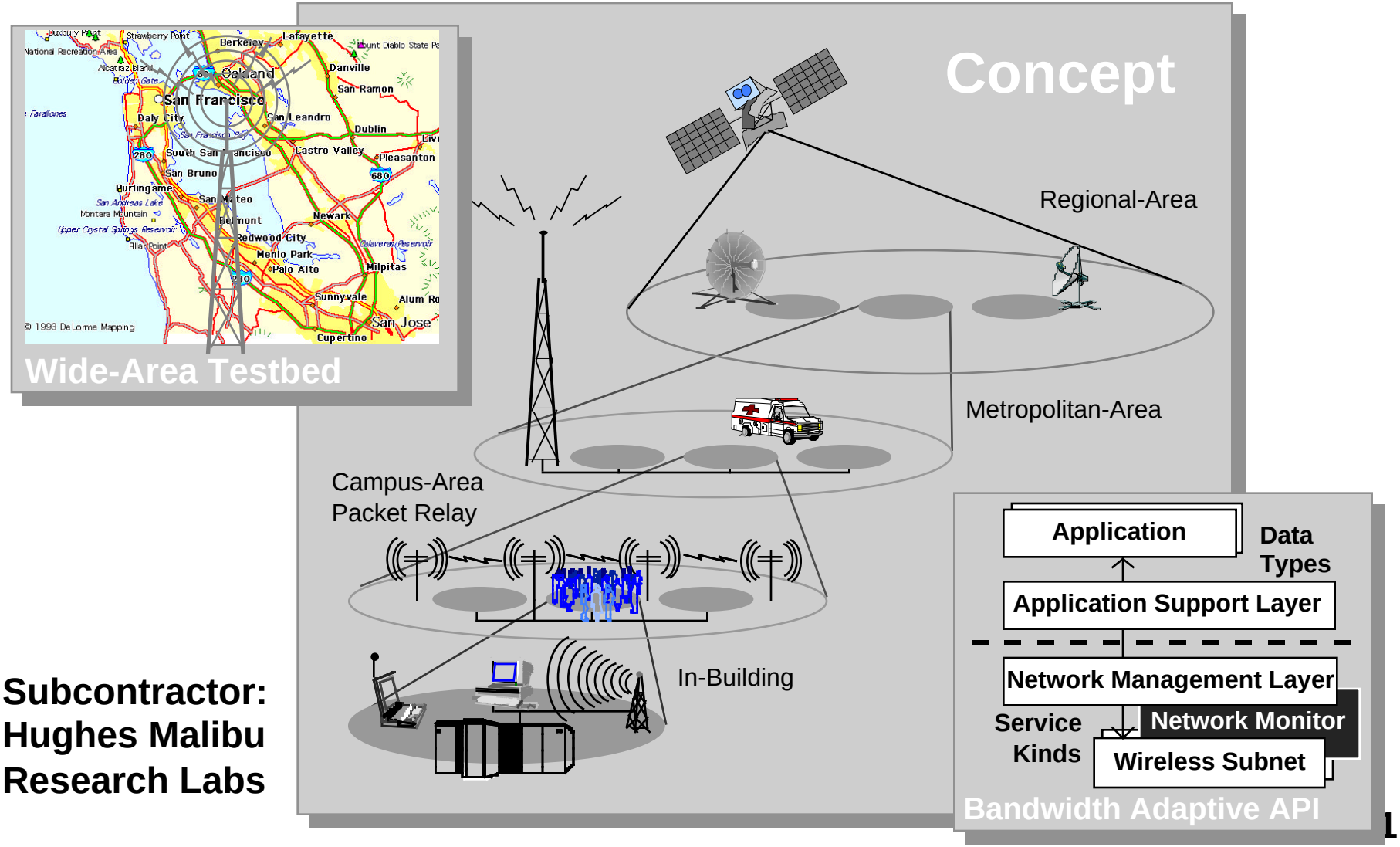
Bay Area Research Wireless Access Network: Towards a Wireless Overlay Internetworking Architecture

Randy H. Katz, Eric A. Brewer, UC Berkeley



Subcontractor: Hughes Malibu Research Labs

The UC Berkeley Team

- **Networking**
  - Hari Balakrishnan (Reliable Transport)
  - Todd Hodes (Wide Area Roaming)
  - Daniel Jiang (Wide Area Roaming)
  - John Loffeld (System Support)
  - Ken Lutz (Network Infrastructure)
  - Giao Nguyen (Mobility Traces)
  - Venkat Padmanabhan (Mobile Routing)
  - Keith Sklower (DBS Unix Driver)
  - Mark Stemm (Vertical Handoff)
- **Applications**
  - Elan Amir (Video over Wireless)
  - Armando Fox (Proxy Architecture)
  - Steve Gribble (Mobile Applications)
  - David Gurley (Applications)

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

Retreat Schedule

- **Sunday, January 7:**
  - **5:00 PM Check-in and Dinner**
  - **6:30 PM Project Overview, Randy Katz**
  - **7:30 PM Work In Progress Session, Randy Katz**
    - » **Mobility Trace Collection, Giao Nguyen**
    - » **Wide Area Architecture Issues**
      - **Hierarchical Routing, Venkat Padmanabhan**
      - **Roaming Services, Todd Hodes**
  - **9:00 PM Posters and Demos**
    - » **UCB, UC Santa Cruz, and Stanford Research Groups**
    - » **Refreshments will be served**

Retreat Schedule

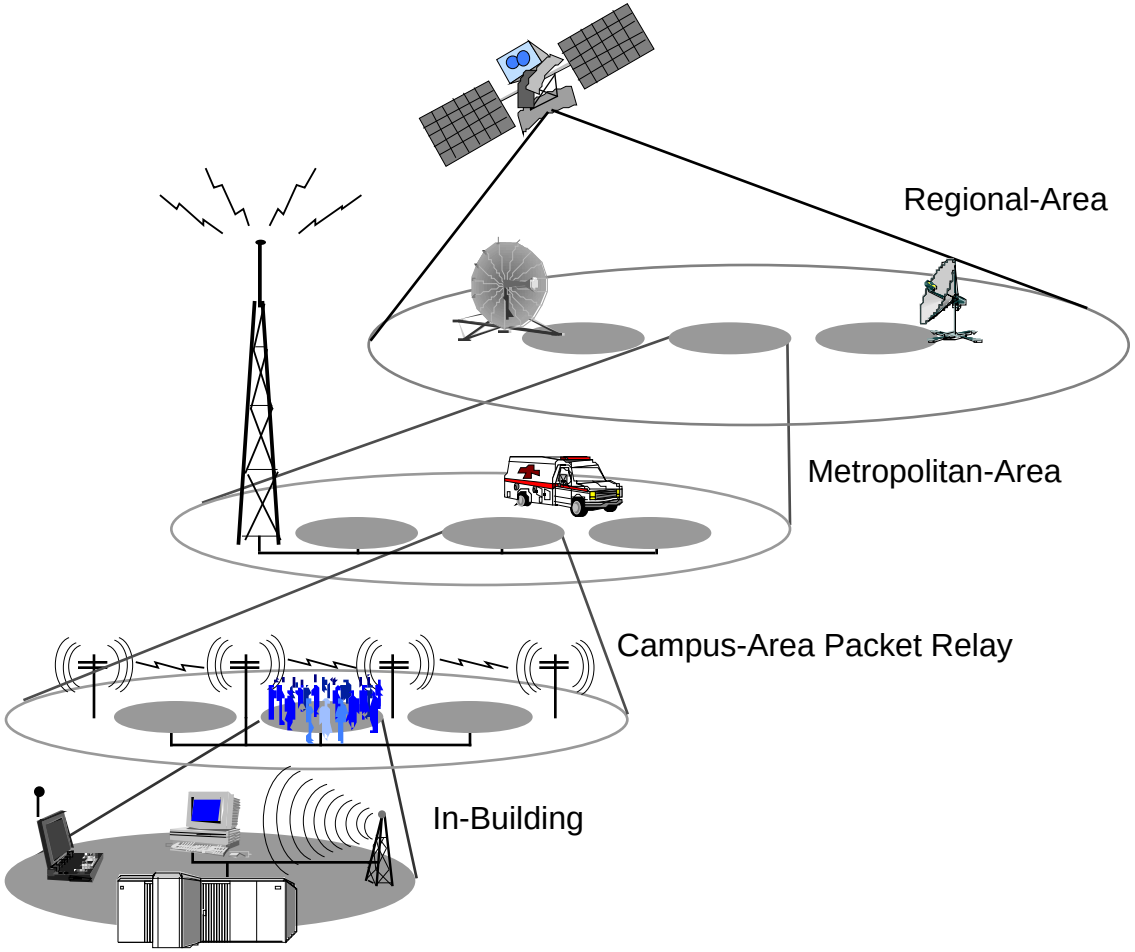
- **Monday, January 8:**
  - **7:30 AM Breakfast**
  - **8:30 AM Application Support Architecture Design Review, Armando Fox and Steve Gribble**
  - **10:00 AM Break**
  - **10:30 AM Work In Progress II, Eric Brewer**
    - » **Vertical Handoff, Mark Stemm**
    - » **Heterogeneous Environments**
      - **Video Dissemination, Elan Amir**
      - **Reliable Transport, Hari Balakrishnan**
  - **Noon Lunch with the InfoPad Retreat**
  - **1:30 PM InfoPad Retreat**
  - **Evening Banquet at the Monterey Bay Aquarium**

Project Vision

“Access is the Killer App”

- **Goals**
  - **Be connected anywhere, anytime via the “best” available (wireless/wireline) network**
  - **Adapt the application to the available bandwidth and latency**
- **Strategies**
  - **Wireless Overlay Internetworking Architecture**
  - **Network- and Type-Aware Applications Building Blocks**

Wireless Overlay Concept



Theatre of Operations

↓

Rear Echelons

↓

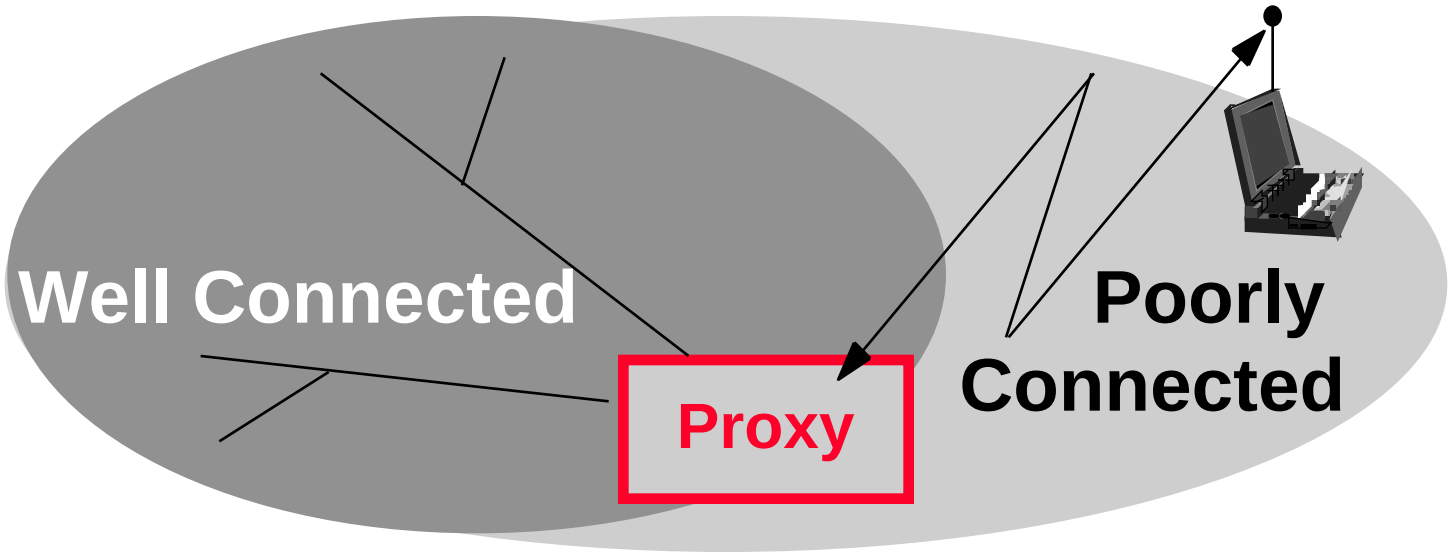
Bases, Depots, Ranges

↓

Command Centers
Training Centers

Proxy Architecture

- **Proxy**
  - Mediates between wireless and wireline environment
  - Ideally executes at “well-connected” boundary of internetwork
  - Changes data representations on-the-fly
  - Trade-off in transcoding time and communications time



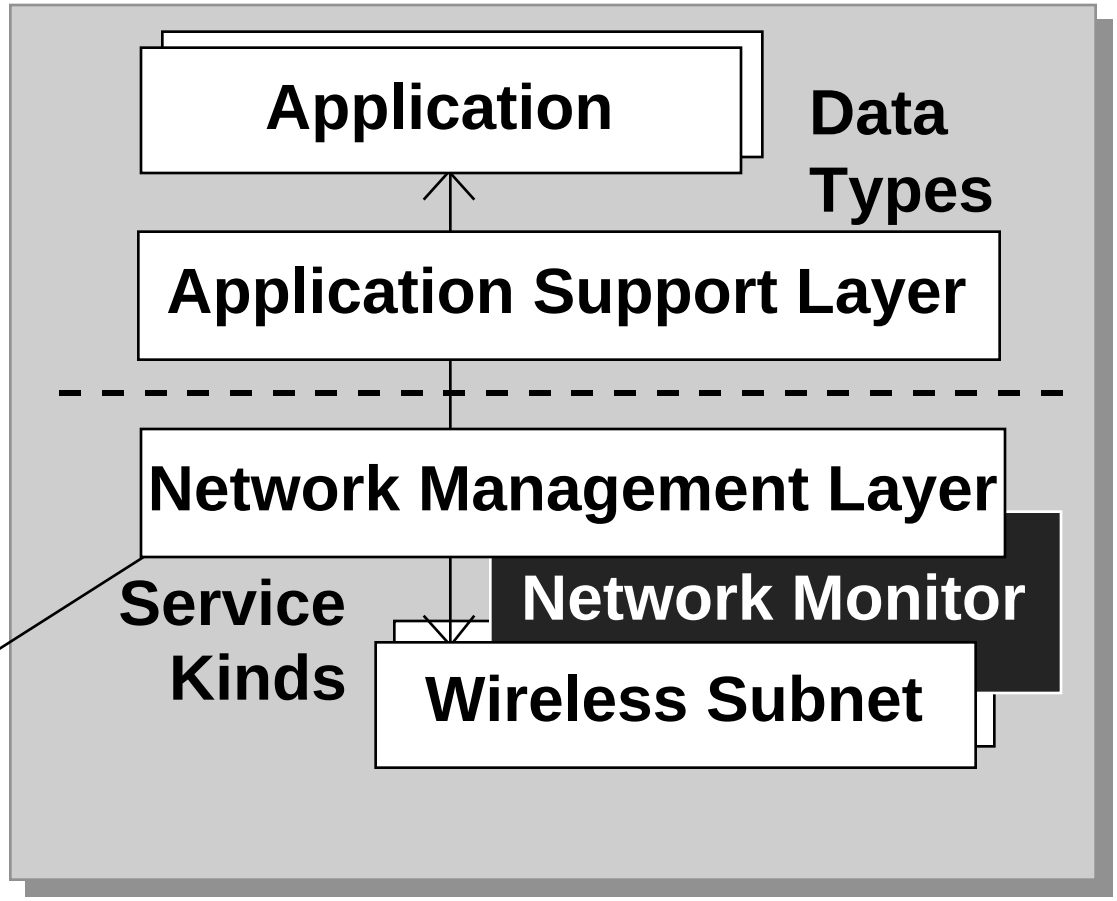
Bandwidth Adaptive Application Interfaces

When to switch from one overlay network to another?

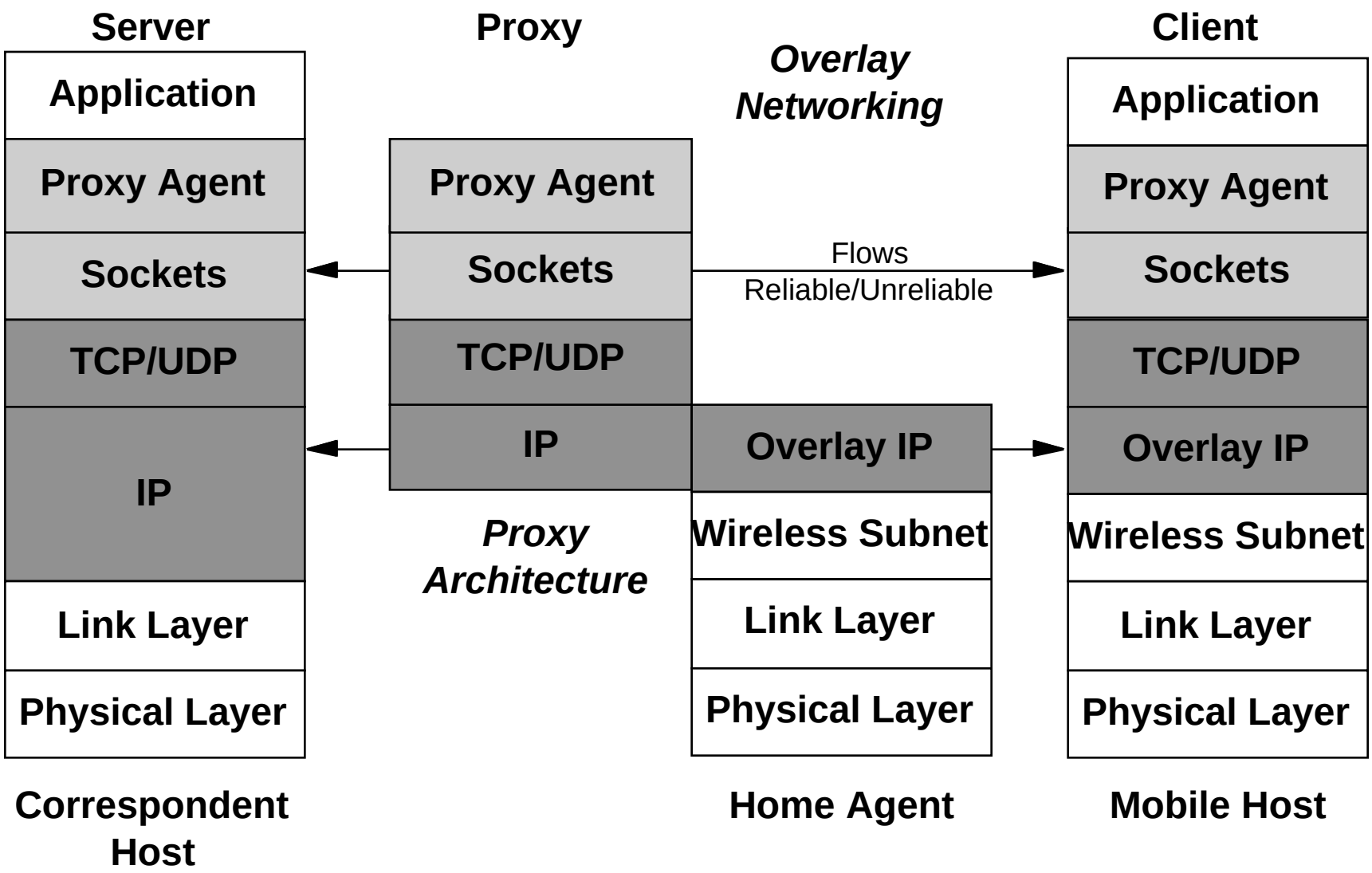
Strategy:
- Monitor network state
- Detect edge of coverage
- Initiate vertical h/o

Network Monitor:
- Determines network state
- Basis for trace collection

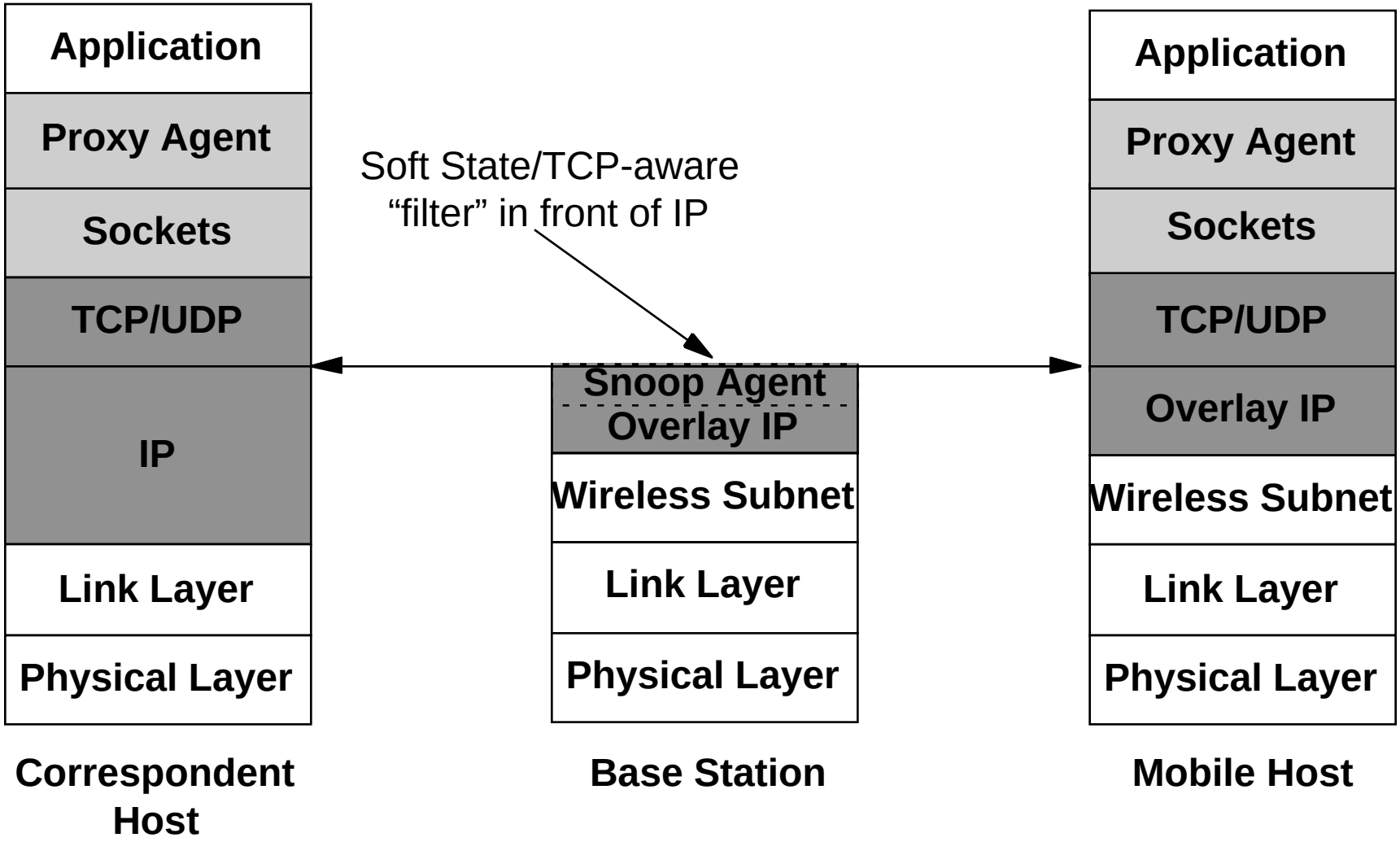
Routing + Handoff



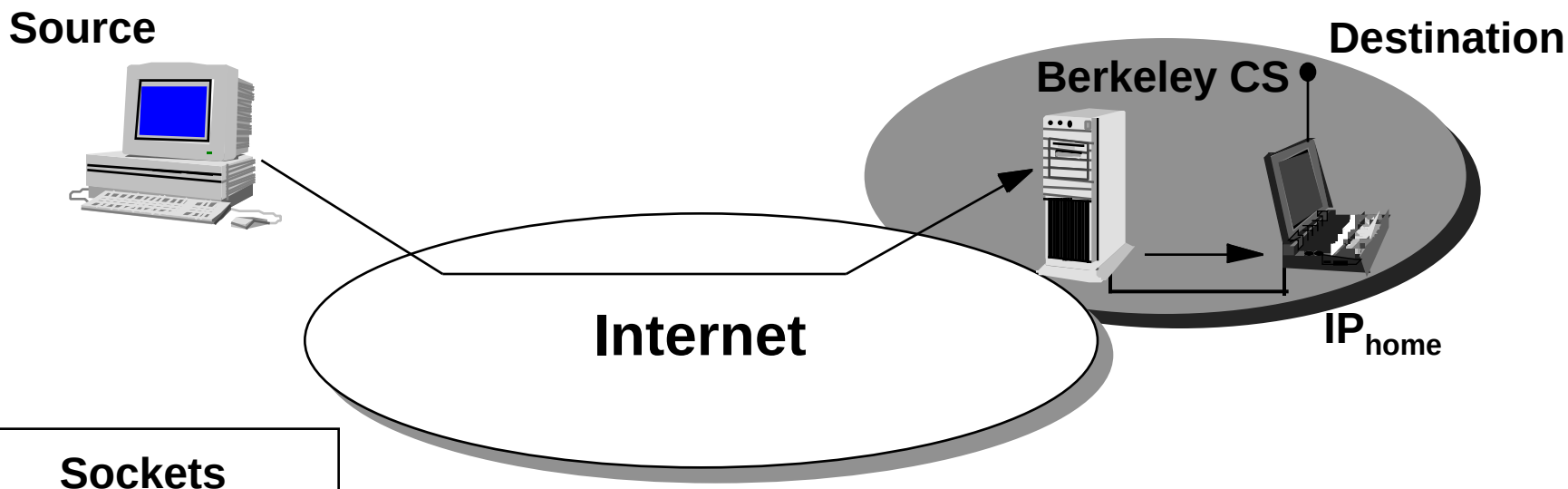
Application/Network Architecture



Application/Network Architecture

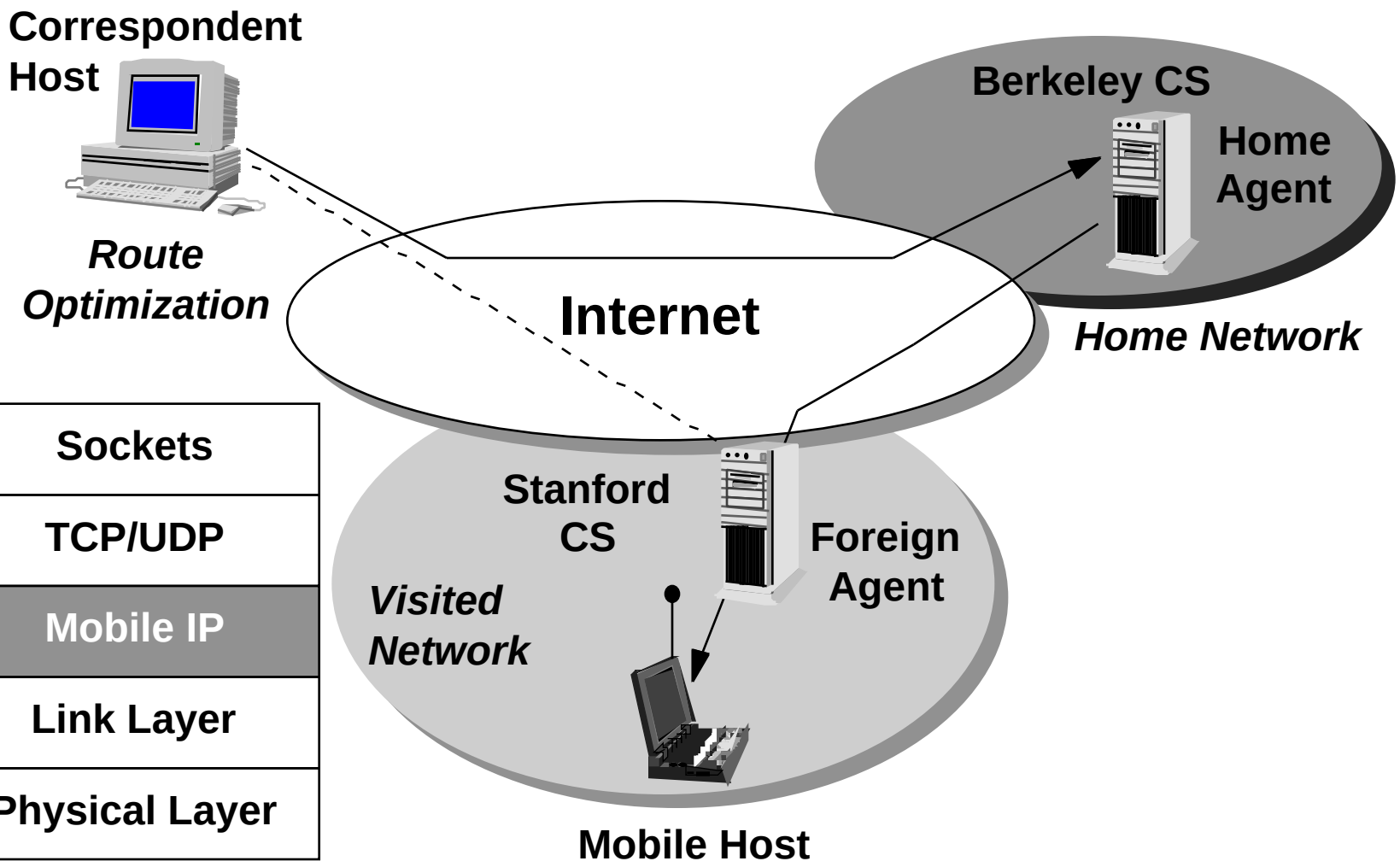


IP Routing



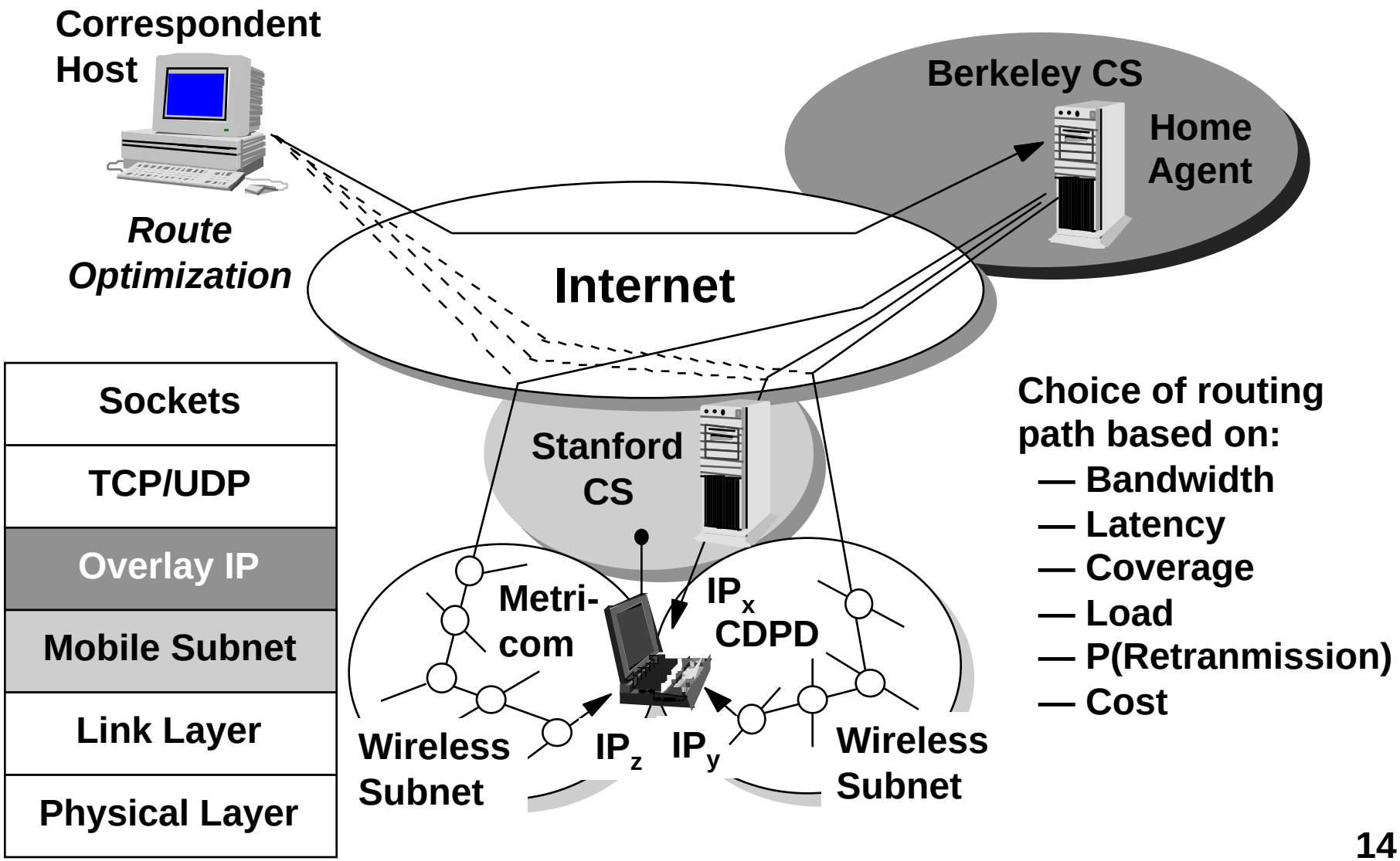
Sockets
TCP/UDP
IP
Link Layer
Physical Layer

Mobile IP



Sockets
TCP/UDP
Mobile IP
Link Layer
Physical Layer

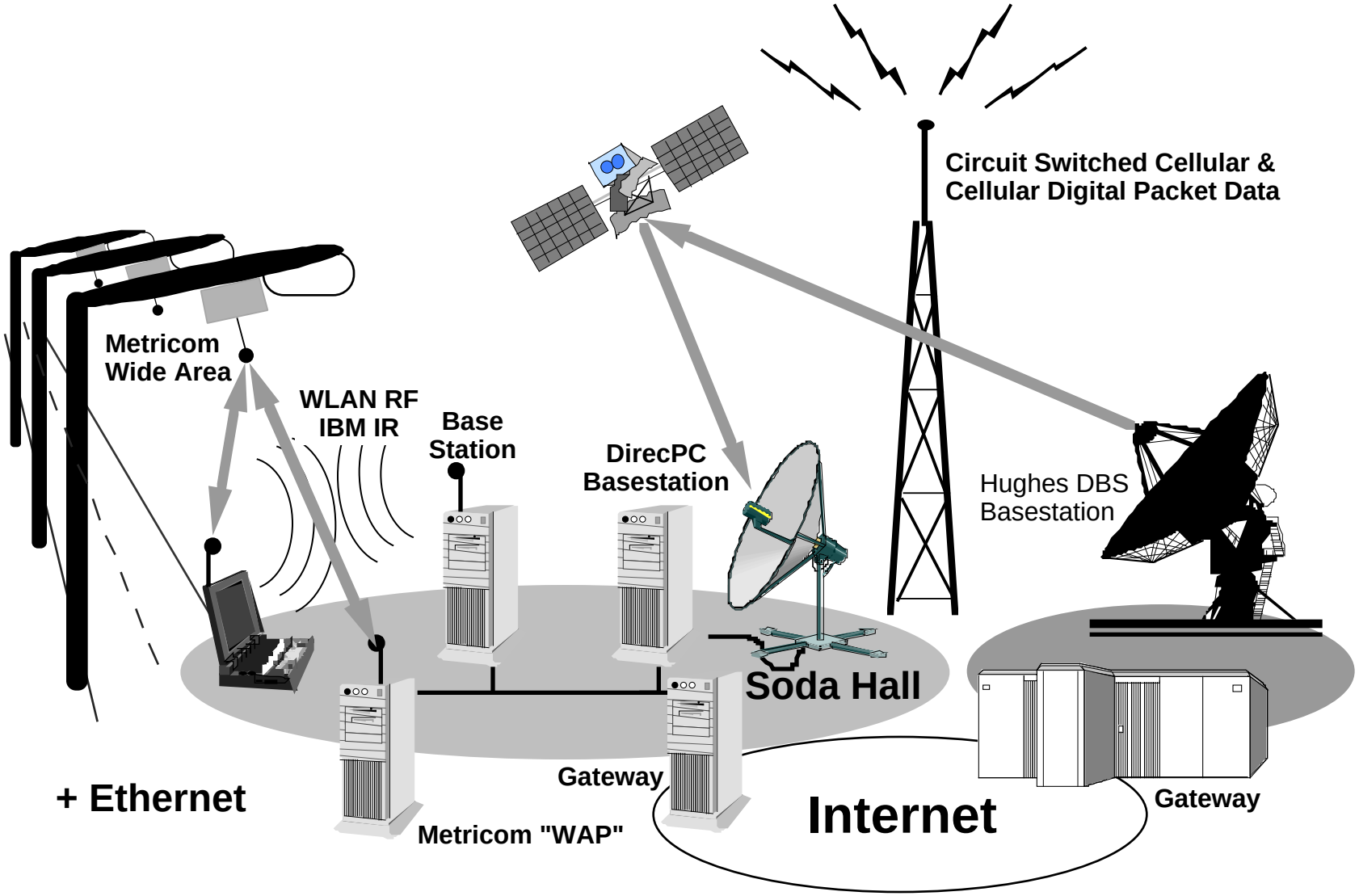
Overlay Networks: Mobile IP + Multi-homed Hosts



Achievements to Date

- 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

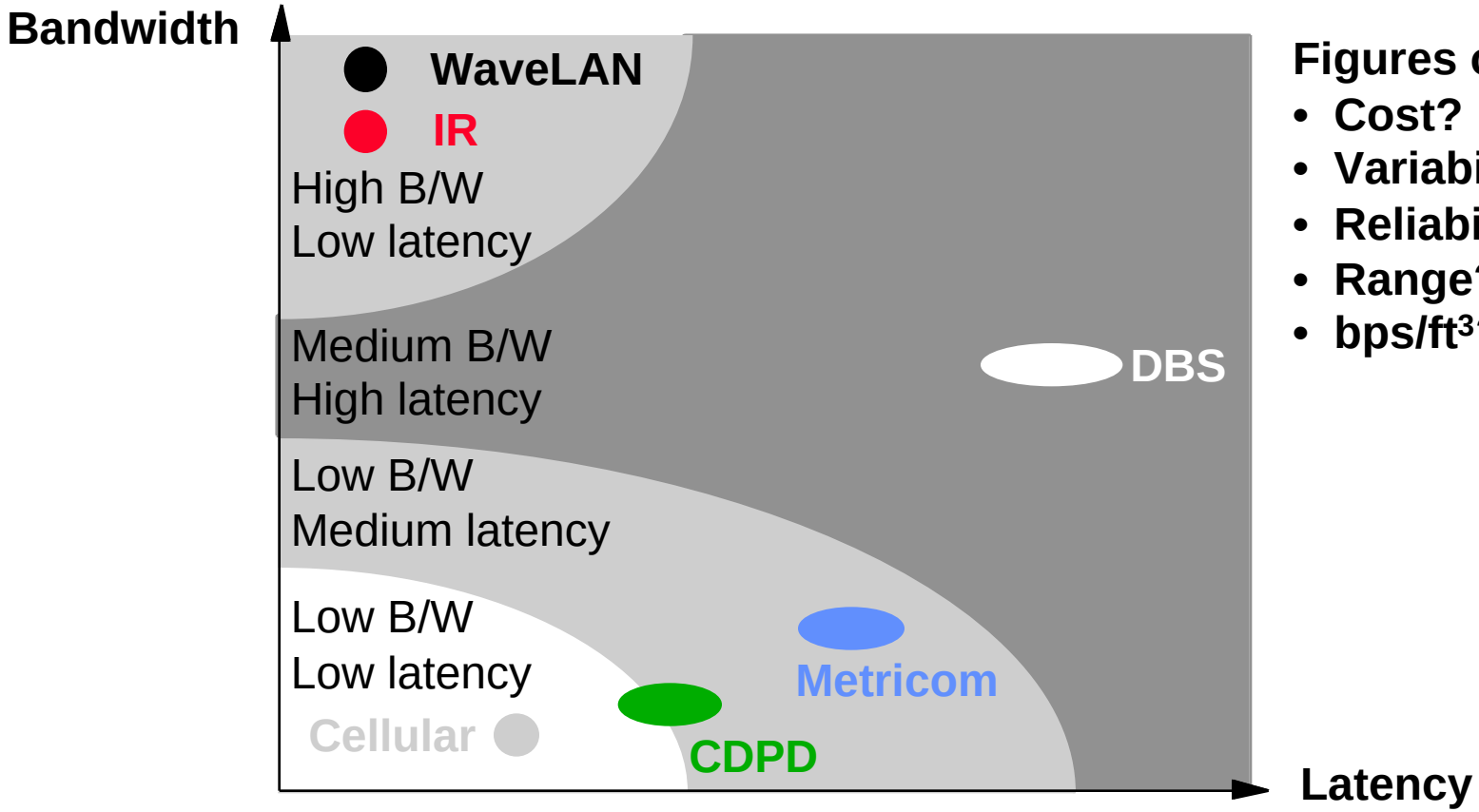
BARWAN Testbed



Characteristics of Alternative Overlay Technologies

Type of Network	Bandwidth	Latency	Mobility	Typ Video Performance	Typ Audio Performance
In-Building			Pedestrian	2-Way 'ractive	High Quality
IBM IR ATT WaveLAN	1 Mbps 1.5 Mbps	<3 ms <3 ms		Full Frame Rate (Compressed)	16-bit Samples 22 Khz Rate
Packet Radio			Pedestrian	Med. Quality	Med. Quality
Metricom	40-60 Kbps pt-to-pt 20-30 Kbps multi-hop	60 ms 100 ms+		Slow Scan	Reduced Rate
Wide-Area			Vehicular	Freeze Frame	Asynchronous
CDPD	9.6 Kbps	100 ms+			"Voice Mail"
Cellular Modem	4.8 Kbps	30 ms			
Regional-Area			Stationary	1-Way Full Frame Rate (Compressed)	High Quality 1 Way or Asynchronous
DirecPC DBS	400-800 Kbps	> 250 ms			

Spanning Space of Wireless Network Technologies

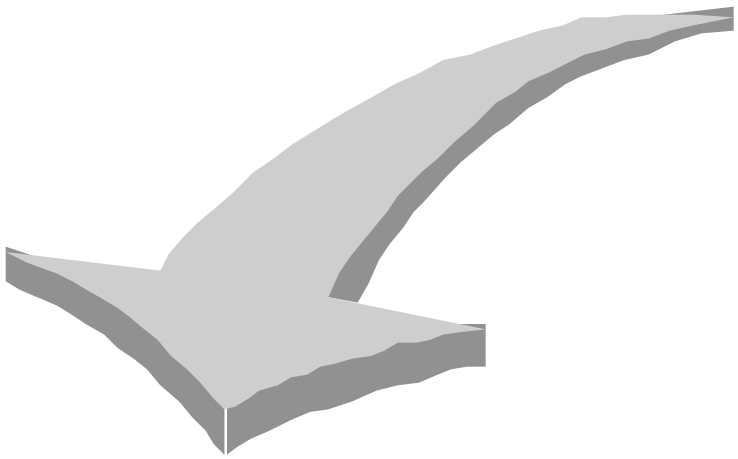


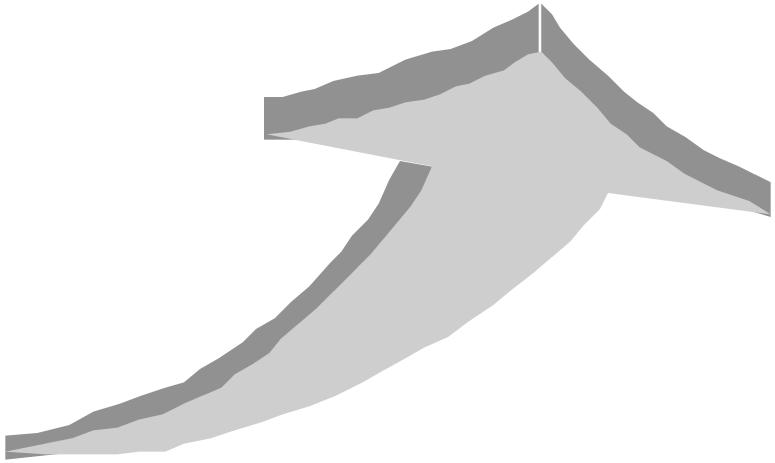
Figures of Merit:

- **Cost?**
- **Variability?**
- **Reliability?**
- **Range?**
- **bps/ft^3?**

Project Strategy

Architectural Design
Scaled Implementations





Early Prototypes
Proof of Concepts
Measurements & Evaluation

Project Plan and Status

Project Start: 15 Aug 95
(Start + 5 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

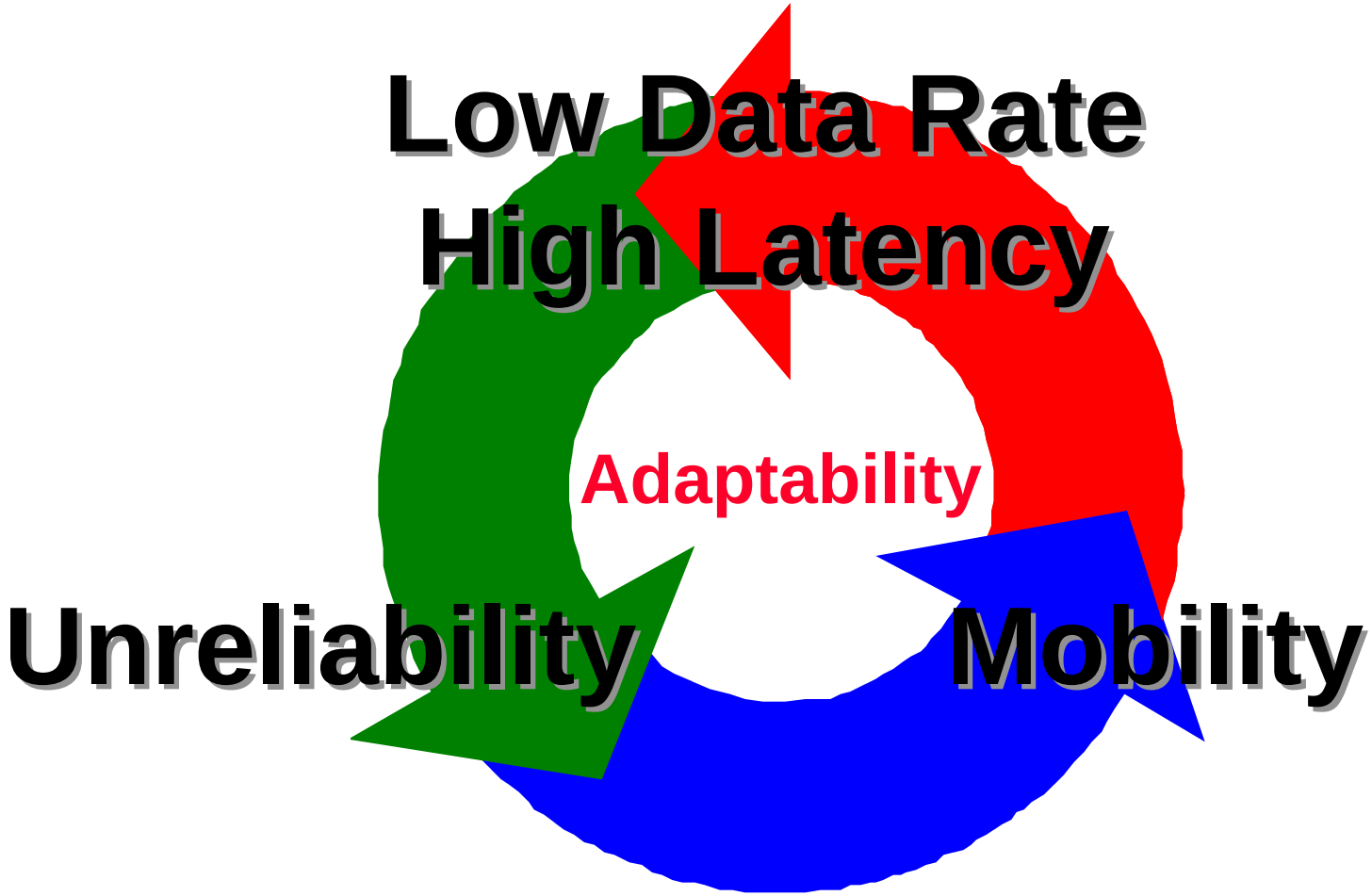
NOWs
Wireless Overlays
Enhanced Net Performance

Extend with Emerging Technologies

Scalability

- **Network Scaling**
  - Mapping of traffic classes onto alternative routing paths
  - Load balancing across overlays
  - Hierarchical Foreign Agents in Mobile/Overlay IP
- **Application Support Scaling**
  - Scalable processing techniques for proxies
  - Exploit networks of workstations (NOWs)
- **Geographic Scaling**
  - Integration of wide-area wireless subnetworks
  - Wide-area roaming architecture

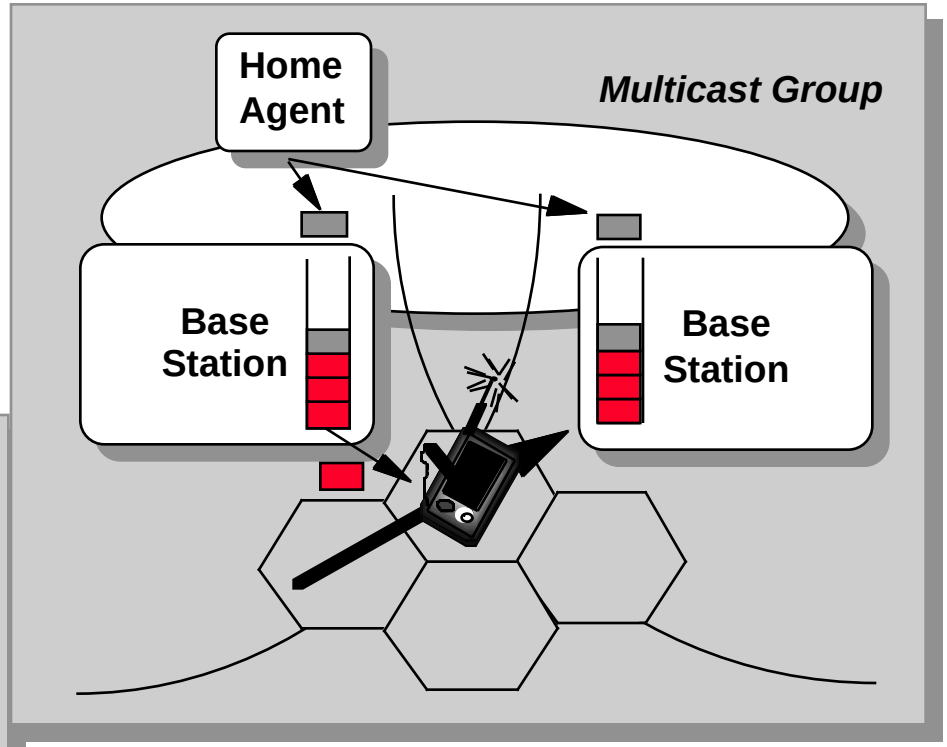
Mobile Computing Challenges

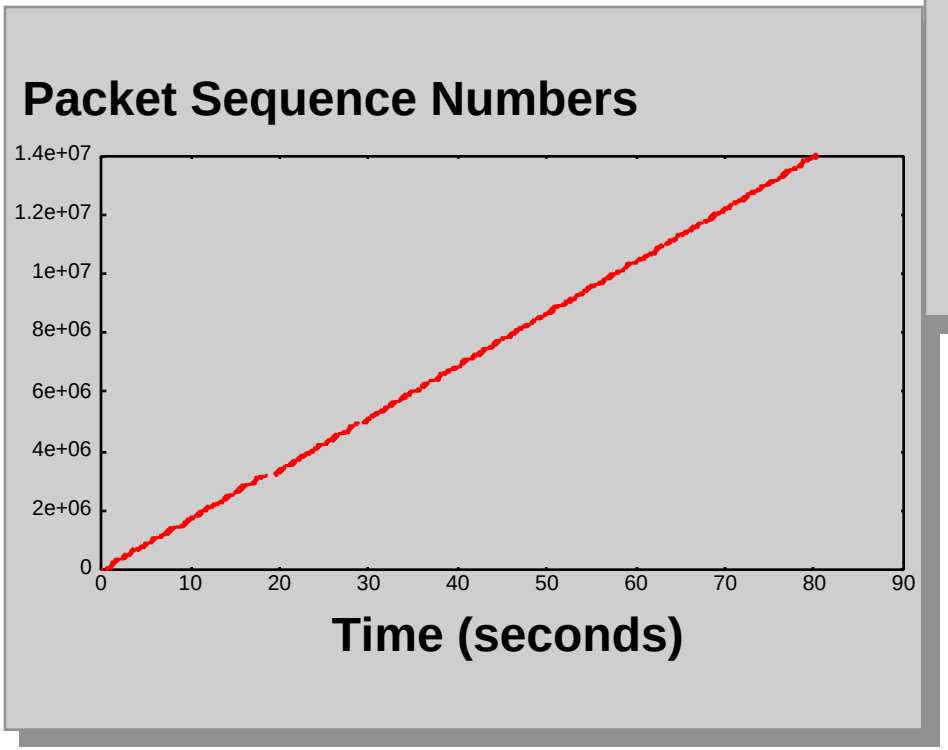


Early Proof of Concepts in all of these areas

Mobility Meets Multimedia: Low Latency Handoff

- Use hints about terminal trajectory to assist in handoffs
- Multicast packets to adjacent base stations to smooth handoffs



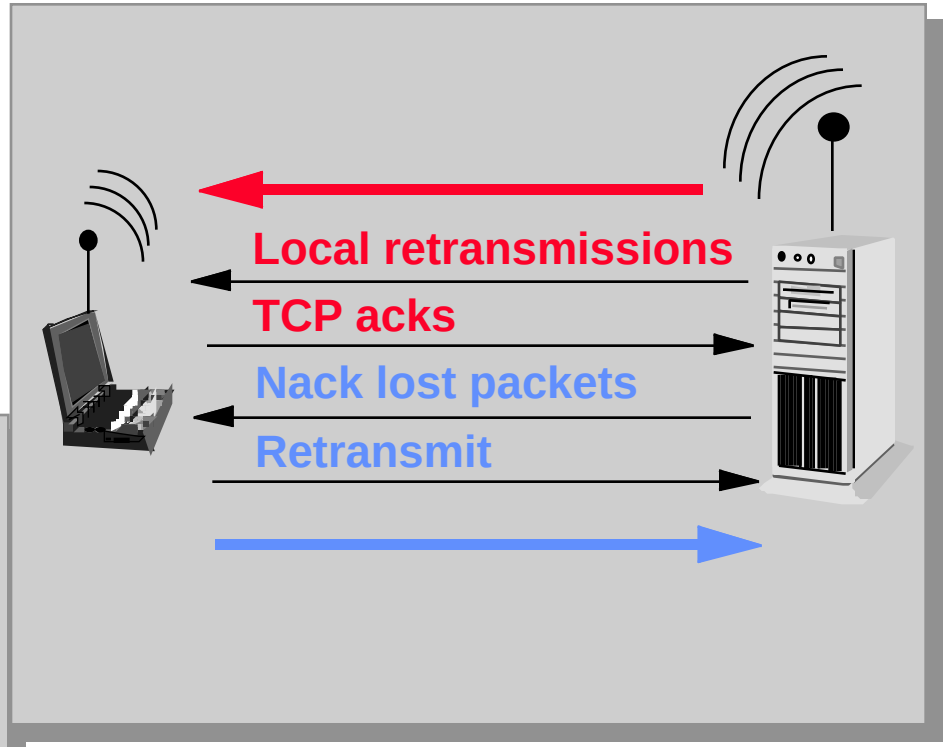


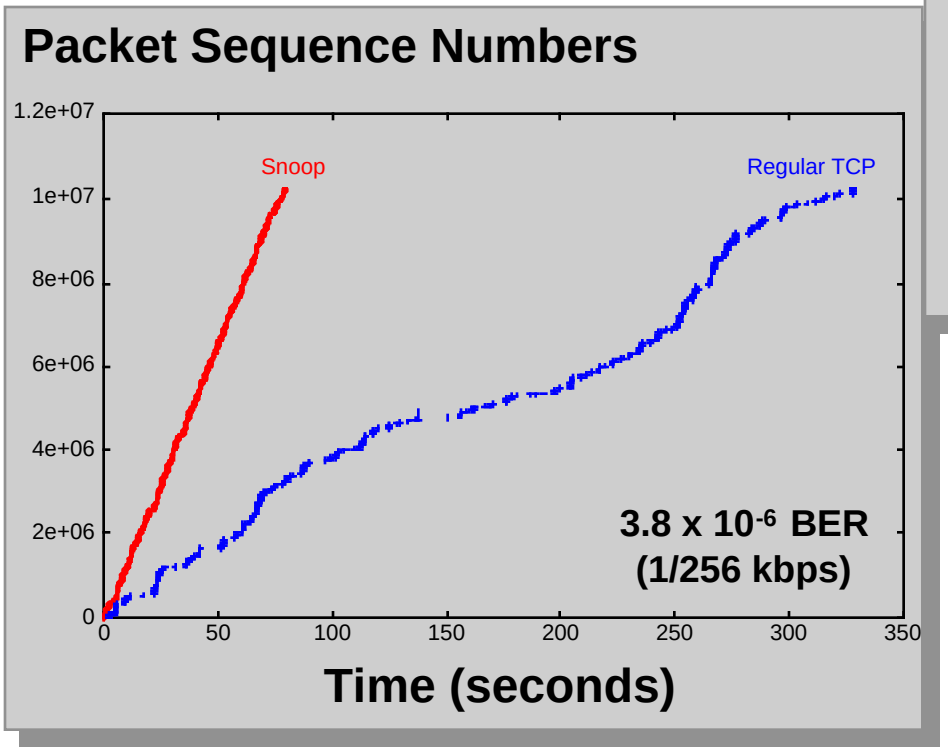
Handoffs every 10 seconds

Code release 1st Quarter 1996

Web Browsing on the Move: Reliable Wireless Transport

- Cache unacknowledged TCP data; Snoop on TCP acks, do local rexmit
- BS explicitly NACKs MH's lost pkts
- Maintain end-to-end TCP semantics





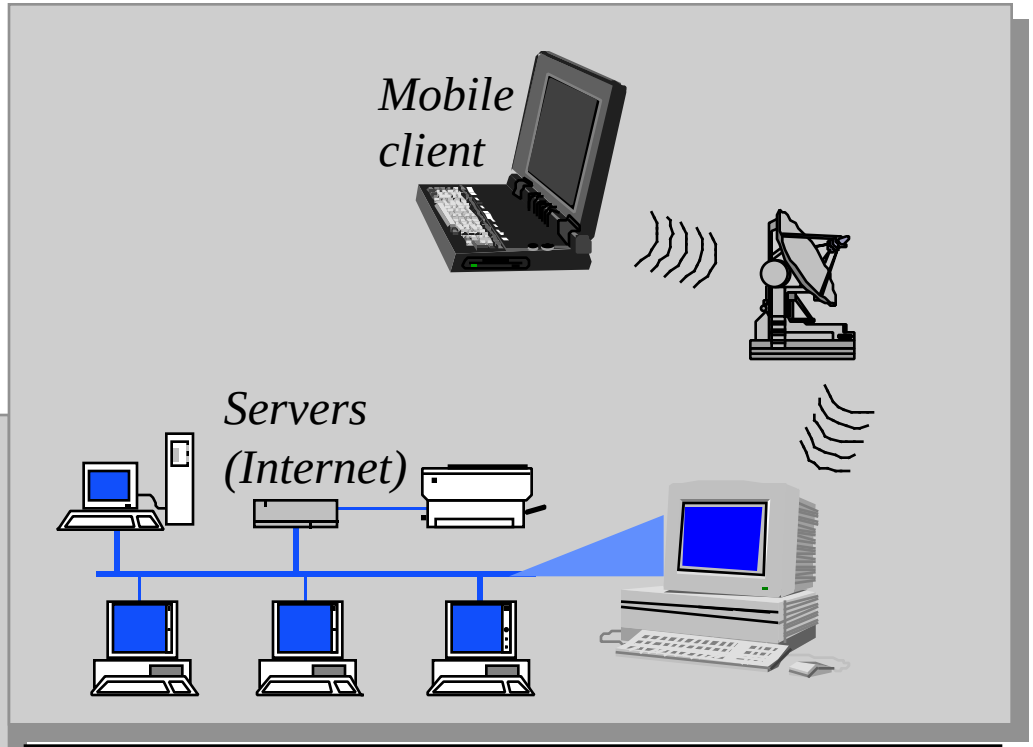
20X speed-up in presence of bit errors

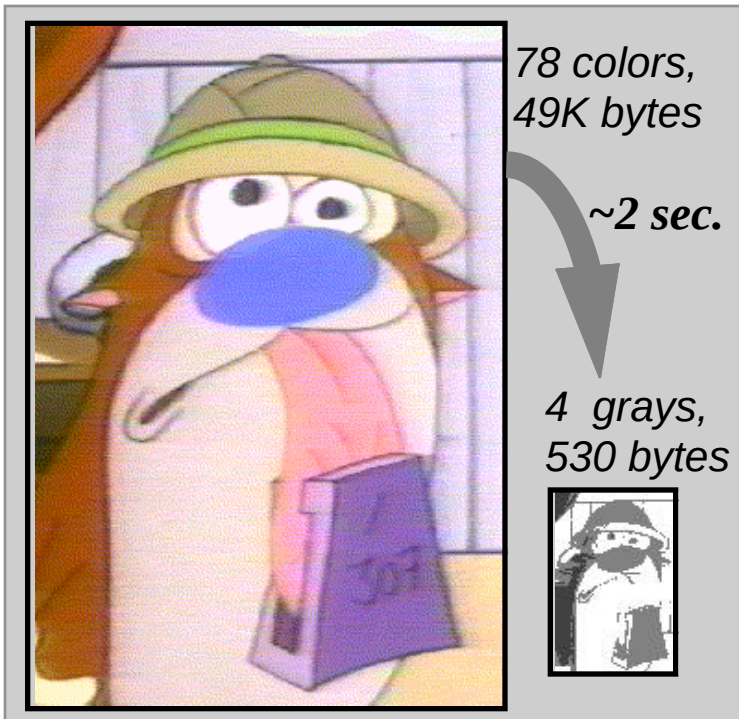
Aggregate b/w 1 Mbps vs. 0.25 Mbps

Code release integrated with handoff

Proxy Architecture: Image Proxy

- **Distillation: lossy compression that preserves semantic content**
- **Works in R/T on desktop PC**
- **Client can request refinement of distilled image**

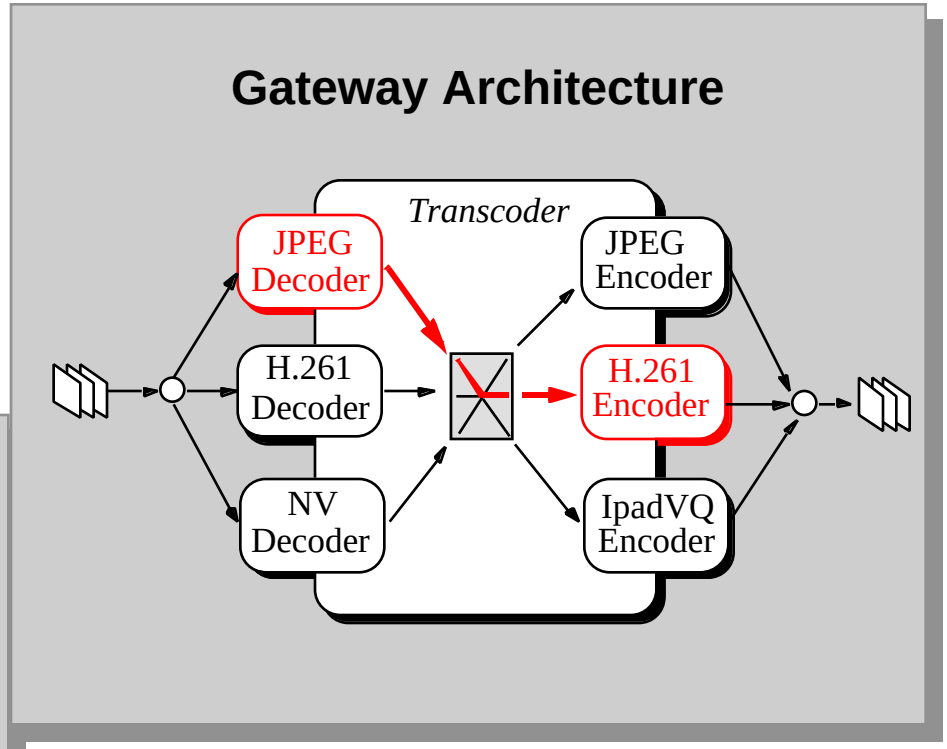


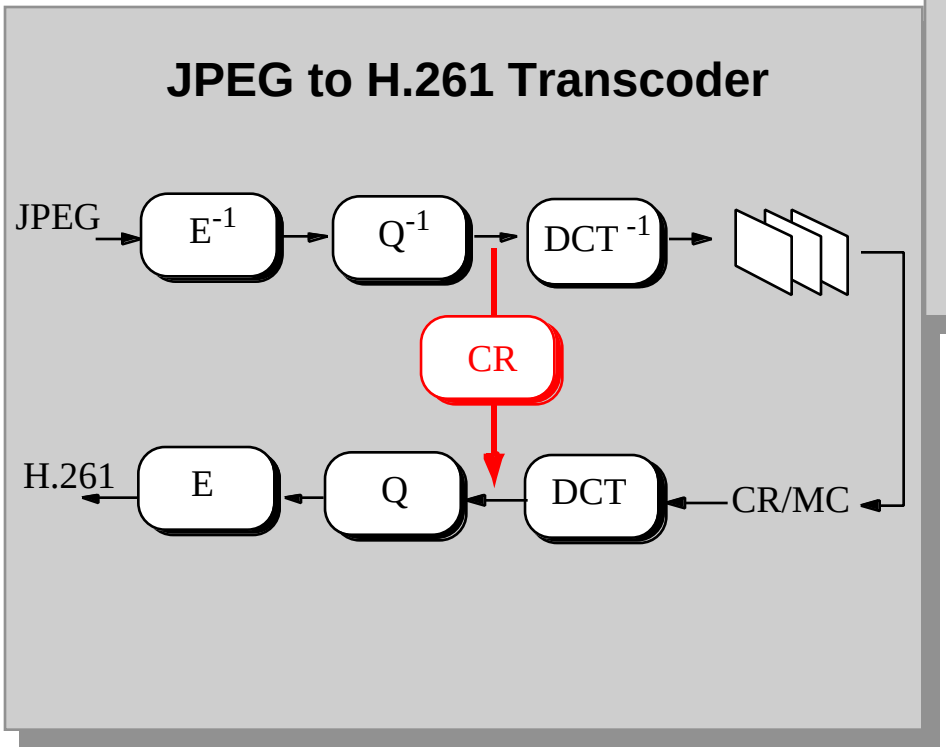


Orig. size (bytes)	New size	New size as % of original	Pixel dimensions	Scaled by	Time (sec.)
34K	2022	0.058	320x200	2	1
848K	5938	0.007	1280x1024	4	13
848K	1676	0.002	1280x1024	8	10
361K	24311	0.066	1022x703	2	8
361K	6240	0.017	1022x703	4	7
173K	4974	0.028	640x480	2	4
173K	1644	0.009	640x480	4	3

Proxy Architecture: Video Gateway

- Another early instance of a proxy
- R/T transcode from high b/w video to low bandwidth video formats
- Integrated with existing Internet MM infrastructure via RTP





Motion	Full Path	Opt. Path
Low	26 fps	30 fps
High	15 fps	27 fps

1/4 NTSC JPEG to CIF H.261 on SparcStation 20

Six Month Plan

- **Mobility traces/benchmarks to drive design efforts**
  - **Collection and analysis in collaboration with CMU**
- **Performance evaluation of alternative *wide-area* wireless overlay technologies**
  - **Metricom, DBS, CDPD**
- **Complete architectural design**
  - **Overlay network and application support architectures**
    - » **Application Layer to Application Support Layer**
    - » **Application Support Layer to Network Layer**
    - » **Mobile Host/Home Agent Path Negotiation**
    - » **Wide Area Mobile Services**

Industrial/University Partnerships

- **Research Access to Wireless Network**
  - **Metricom (Ricochet)**
  - **GTE MobileNet (CDPD)**
  - **Hughes DBS (DirecPC)**
  - ***PacTel (PCS)***
- **Research Collaborations**
  - **Fuji Xerox PA Labs (Mobile applications and networks)**
  - **Hughes (DBS data architecture, satellite protocols)**
  - **Metricom (High performance reliable transport)**
  - **IBM (Mobile routing)**
  - **CMU (Mobile trace collection and analysis)**
  - **UCSC Wings (Extend BARWAN to Monterey Bay)**
  - ***Stanford (Wide area mobile services architecture)***
  - ***UCSF (Medical imaging applications)***