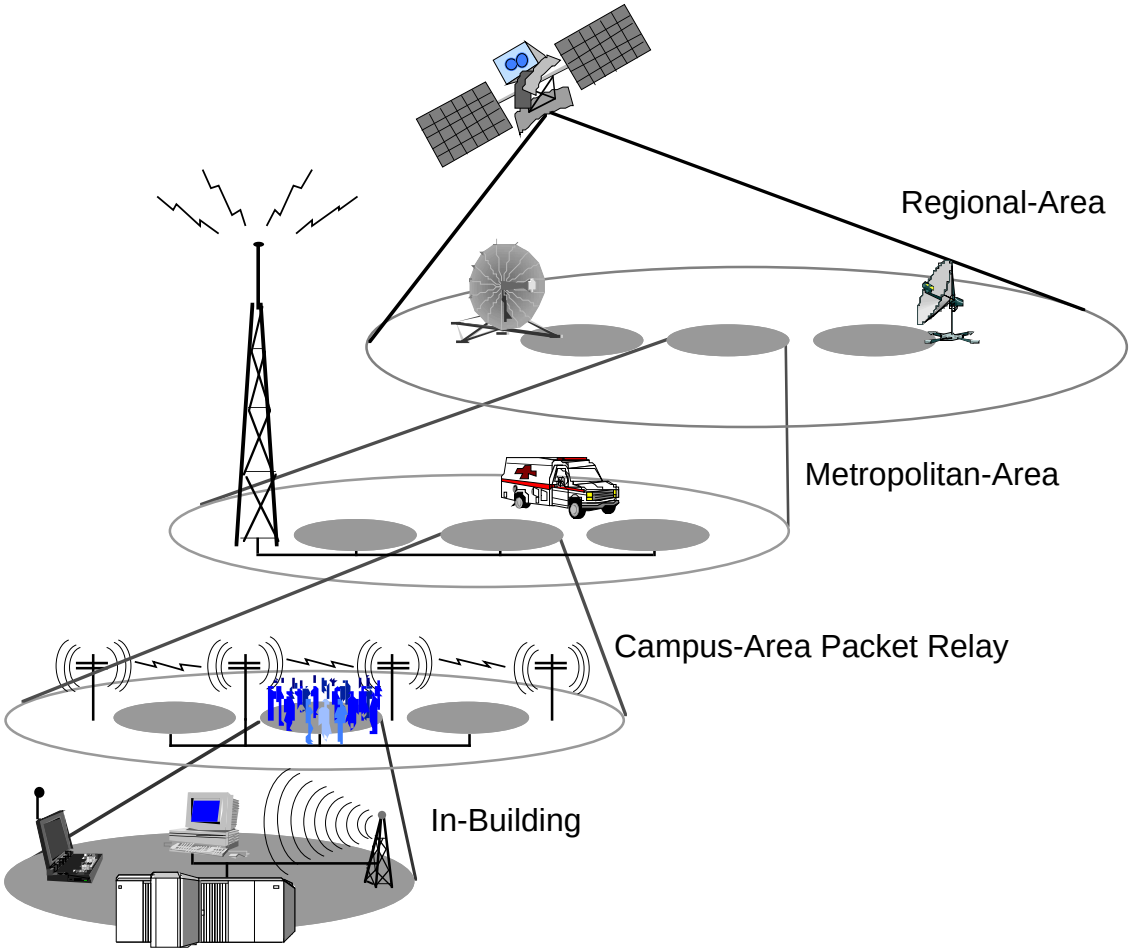
Access is the Killer App

- **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



Theatre of Operations

↓

Rear Echelons

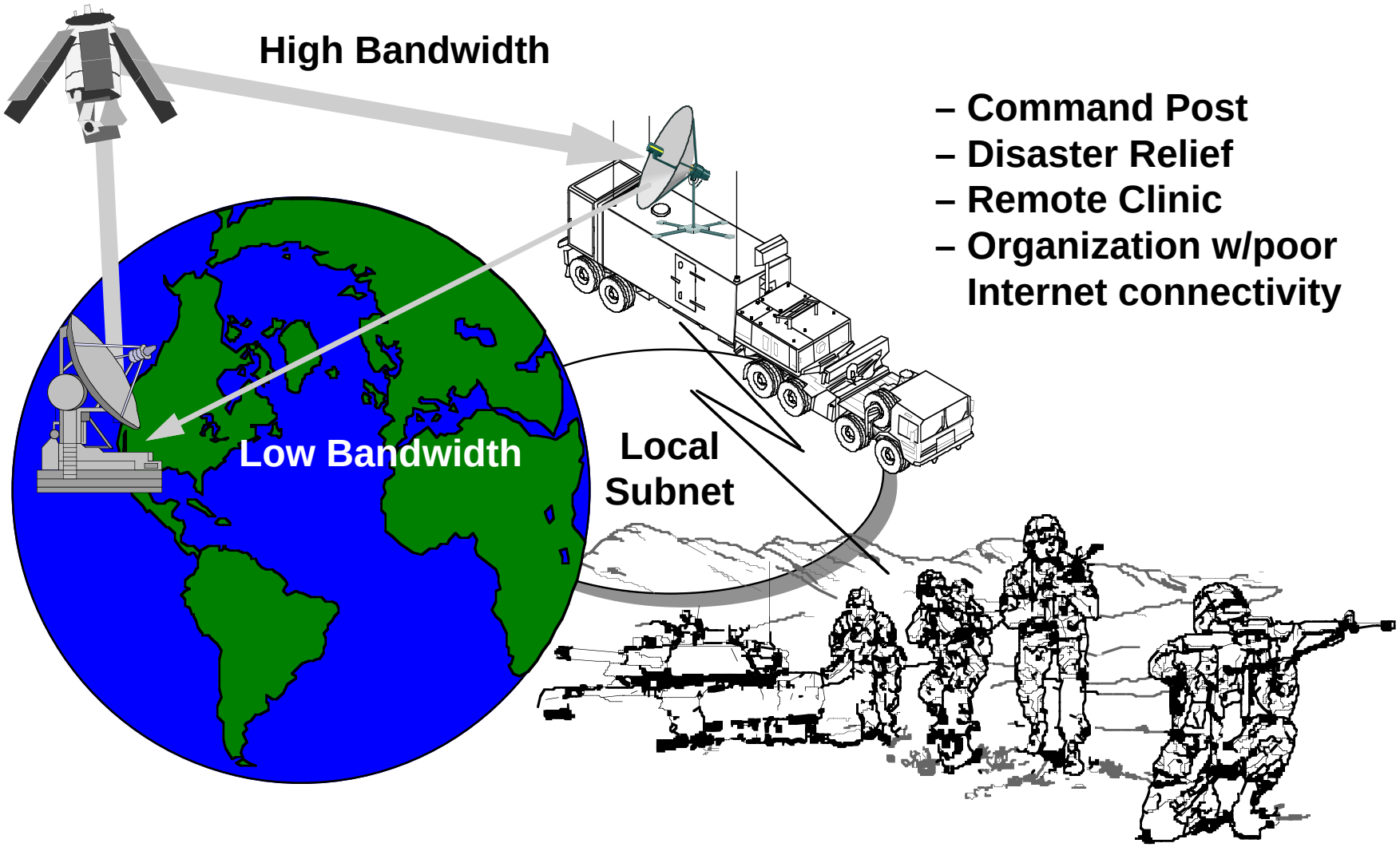
↓

Bases, Depots, Ranges

↓

Command Centers
Training Centers

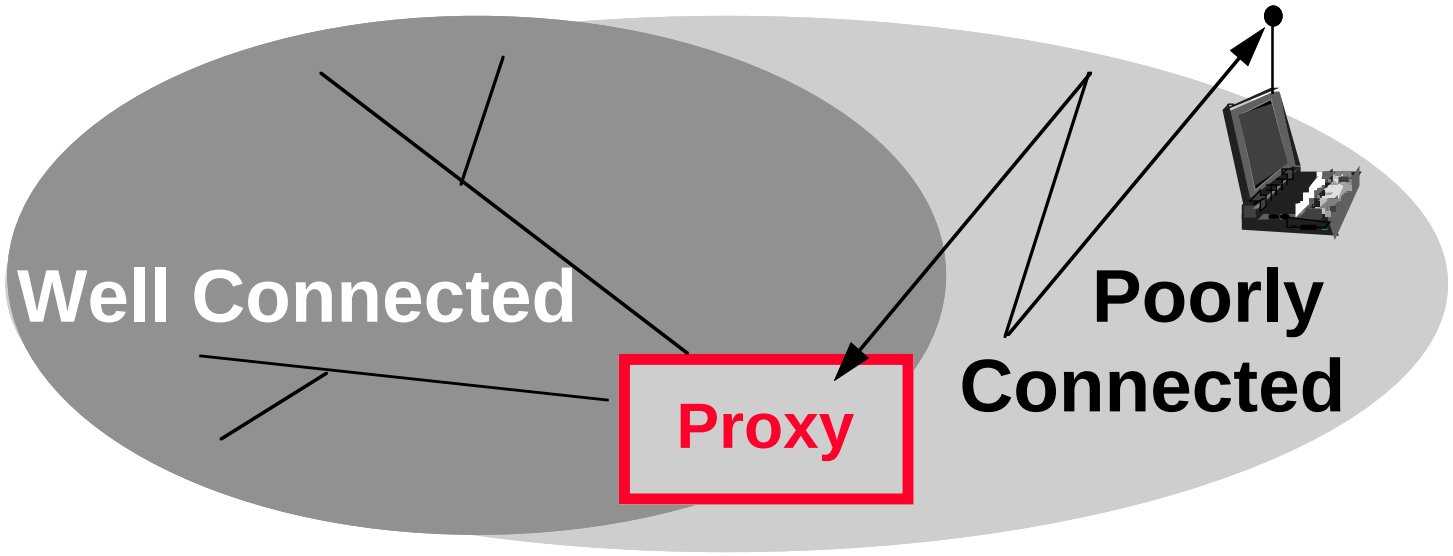
Asymmetric, Heterogeneous, and Hybrid Access



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

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**

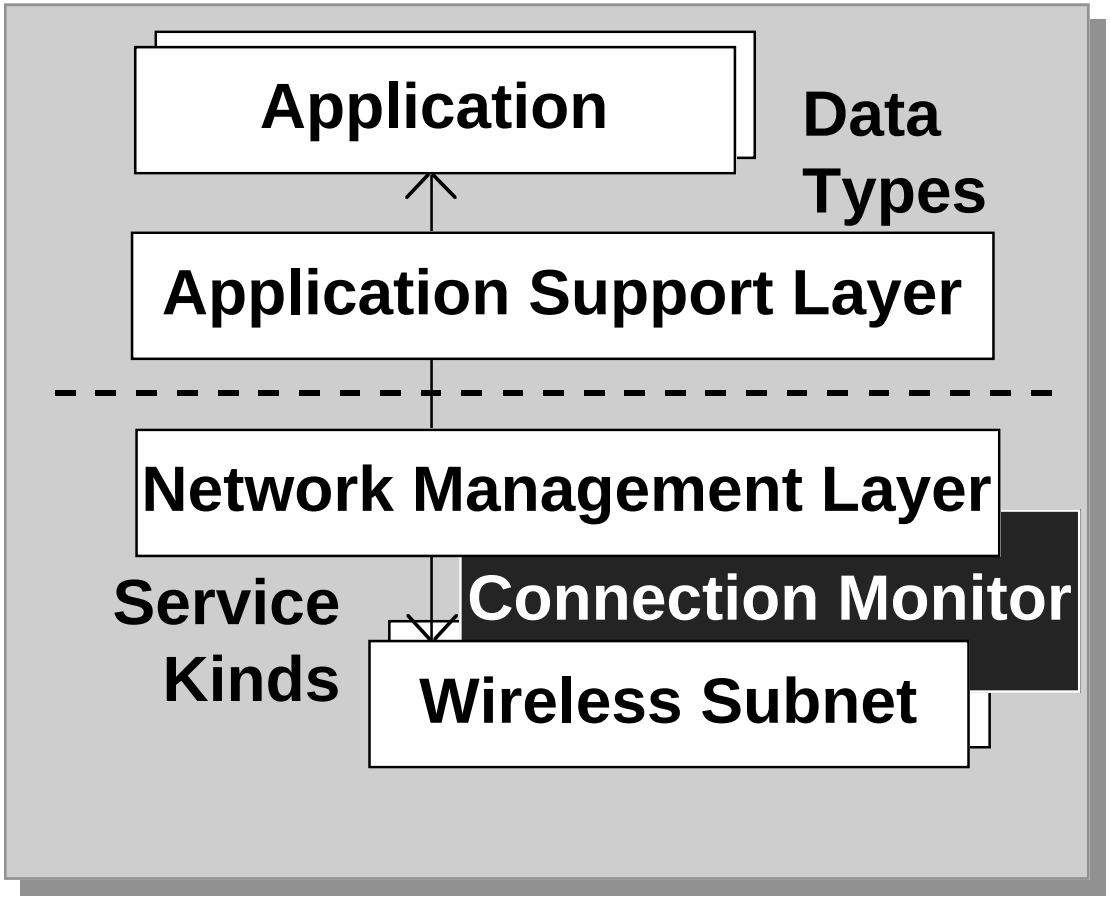


Bandwidth Adaptive Application Interfaces

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

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	< 10 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
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"

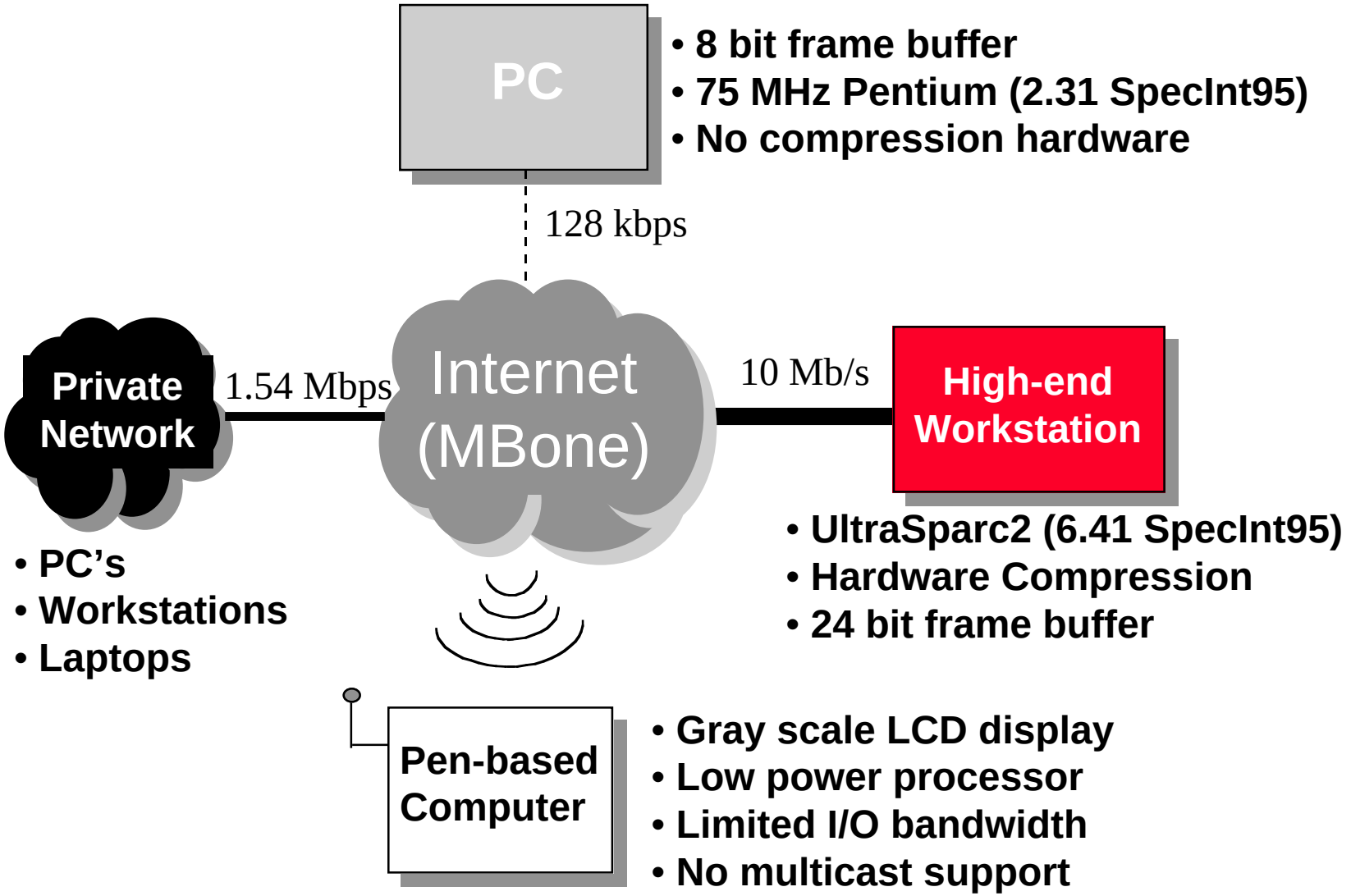
Latency as critical as bandwidth in wireless networks
Wide diversity of network performance parameters
Competing infrastructure providers
Pedestrian vs. vehicular mobility

Application Support Challenge

Device	Bandwidth, bits/sec	CPU	Mem/ Disk	Screen size	Bits/ pixel
High-end PC	Ethernet (10Mbits), ISDN (128K)	120 Mhz Pentium	16/2G	1280x1024	16-24, color
Low-end PC		75-100 Mhz Pentium	8/500	1024x768	8-16, color
High-end notebook	Cellular (9600) or wireline (28.8K) modem			800x600	8, color
Low-end notebook		50-66 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

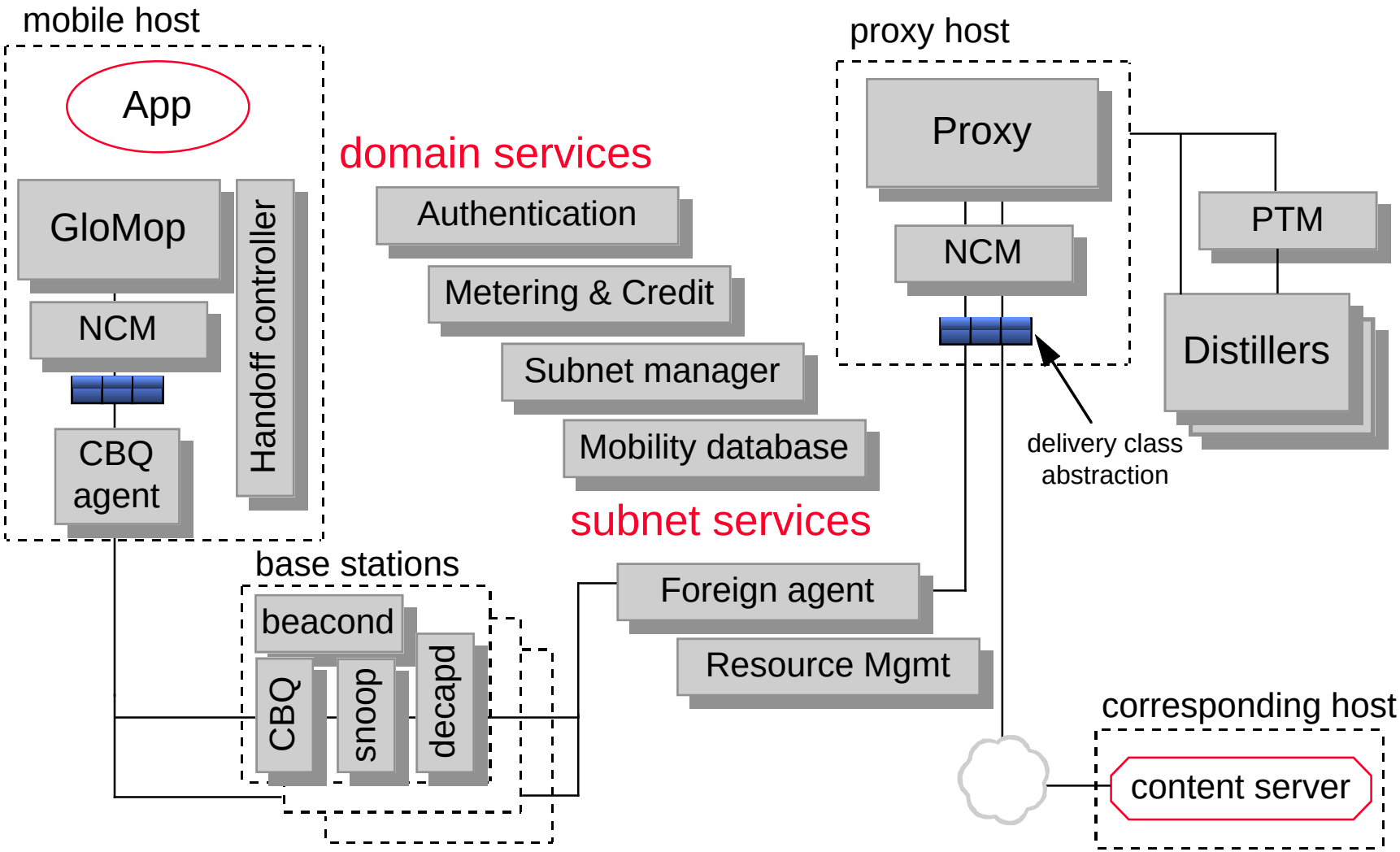
Collaboration Heterogeneity



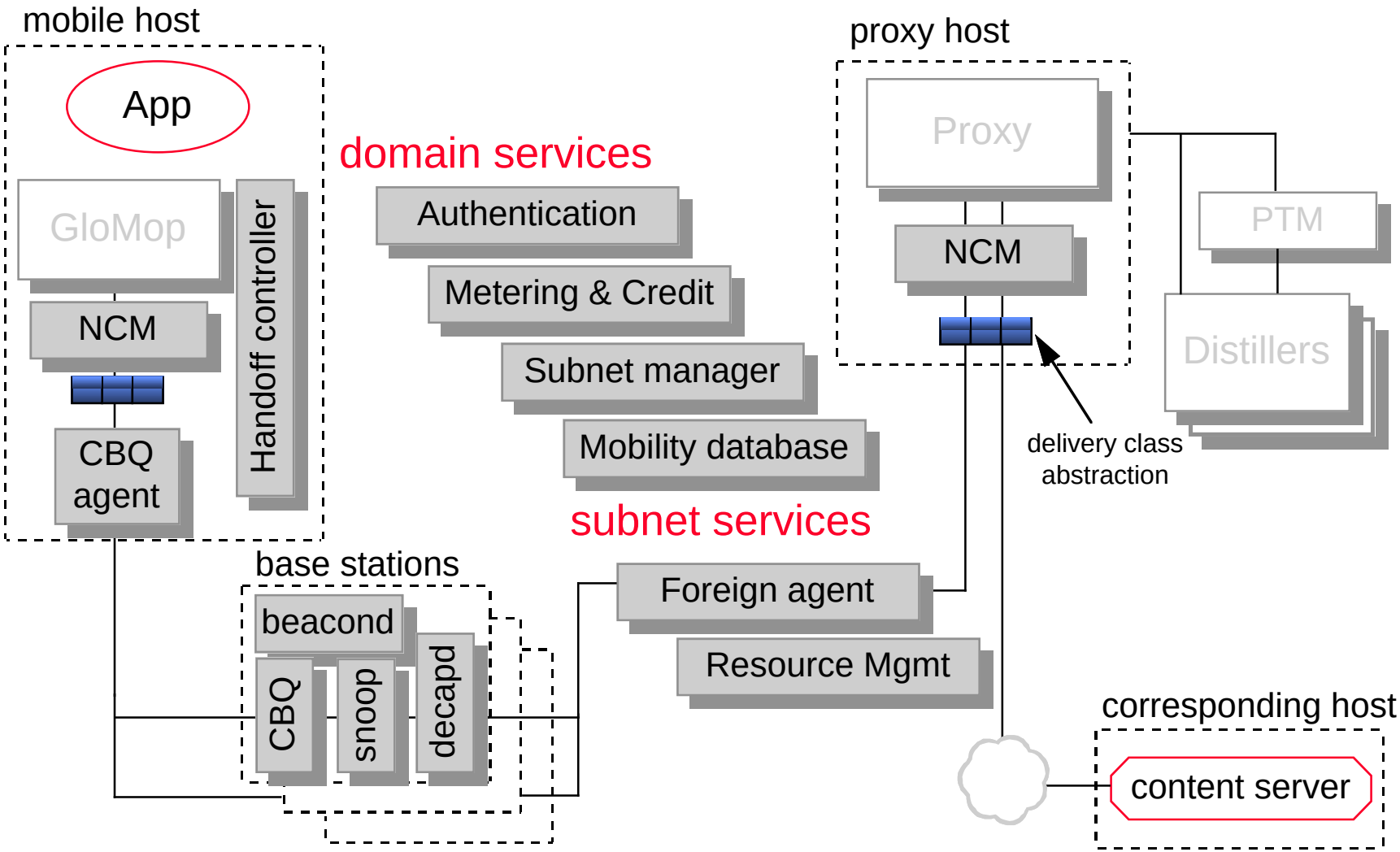
Architectural Issues

- **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**

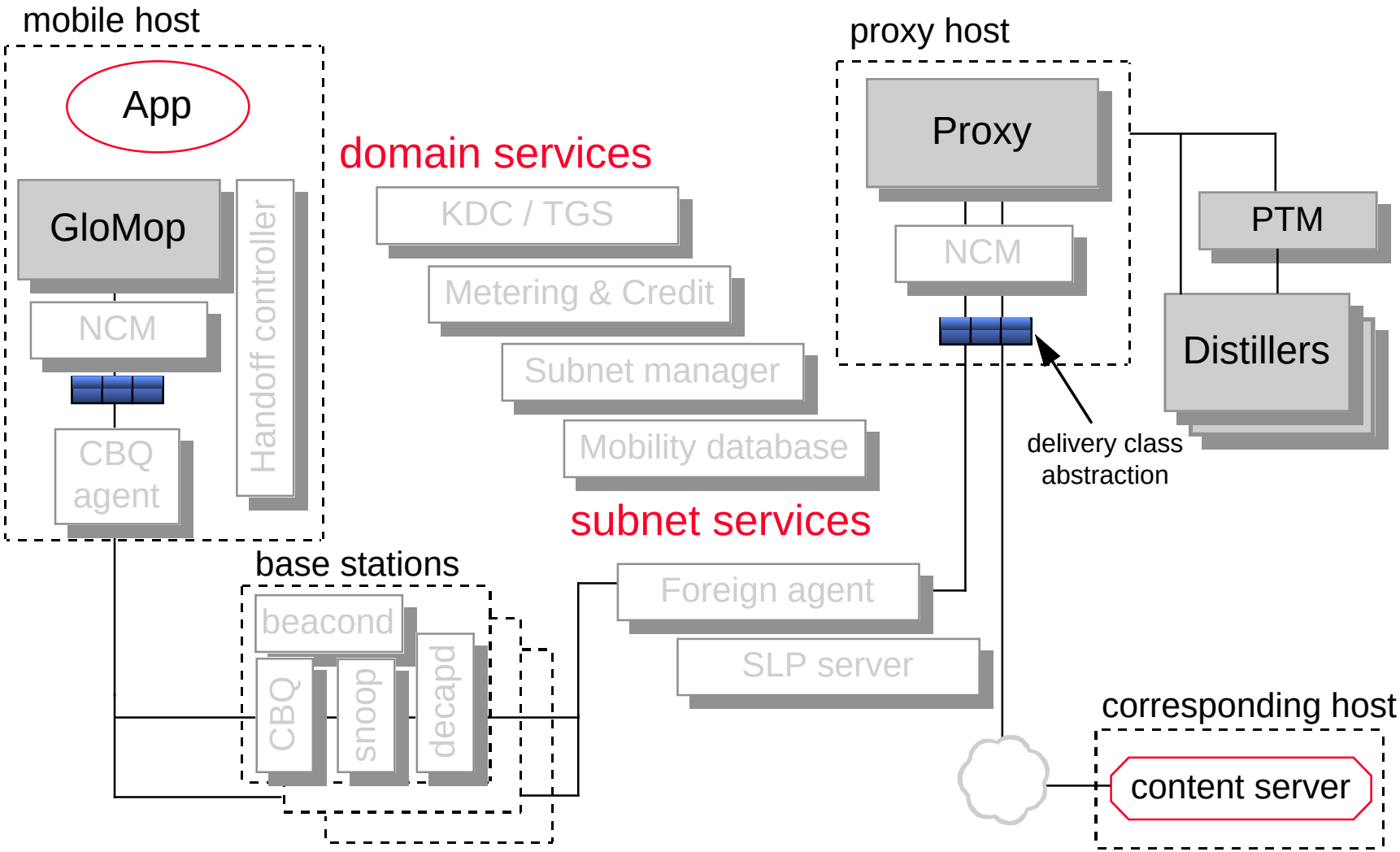
The Daedalus/GloMop Architecture



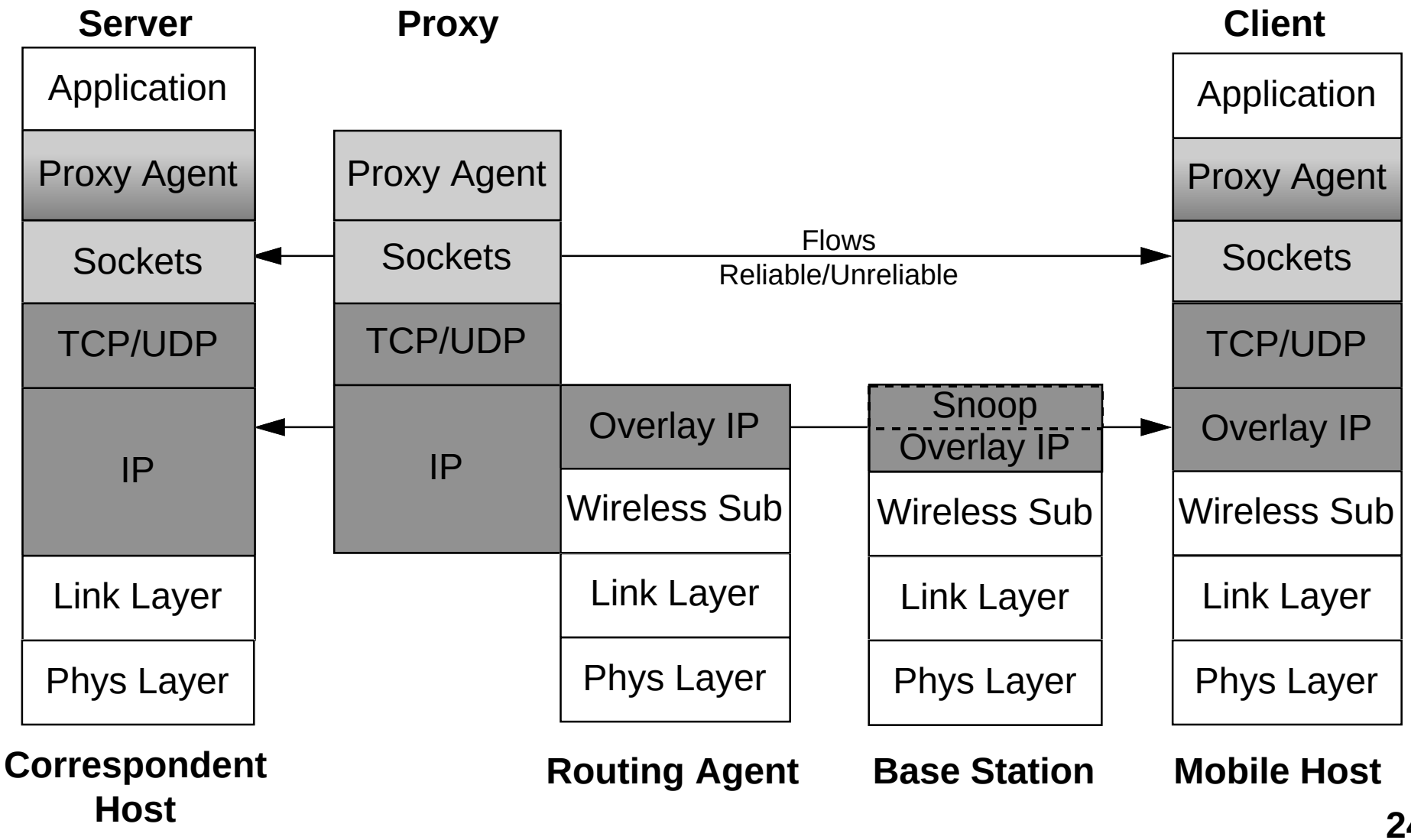
Daedalus Network Components



GloMop Application Support Components



Application/Network Architecture



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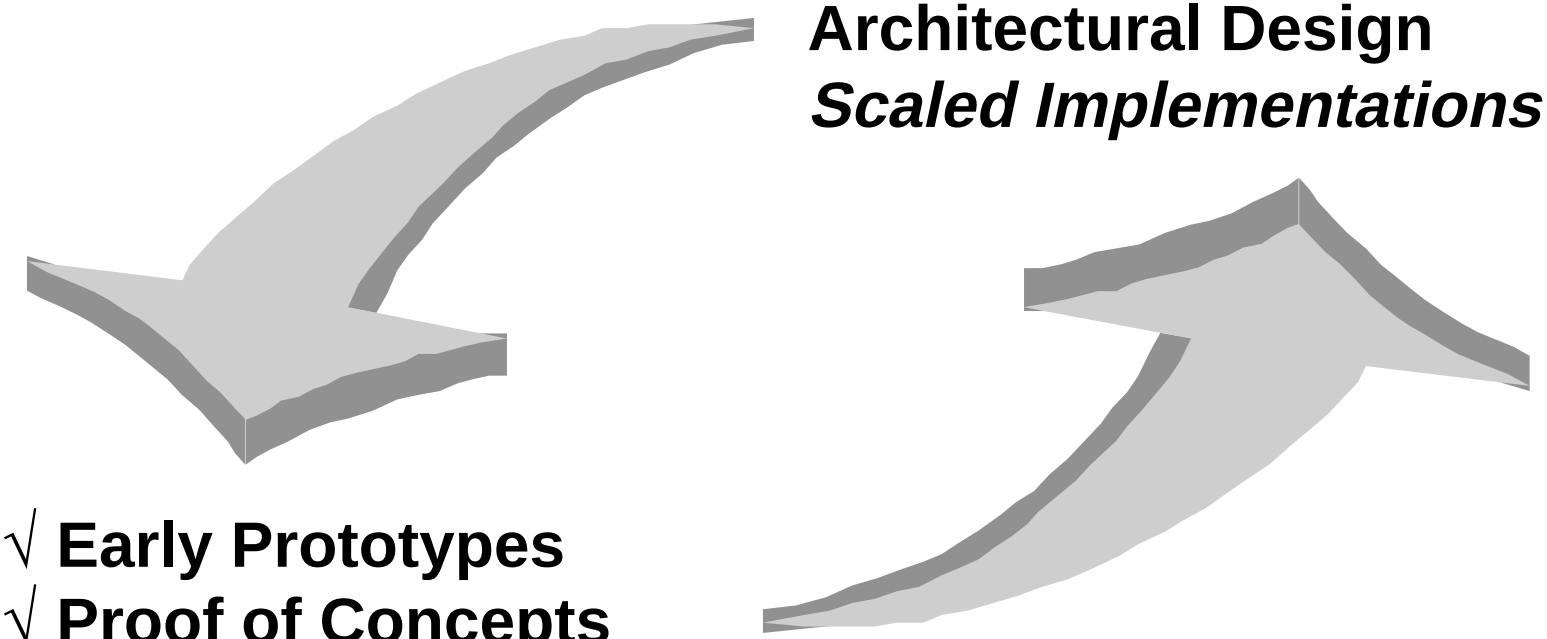
Project Strategy

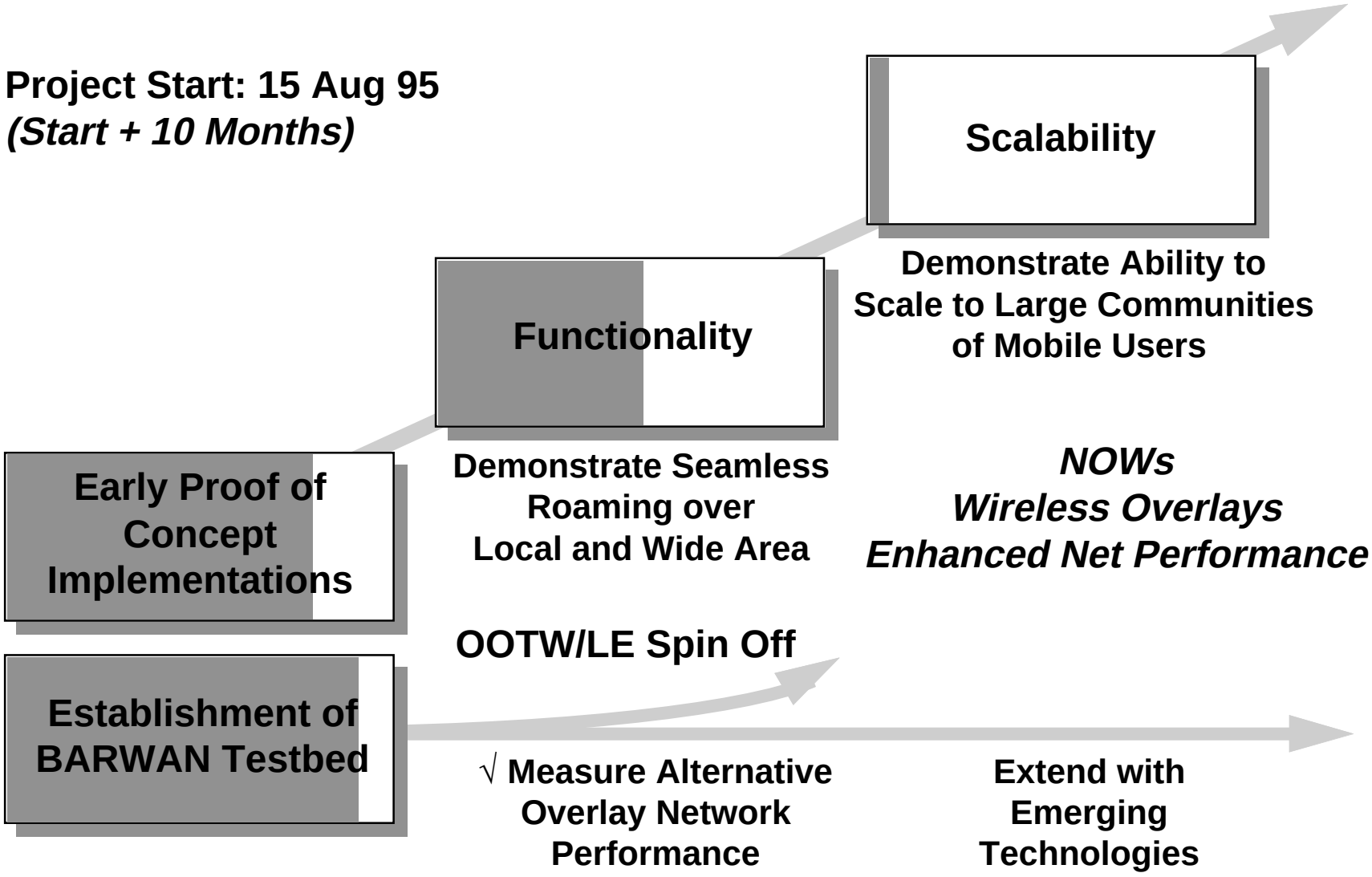


Architectural Design
Scaled Implementations

√ **Early Prototypes**
√ **Proof of Concepts**
√ **Measurements & Evaluation**

Project Plan and Status

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



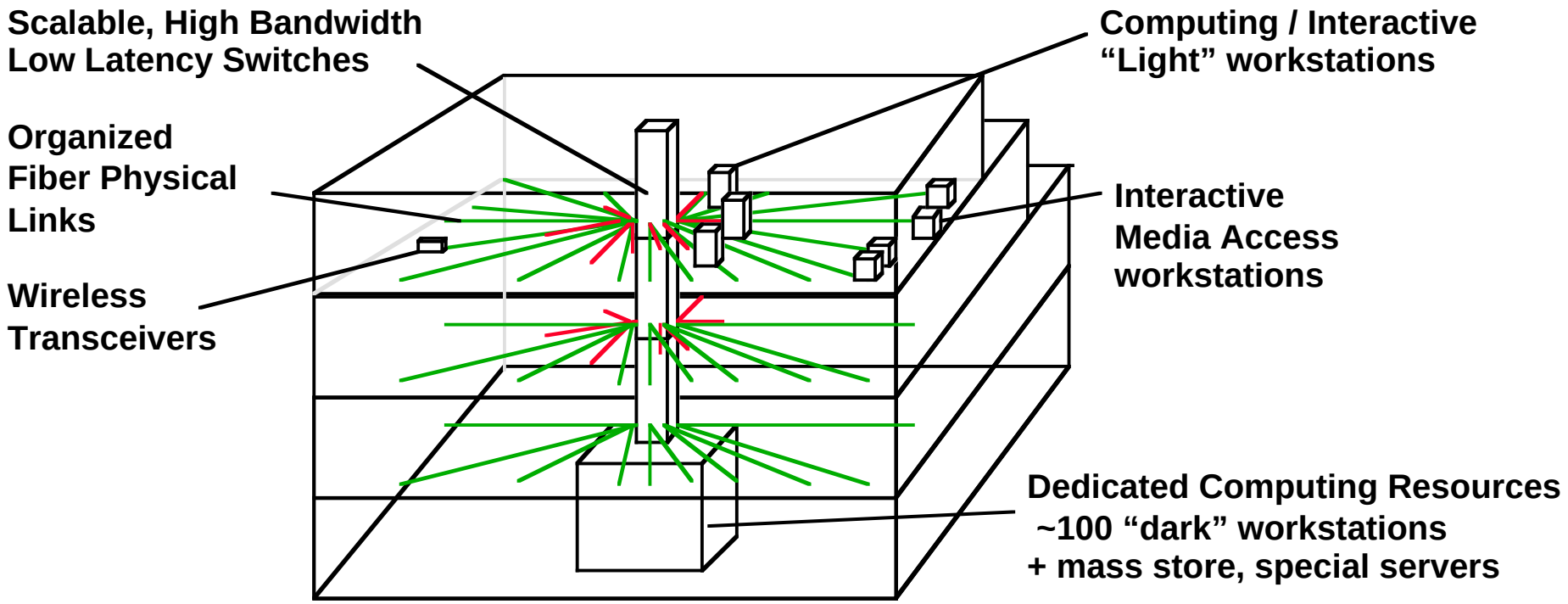
Achievements—January 1996

- 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



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

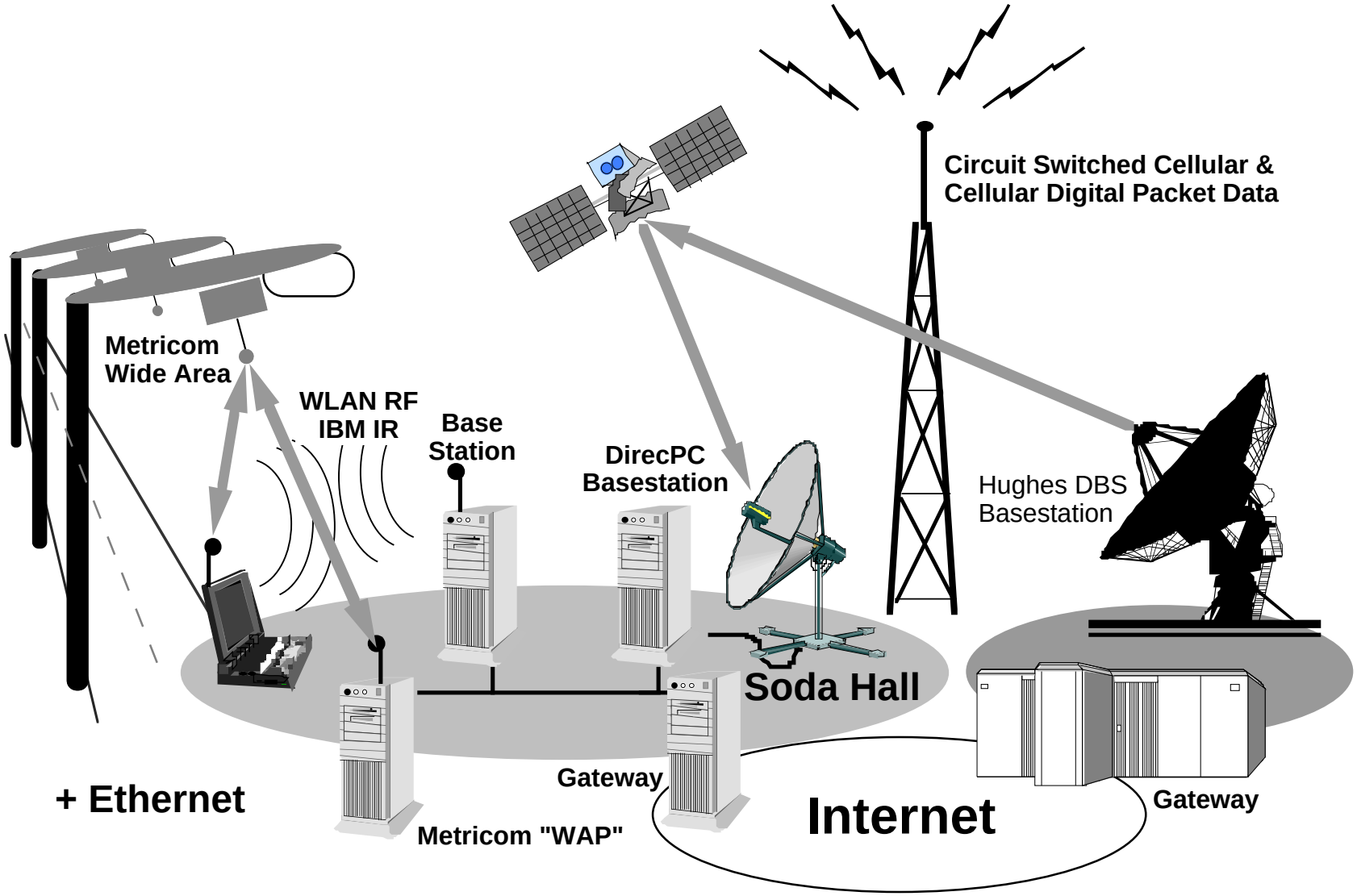
Wide-Area Wireless Testbed

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

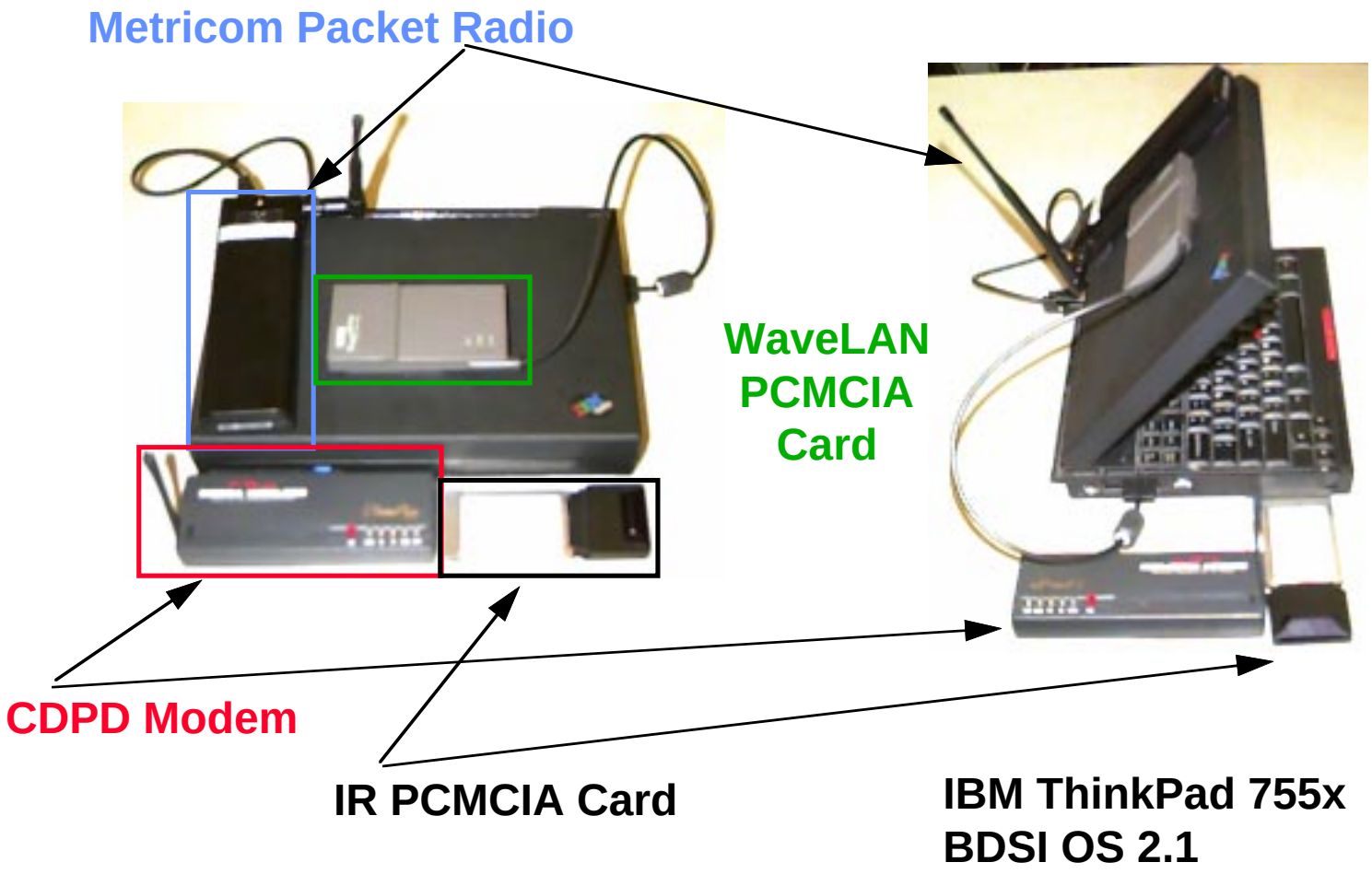
- √ **Metricom PR Network**
- √ **DirecPC DBS Service**
- • **Cellular Modems**
- • **Cellular Digital Packet Data**

- • ***Wireless Cable Modems***
- • ***GSM General Packet Radio Service***

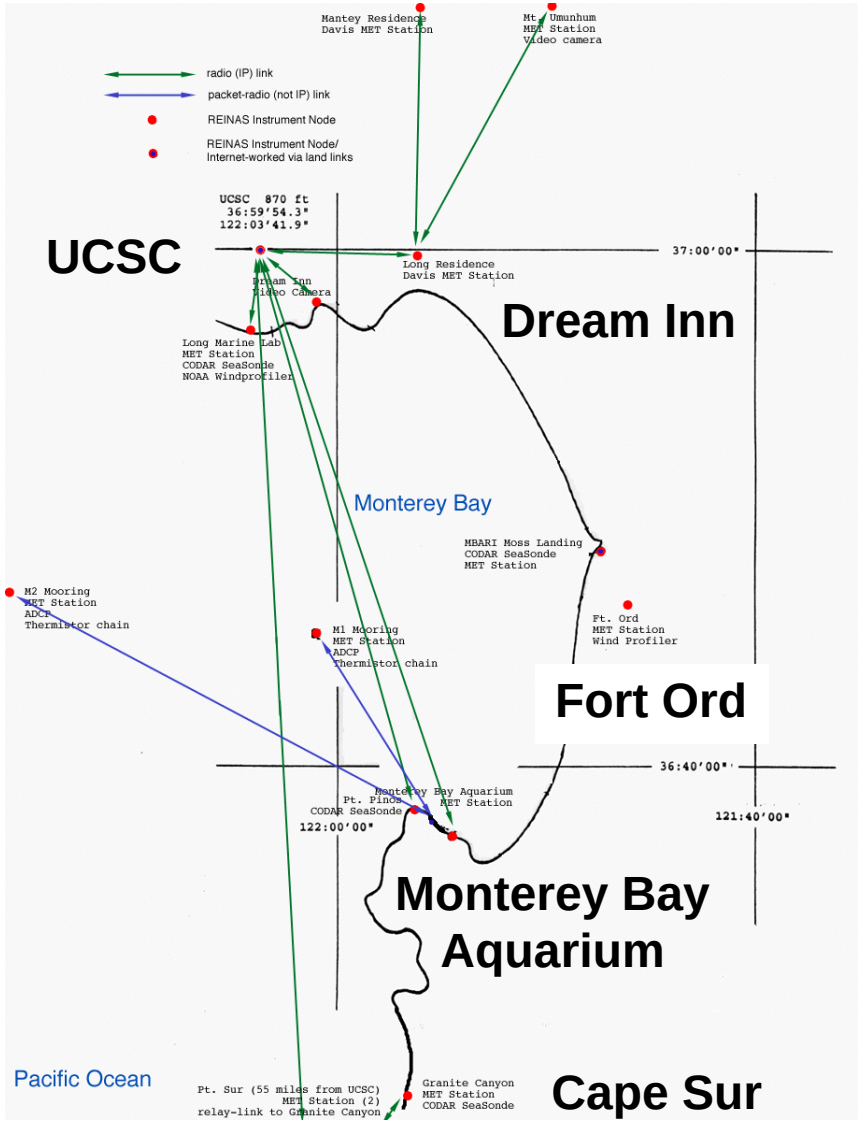
BARWAN Testbed



BARWAN Testbed



BARWAN Testbed Extensions



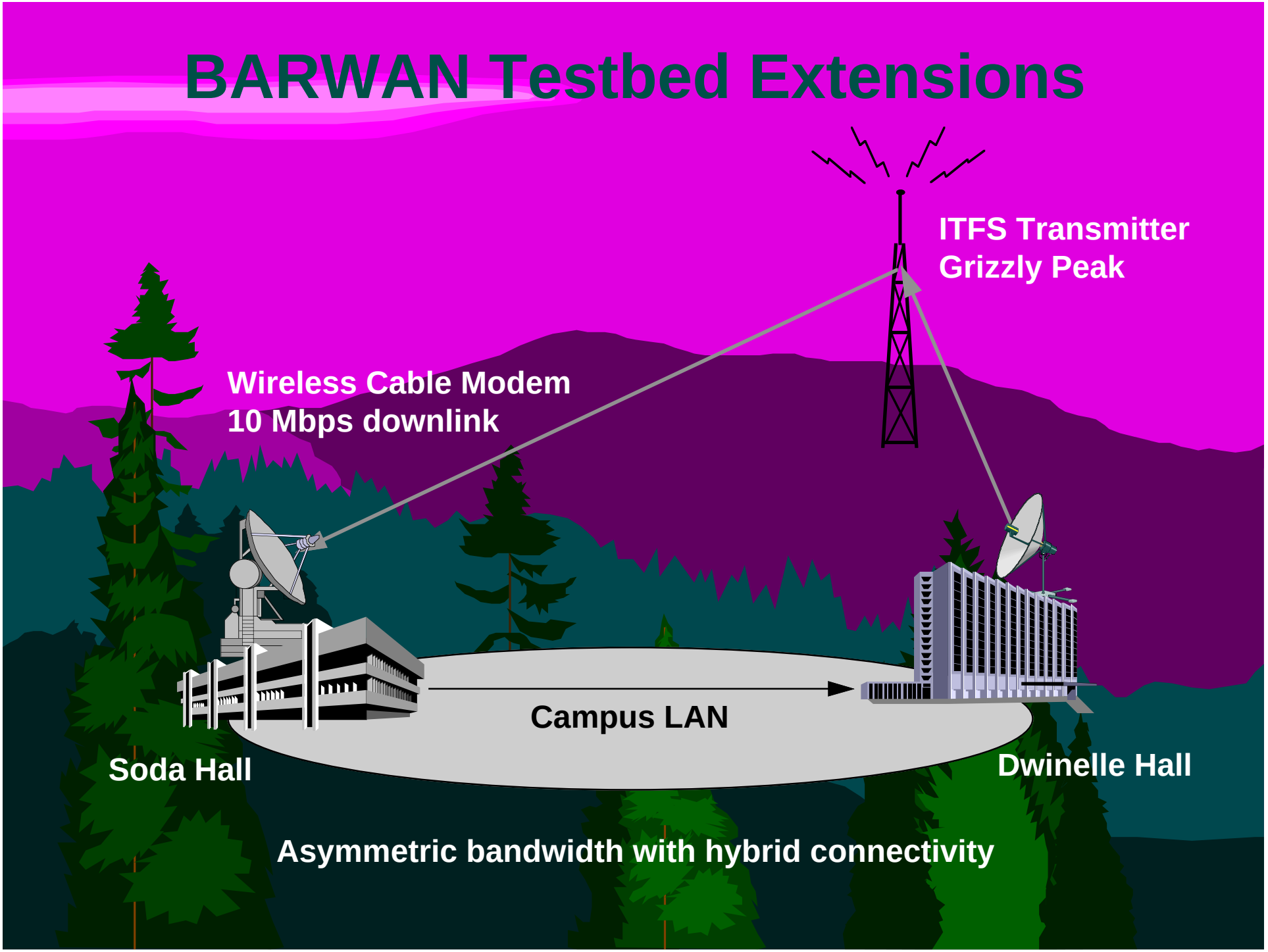
Reinas Env. Monitoring Network Monterey Bay

Profs. Patrick Mantey, Darrell Long

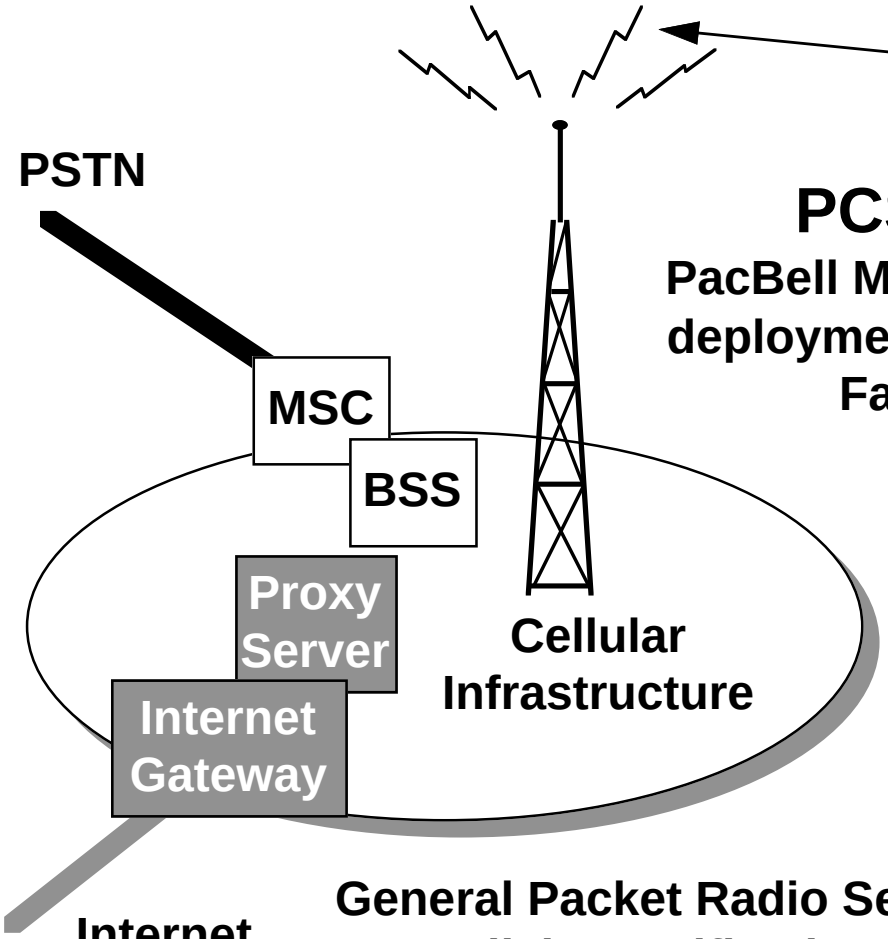
Tetherless Access Long Haul Links WaveLAN Point-to-Point Links

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

BARWAN Testbed Extensions



BARWAN Testbed Extensions



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

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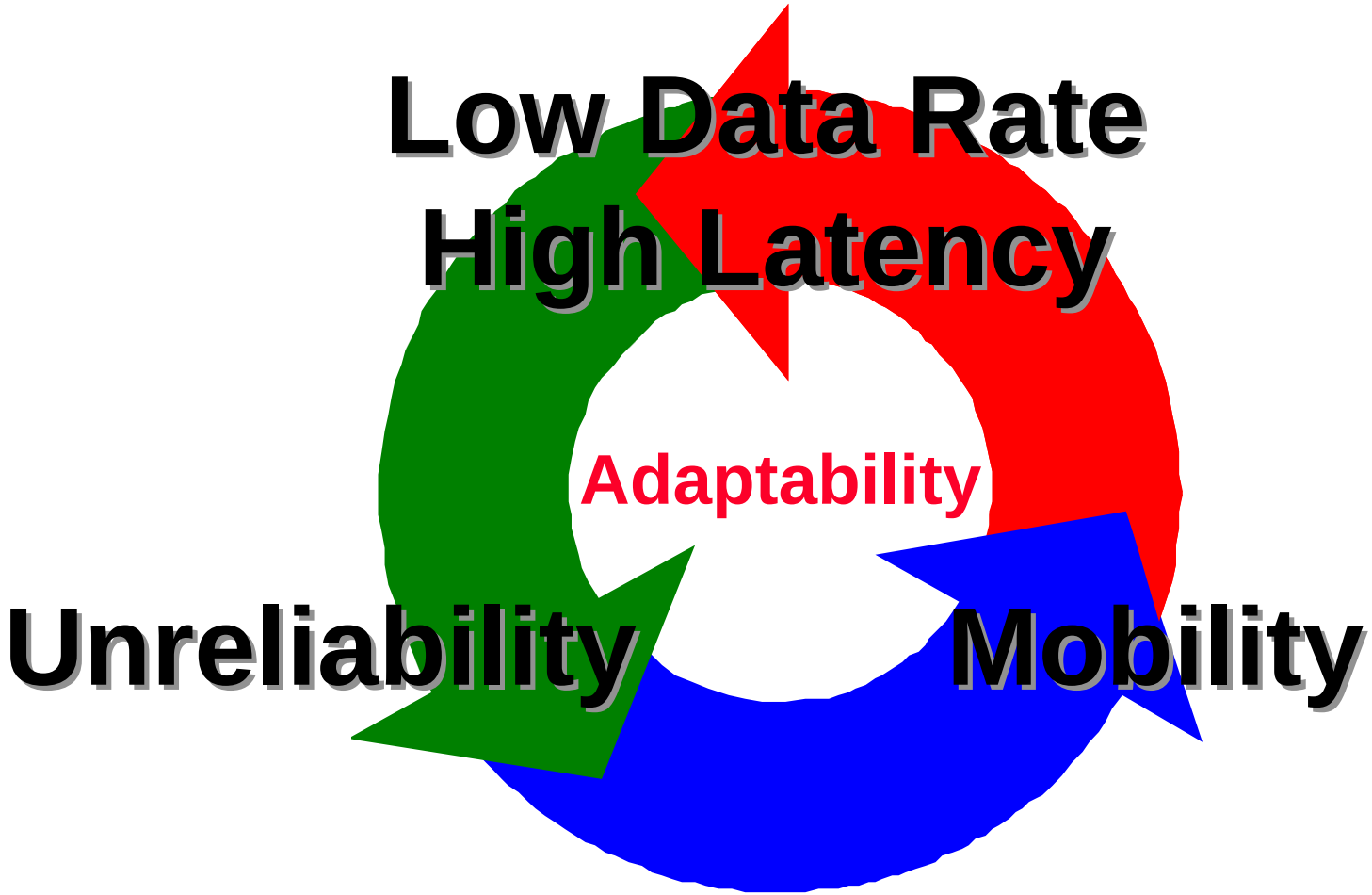
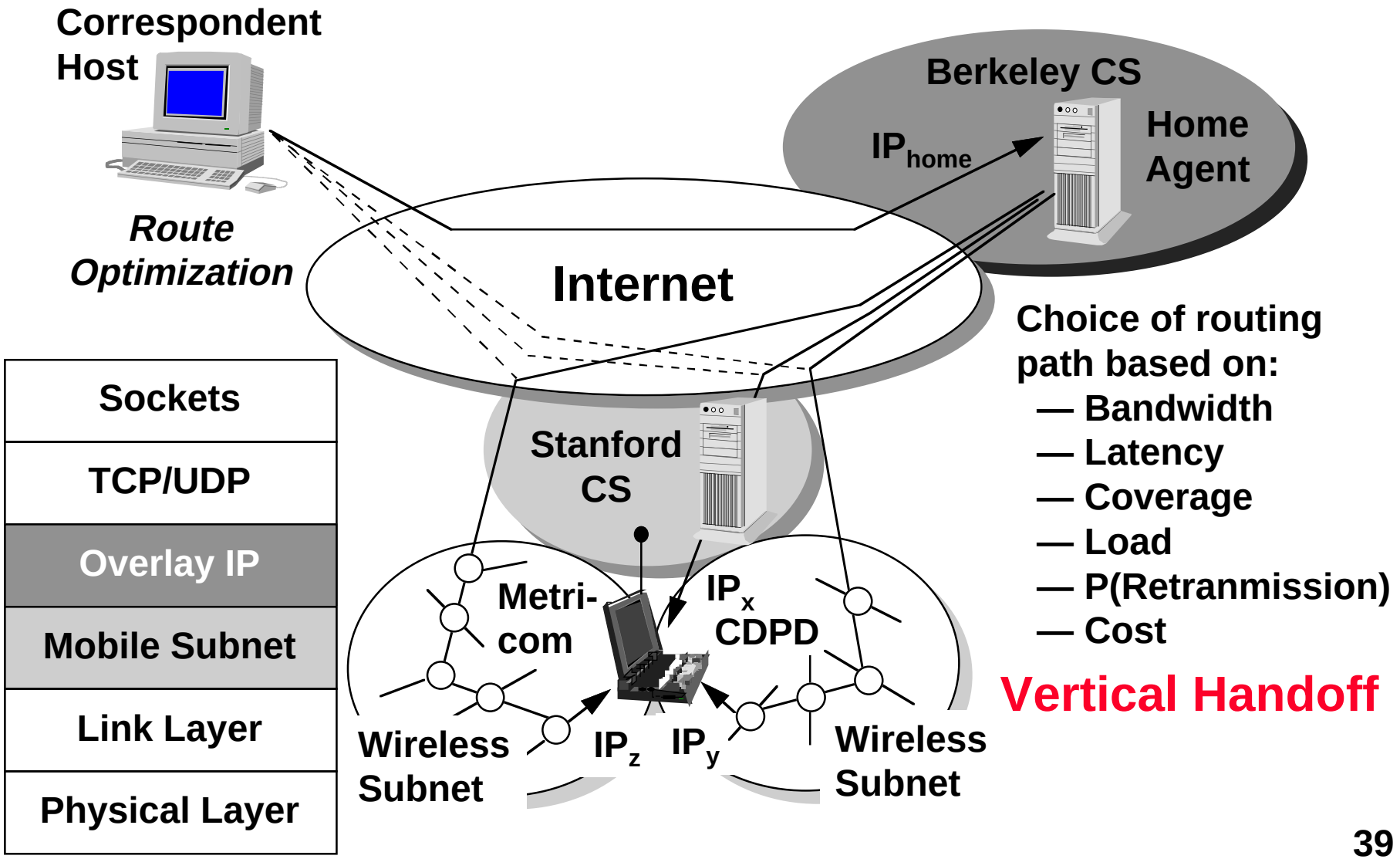
Mobile Computing Challenges



Overlay Routing: Mobile IP + Multi-homed Hosts

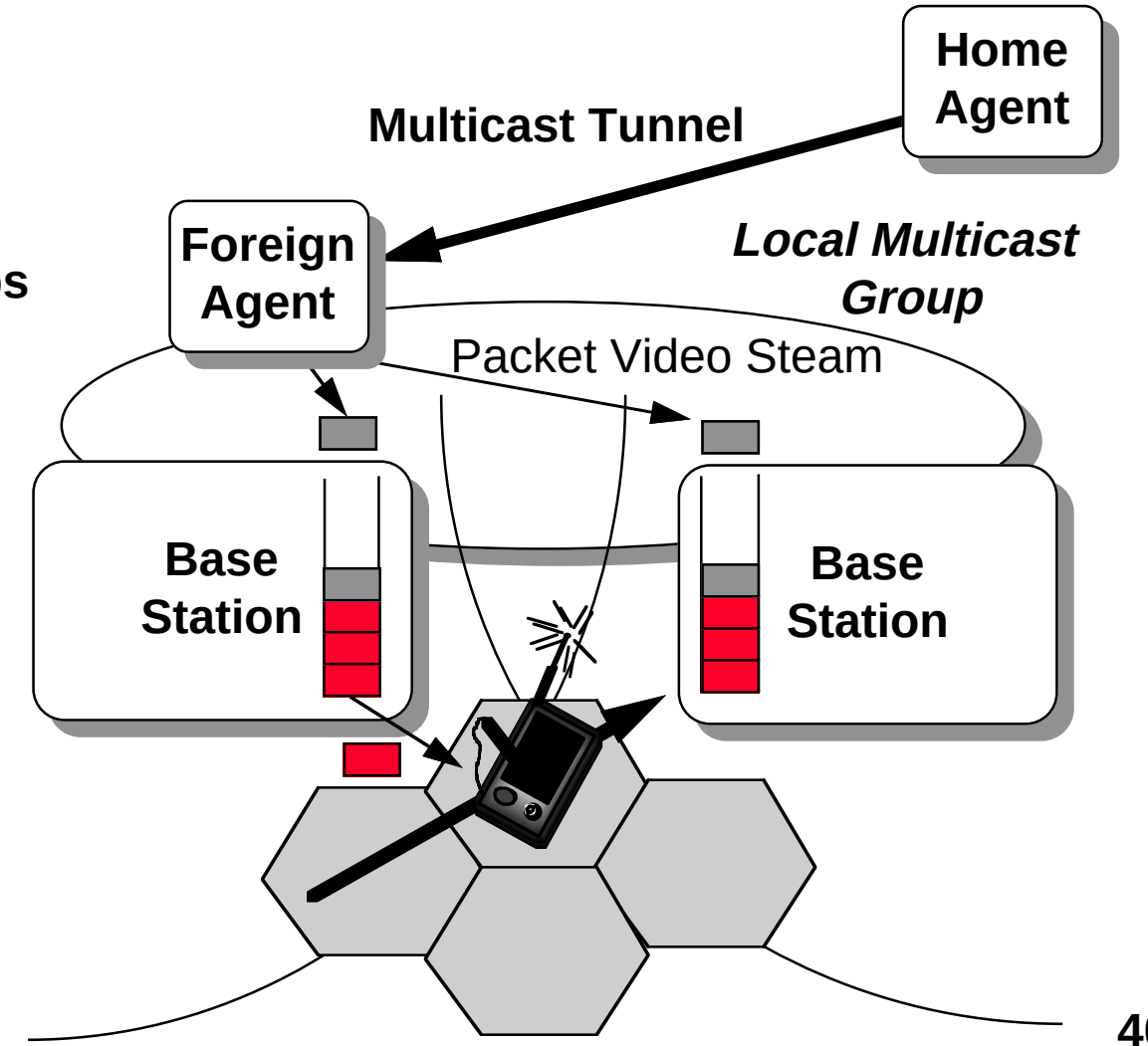


Low Latency Handoff

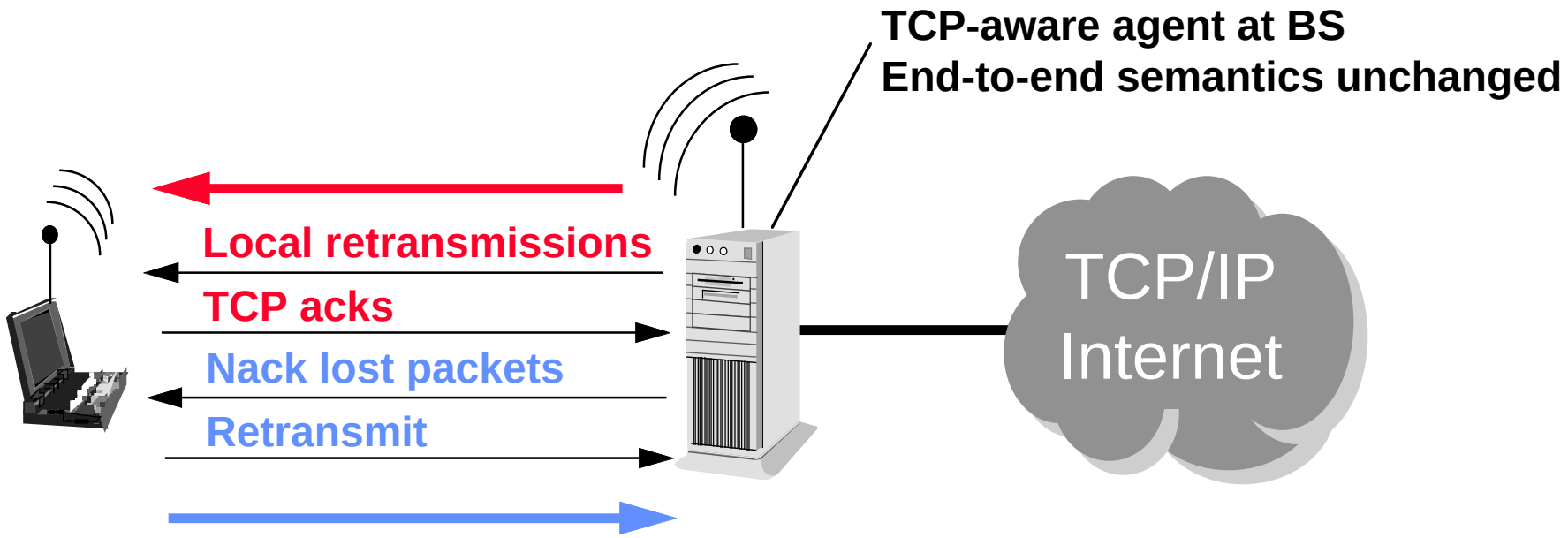
Use hints about terminal trajectory to form MC groups

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



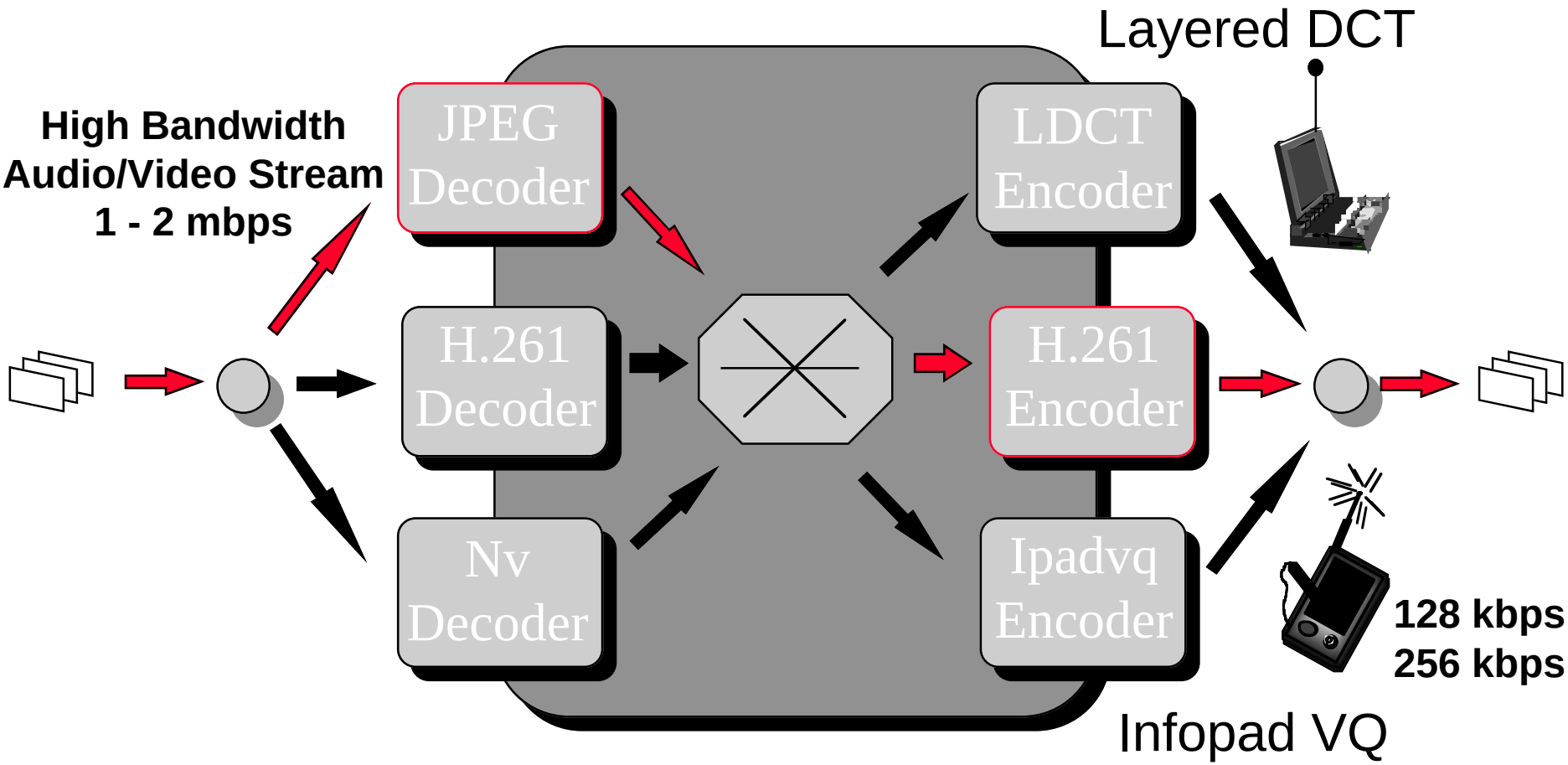
Reliable Mobile Transport: Snoop Packet Filter



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

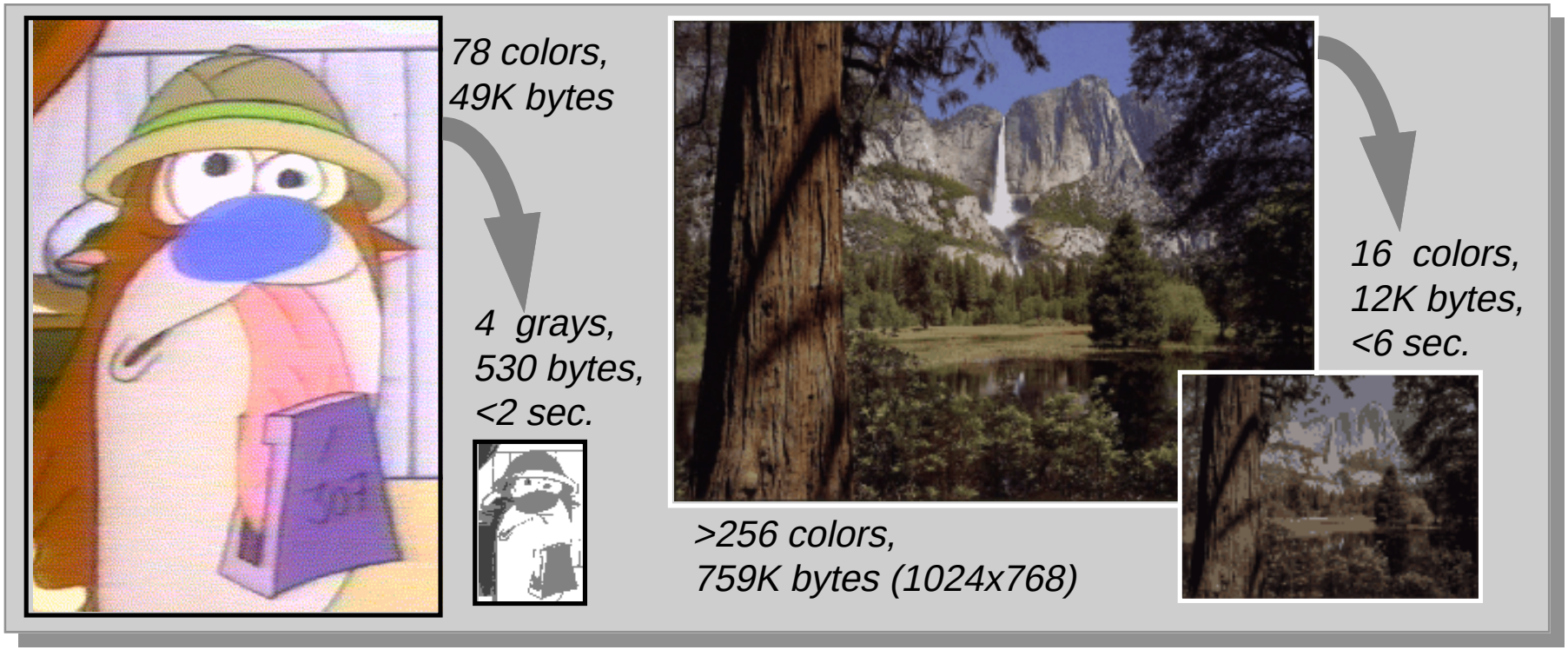
Video Stream Proxy: Video Gateway



Heterogeneous Video Conferencing Environments

RTP knowledgeable; multicast-to-unicast routing

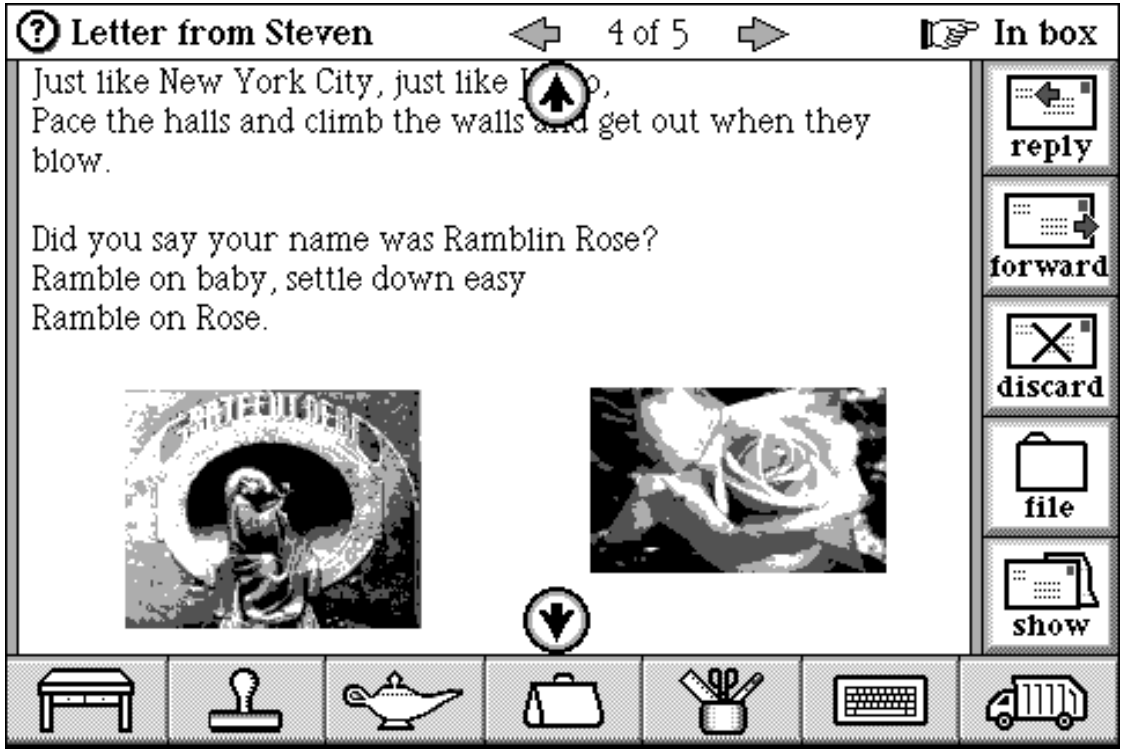
Web Proxy: On-Demand Distillation



- **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

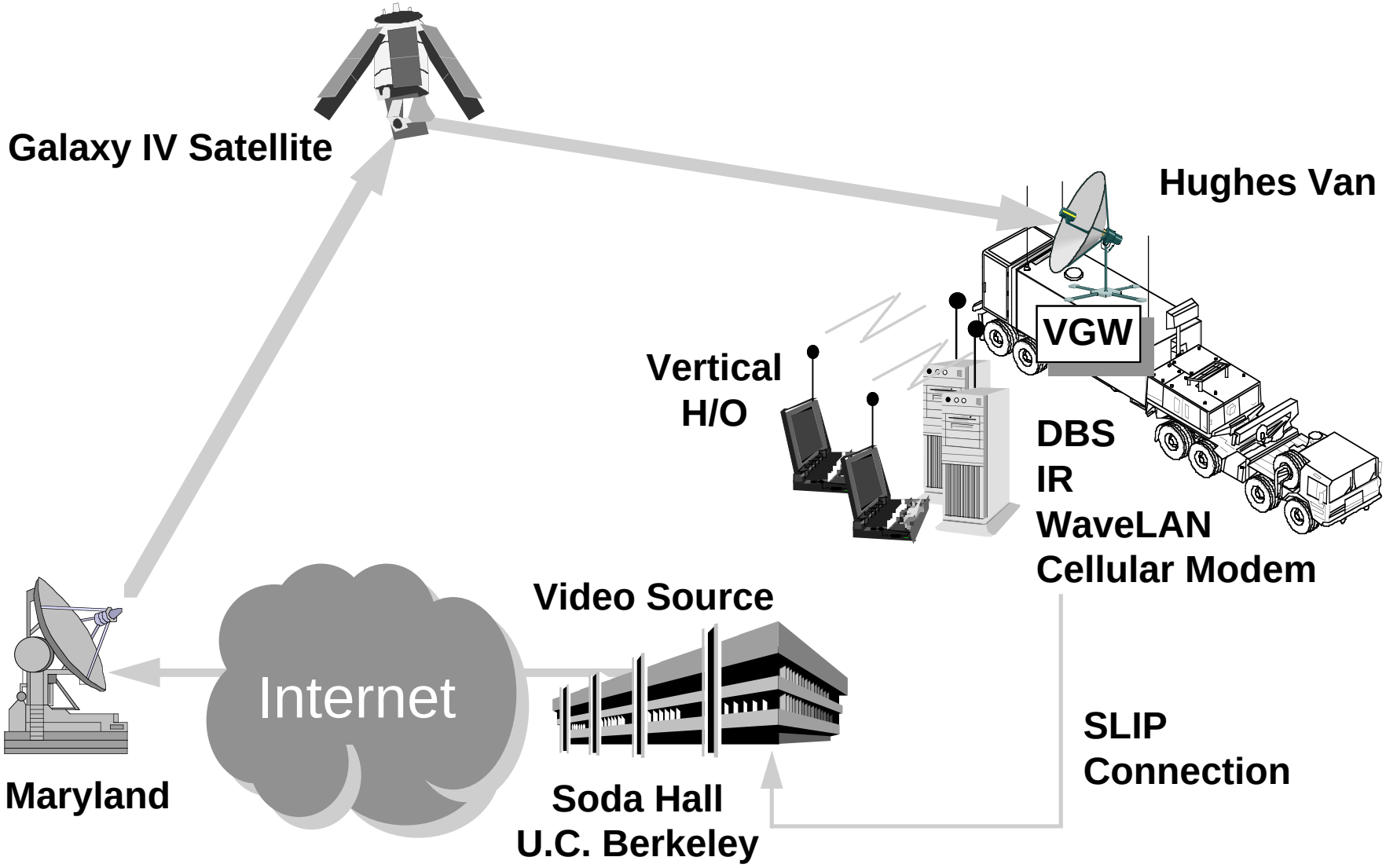
- **Integrate PDA “islands” with desktop/wireline world via Internet standards**
- **Proxy Mail: Virtual folders, MIME images, graceful disconnection**
- **Proxy architecture for authentication, white board**



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



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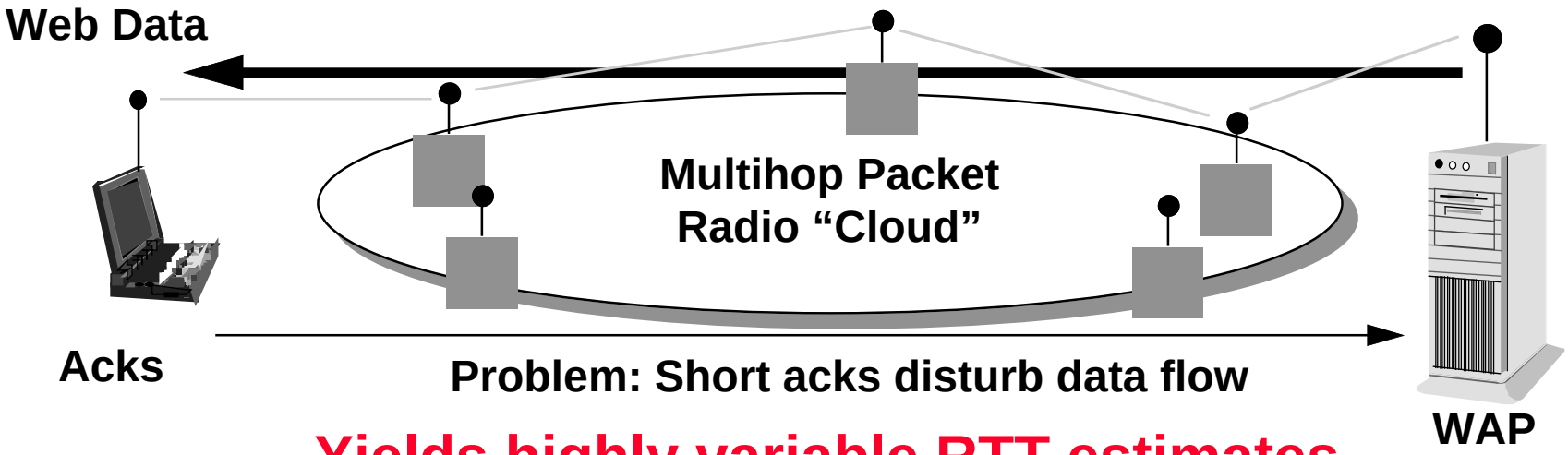
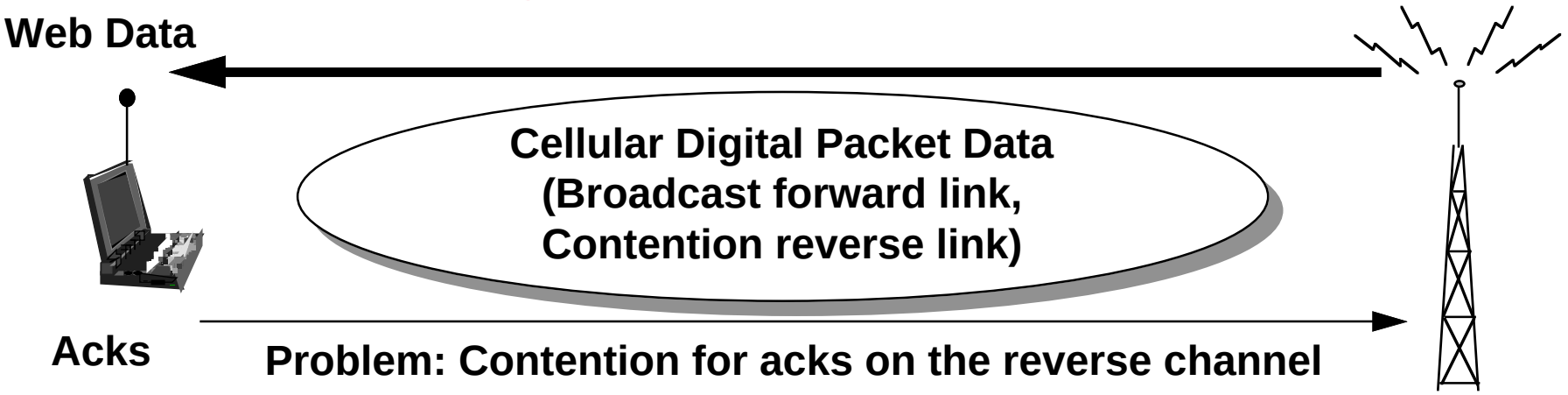
Reliable Transport Performance in Wide-Area Wireless Networks



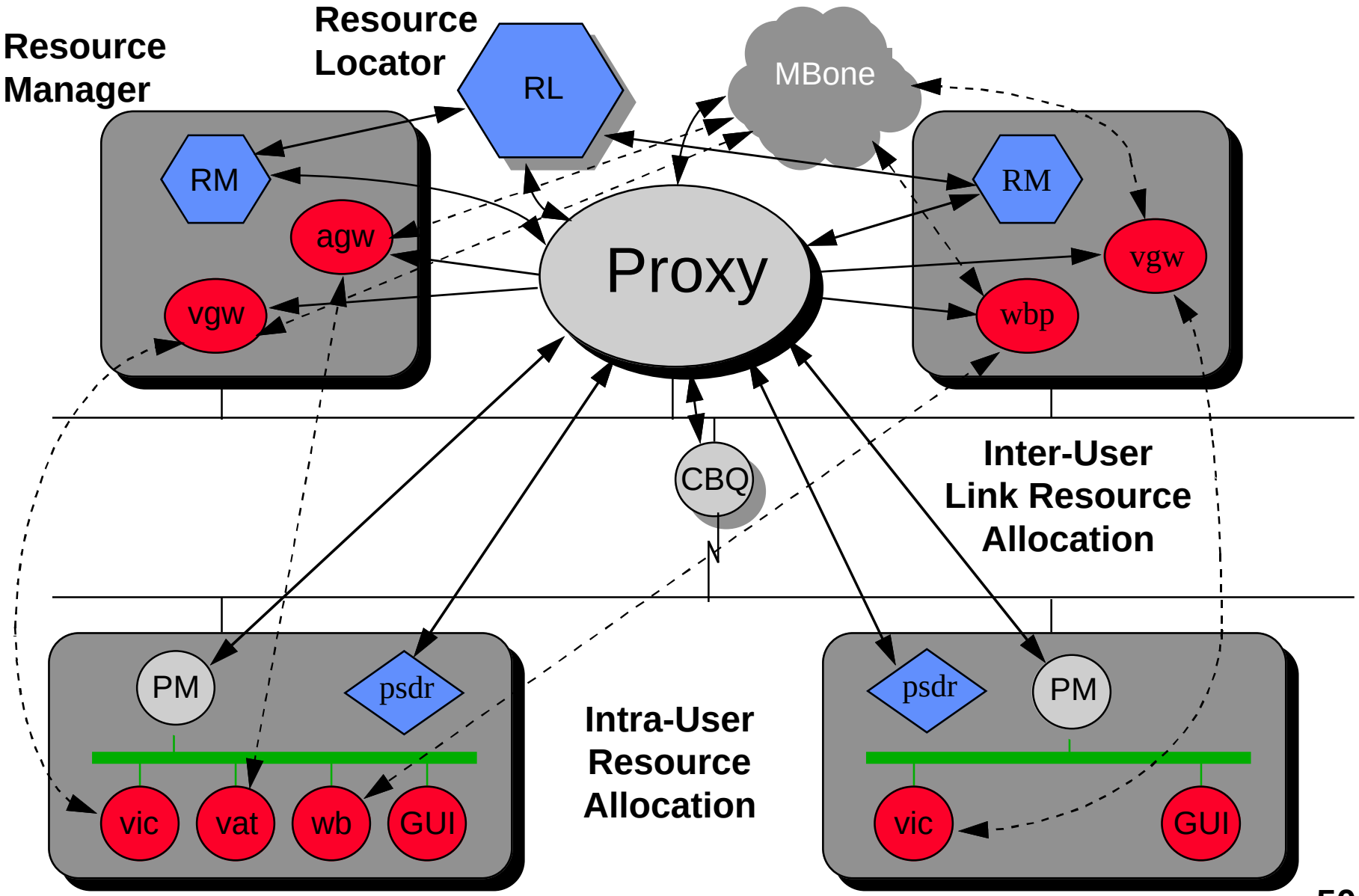
Yields highly variable RTT estimates



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 Digita 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”



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

	Year 1	Year 2	Year 3
T1: Overlay Internetwork Management Services	Measure & Eval Ovly Nets Design for In-Building Ovly	Design for Wide-Area Ovly Demo In-Building Ovly Net	Demo Wide-Area Ovly Demo Scaled Net Perfor
T2: Mobile Application Support Services	Design API & Appl Toolkit	Demo API for In-Building Develop Simple Collab Apps	Integrate with NOW Servers Demo Scaled Apps Perf
O1: Wide-Area Deployment and Demonstration	Accelerate Design for Wide-Area Ovly Integration	Demo Wide-Area Overlay Design for Multiple Ovlys	Demo Extension to Multiple Wide-Area Overlays
O2: Pilot Application Demonstrations	Deploy In-Build Net@UCSF Eval Med Image Apps Reqs	Design Libr Nav & Med Image Distr Apps using API	Large Scale Demo of Nav & Med Image Distr Apps
	9/95 - 8/96	**9/96 - 8/97**	**9/97 - 8/98**

DARPA GloMo Program Goals

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

Industrial/University Partnerships

- **Research Access to Wireless Network**
  - **Metricom (Ricochet), GTE MobileNet (CDPD), Hughes Network Systems (DirecPC), *PacTel (PCS)—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**