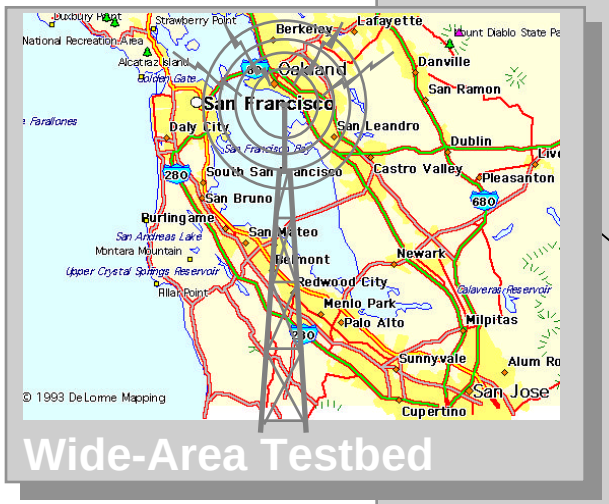
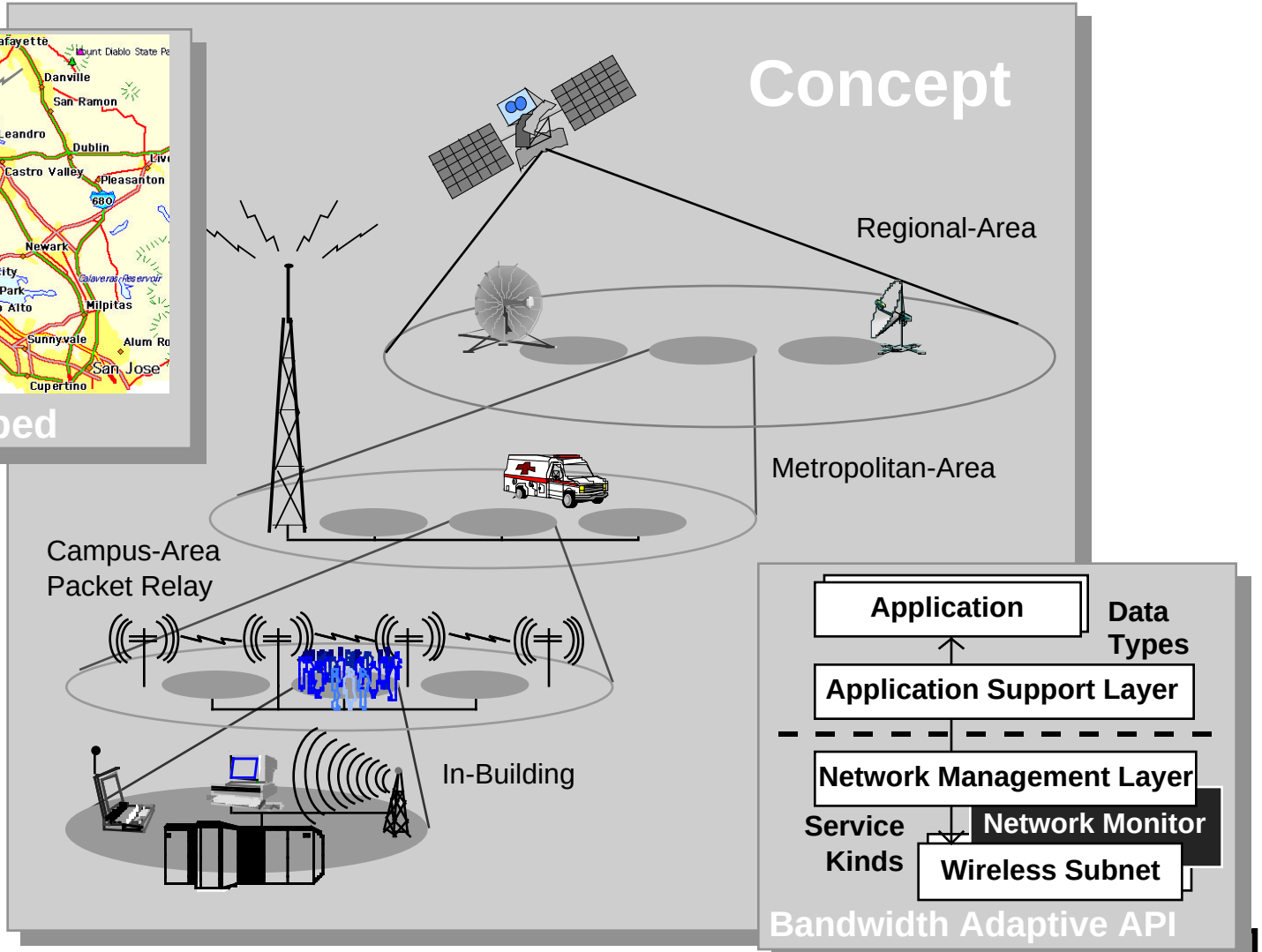
# Bay Area Research Wireless Access Network: Towards a Wireless Overlay Internetworking Architecture

**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

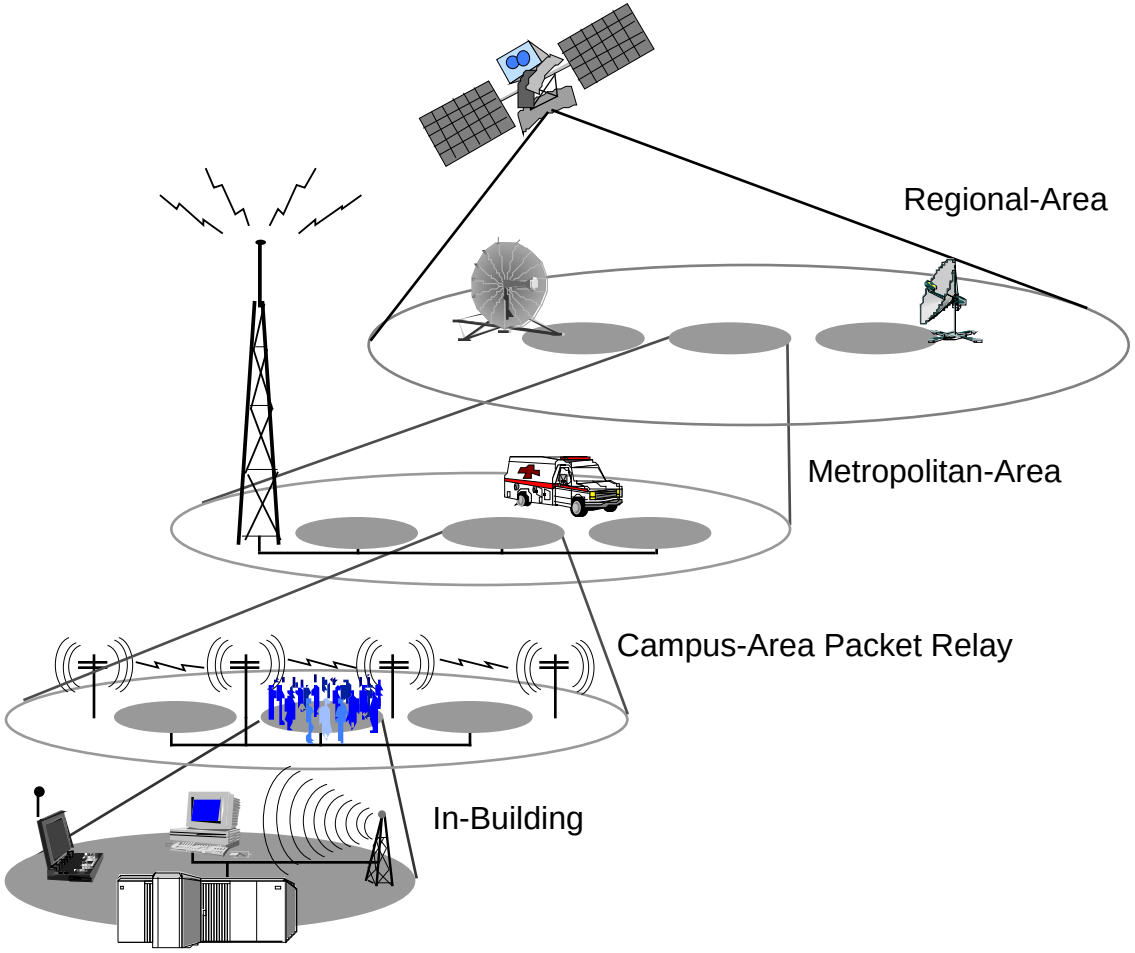
- **Monday, January 8:**
  - **7:30 AM Breakfast**
  - **8:30 AM Application Support Architecture Design Review, Armando Fox and Steve Gribble**
  - **10:00 AM Break**
  - **10:30 AM Work In Progress II, Eric Brewer**
    - » **Vertical Handoff, Mark Stemm**
    - » **Heterogeneous Environments**
      - **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**

↓

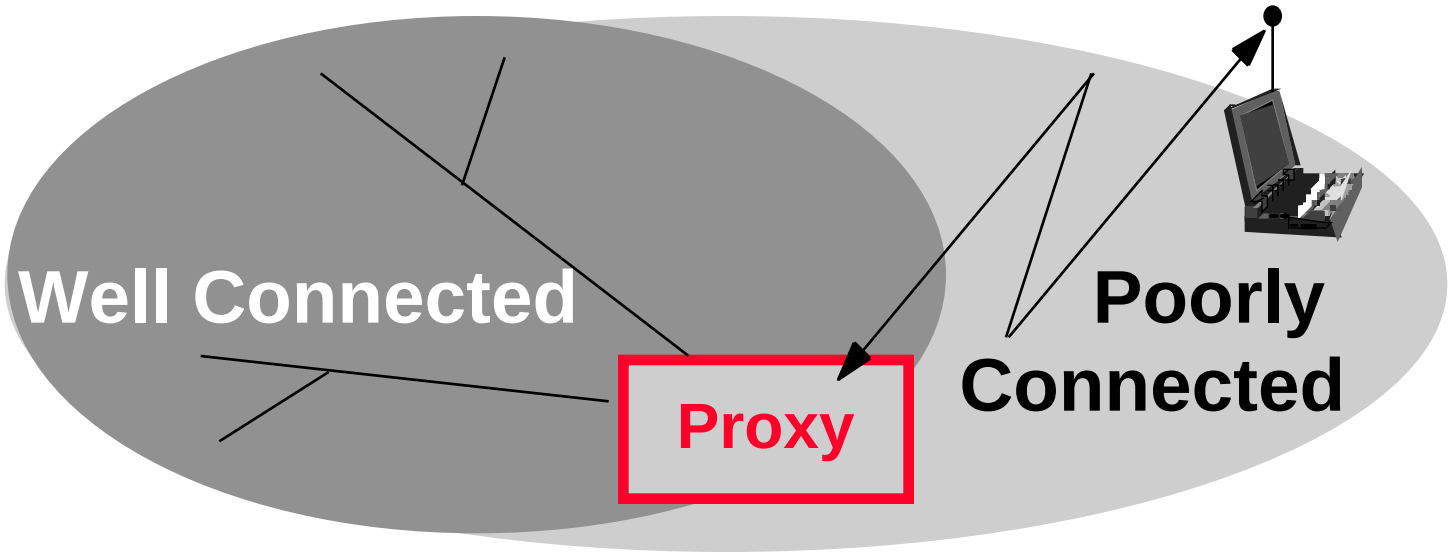
**Bases, Depots, Ranges**

↓

**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**



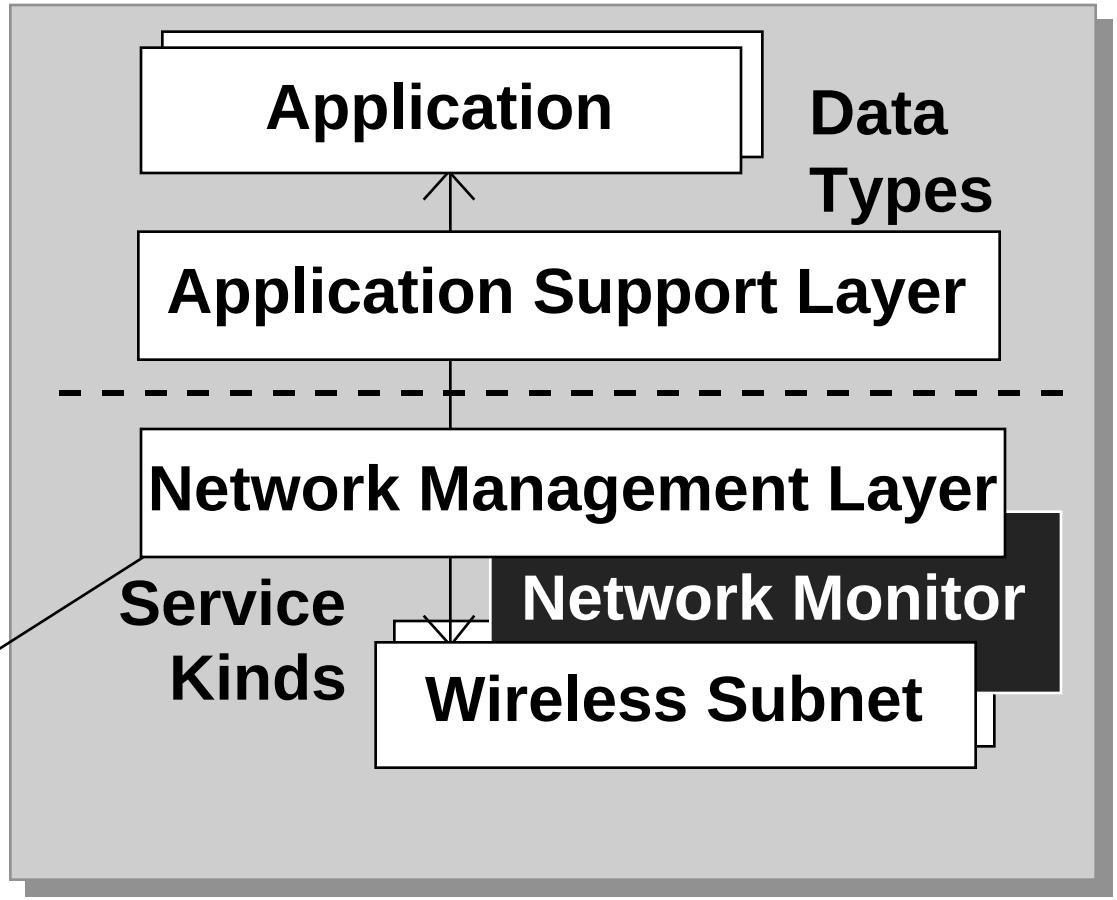
# Bandwidth Adaptive Application Interfaces

When to switch from one overlay network to another?

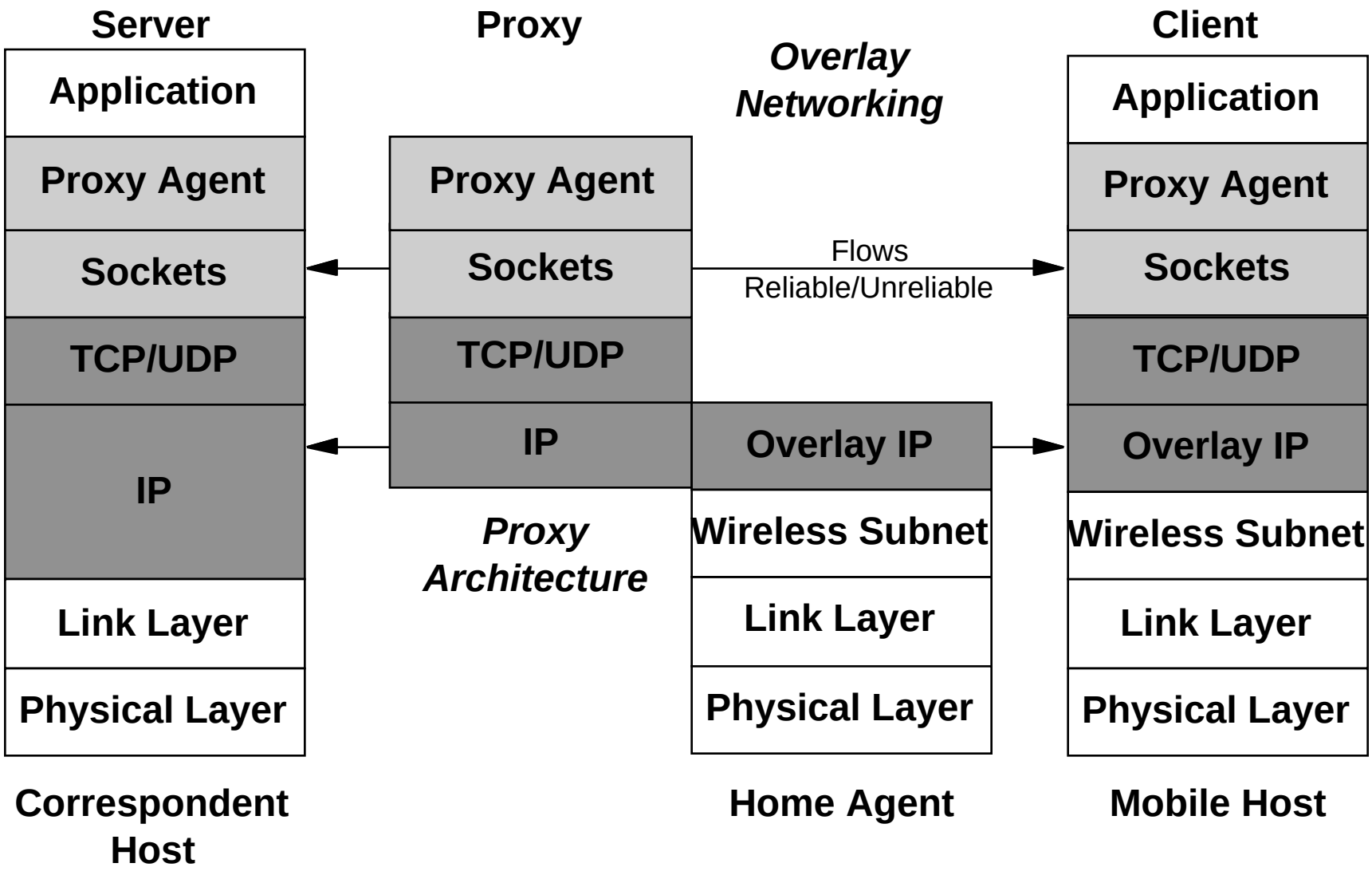
Strategy:
- Monitor network state
- Detect edge of coverage
- Initiate vertical h/o

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

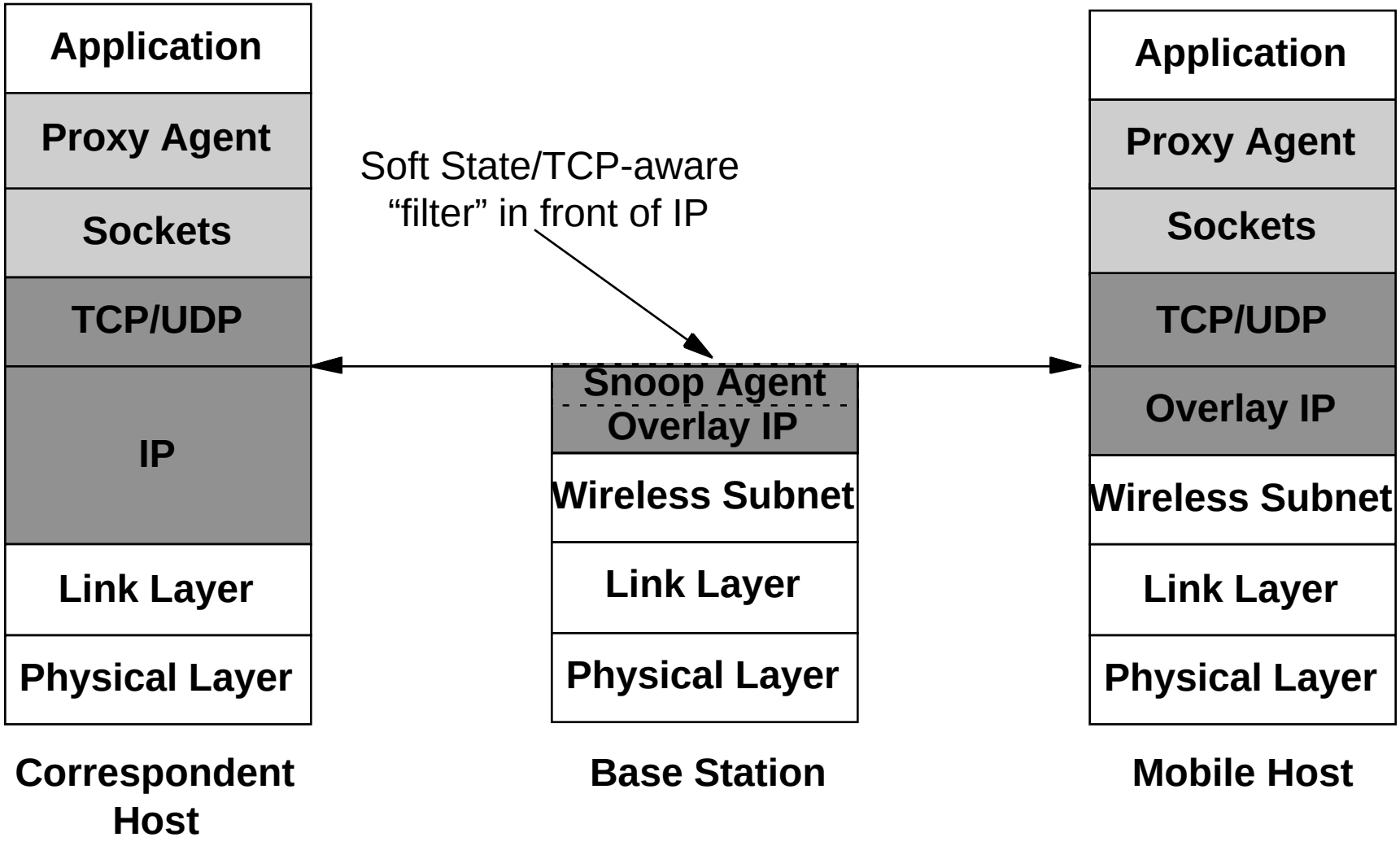
Routing + Handoff



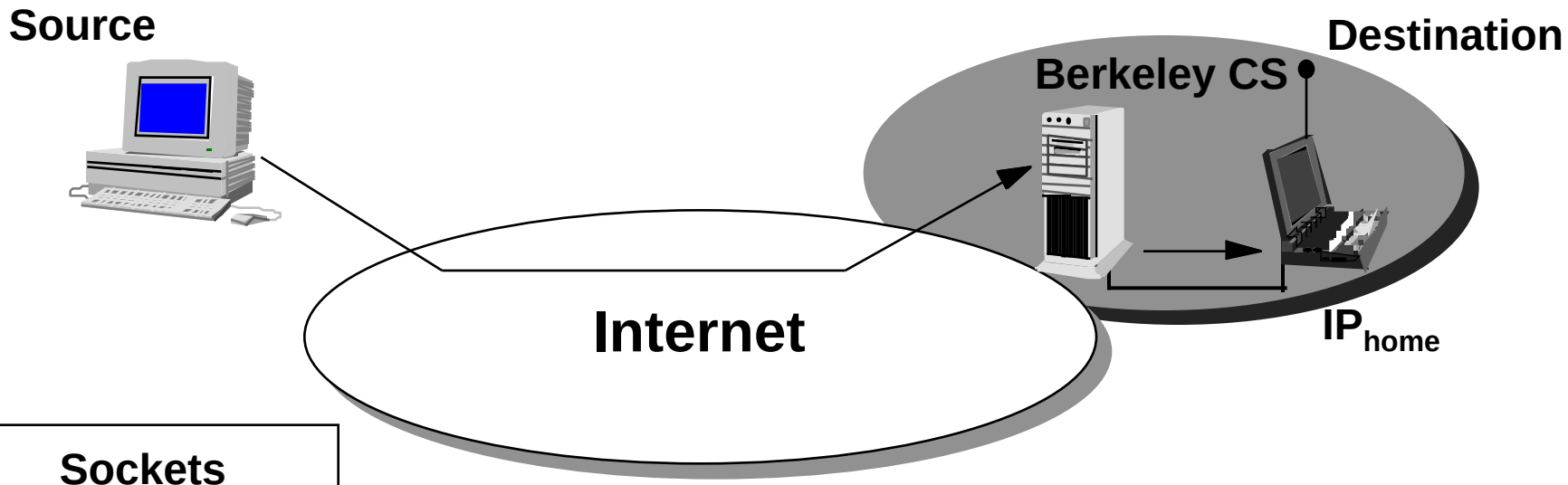
# Application/Network Architecture



# Application/Network Architecture

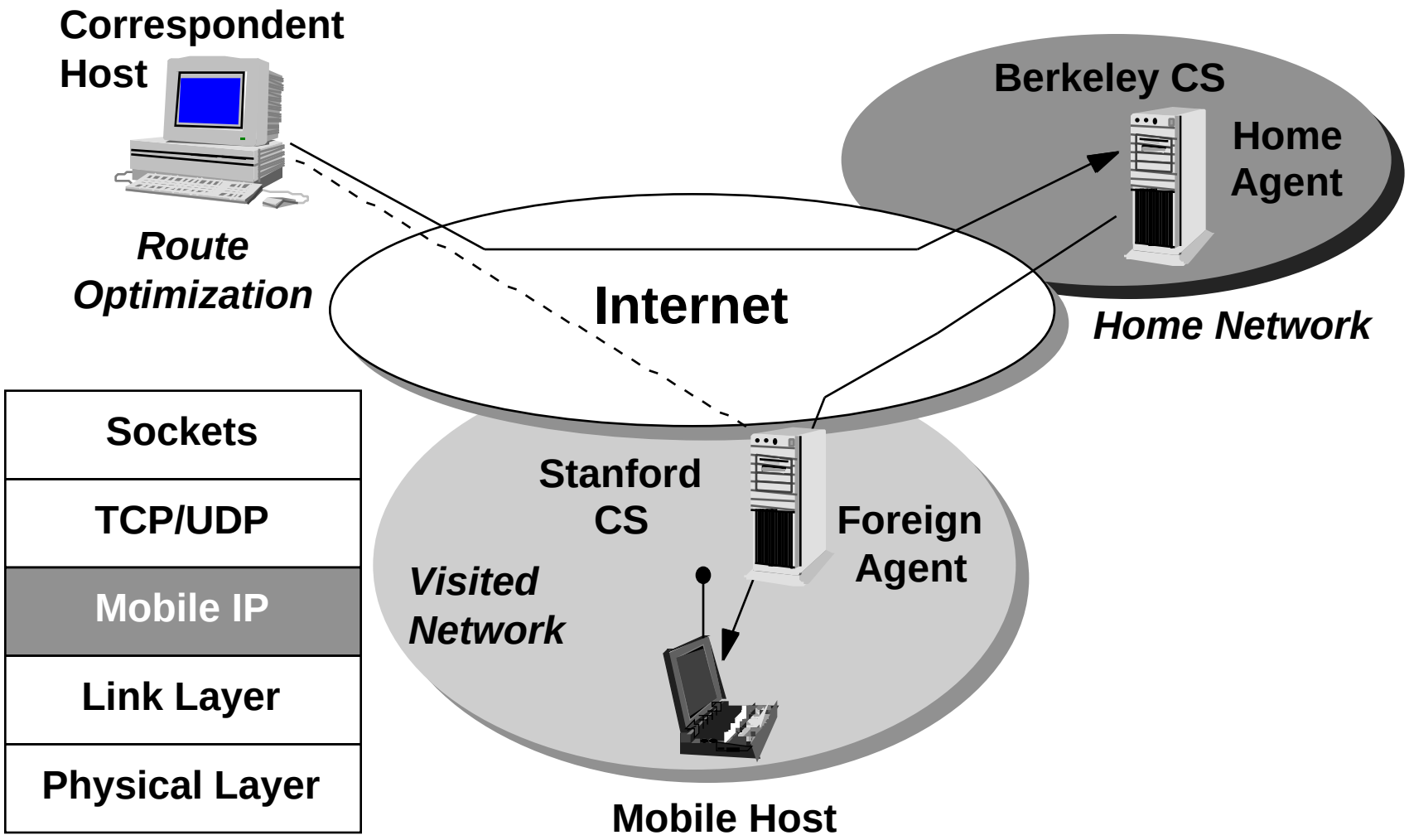


# IP Routing

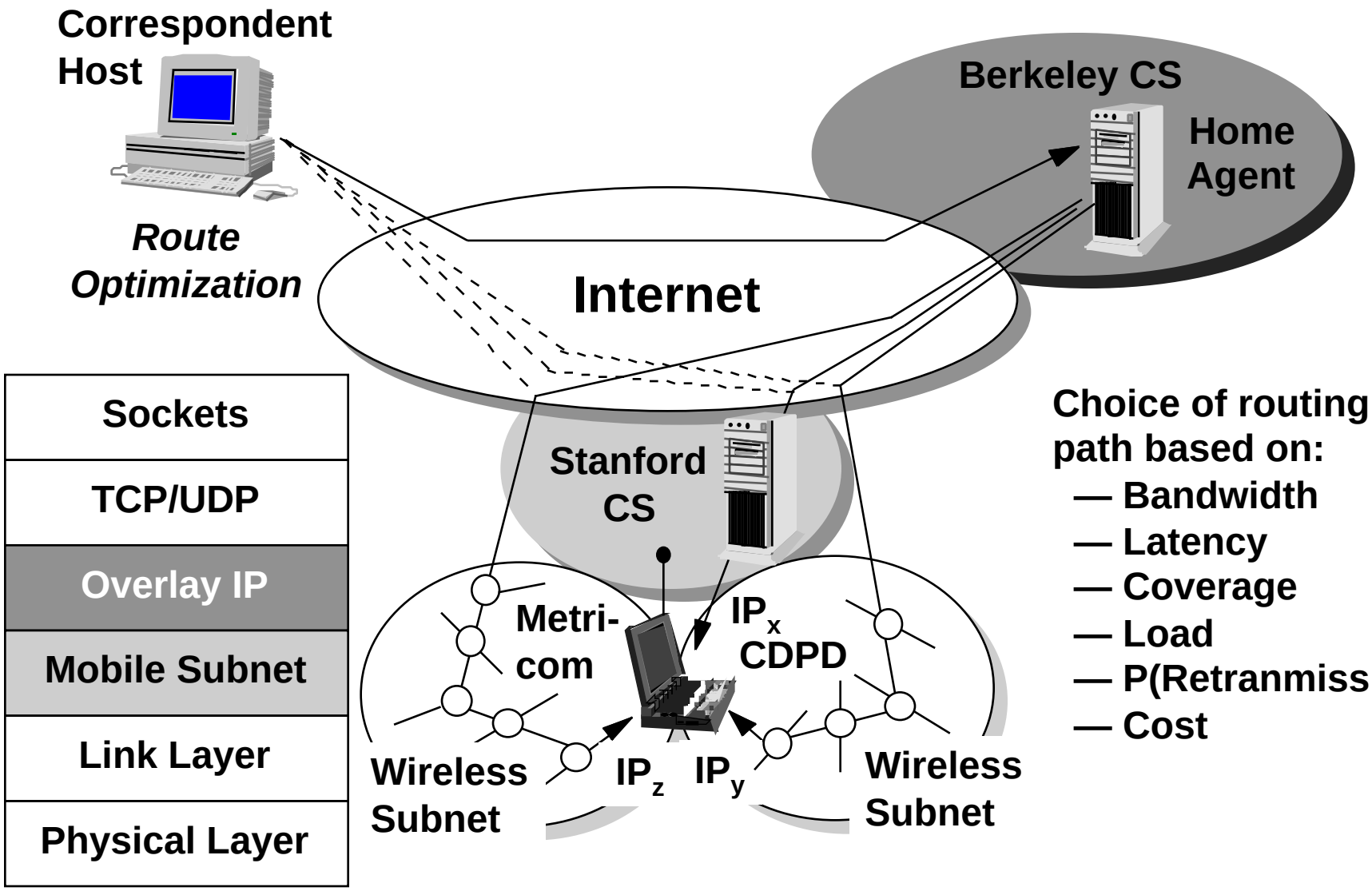



| Sockets |
| --- |
| TCP/UDP |
| IP |
| Link Layer |
| Physical Layer |

# Mobile IP


Correspondent Host
Berkeley CS
Home Agent
Route Optimization
Internet
Home Network
Sockets
TCP/UDP
Mobile IP
Link Layer
Physical Layer
Stanford CS
Foreign Agent
Visited Network
Mobile Host

# Overlay Networks: Mobile IP + Multi-homed Hosts



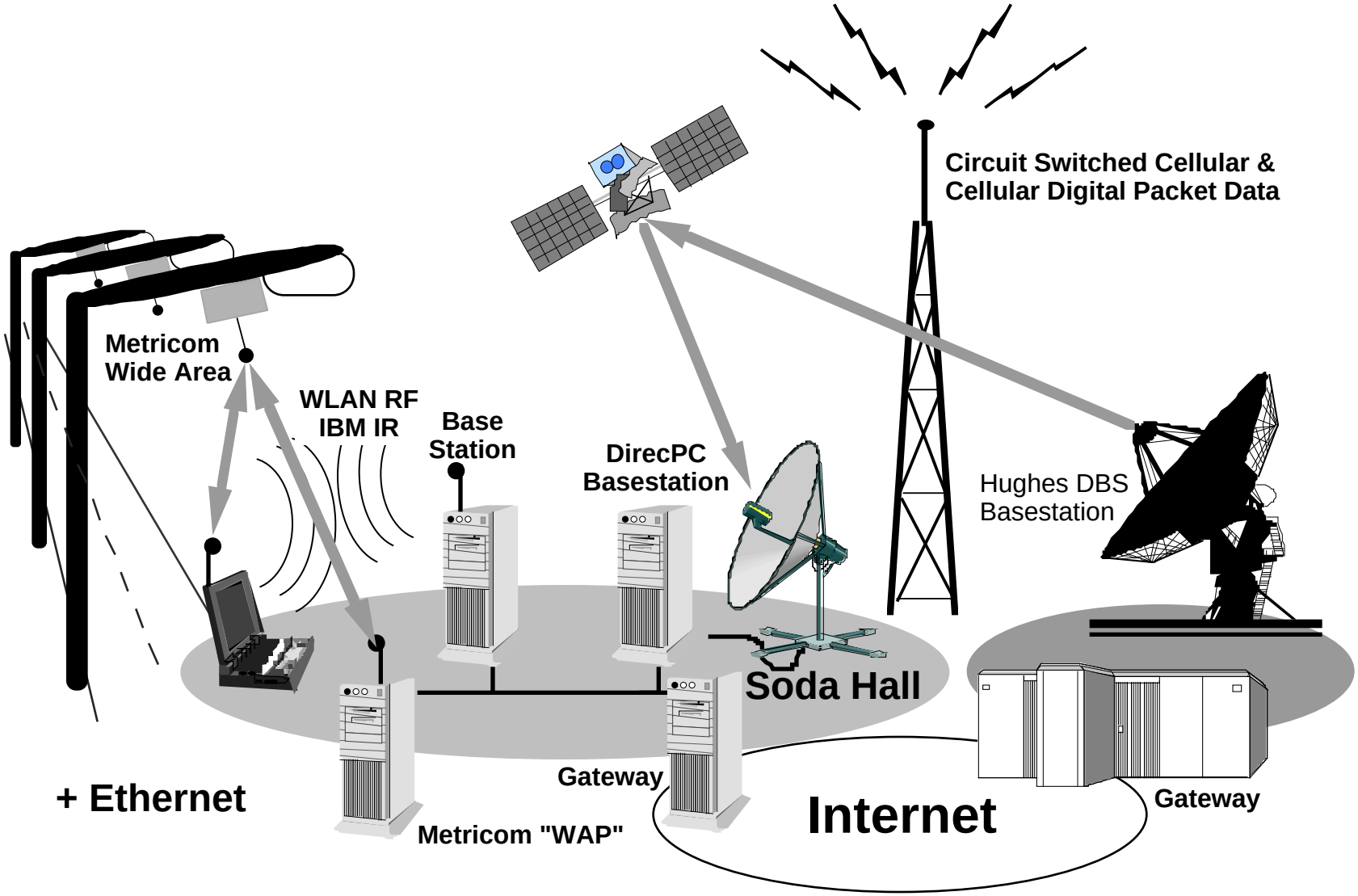

**Choice of routing path based on:**

- — Bandwidth
- — Latency
- — Coverage
- — Load
- — P(Retranmission)
- — Cost

# 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**

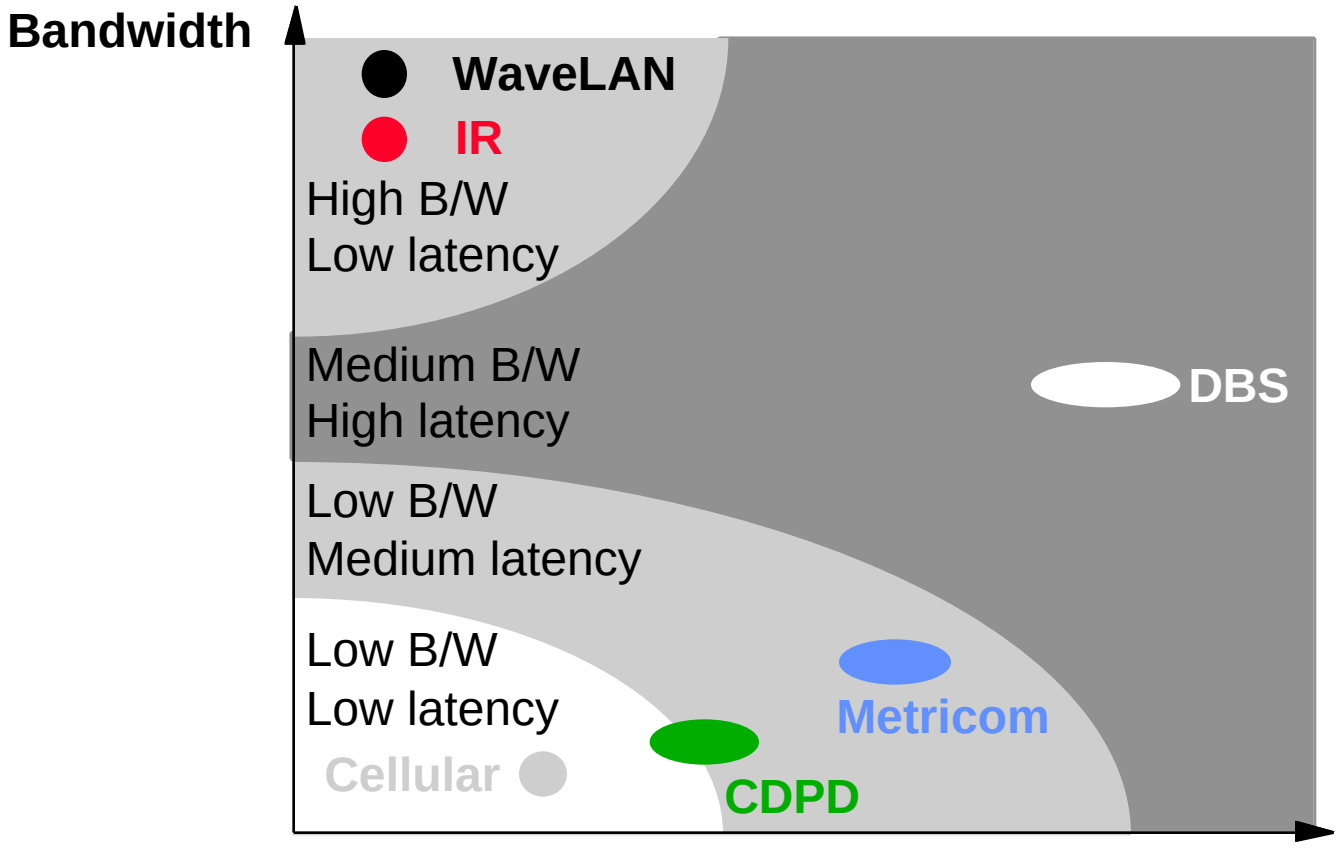
# BARWAN Testbed



# 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<br>ATT WaveLAN | 1 Mbps<br>1.5 Mbps | <3 ms<br><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<br>20-30 Kbps multi-hop | 60 ms<br>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 | | | |

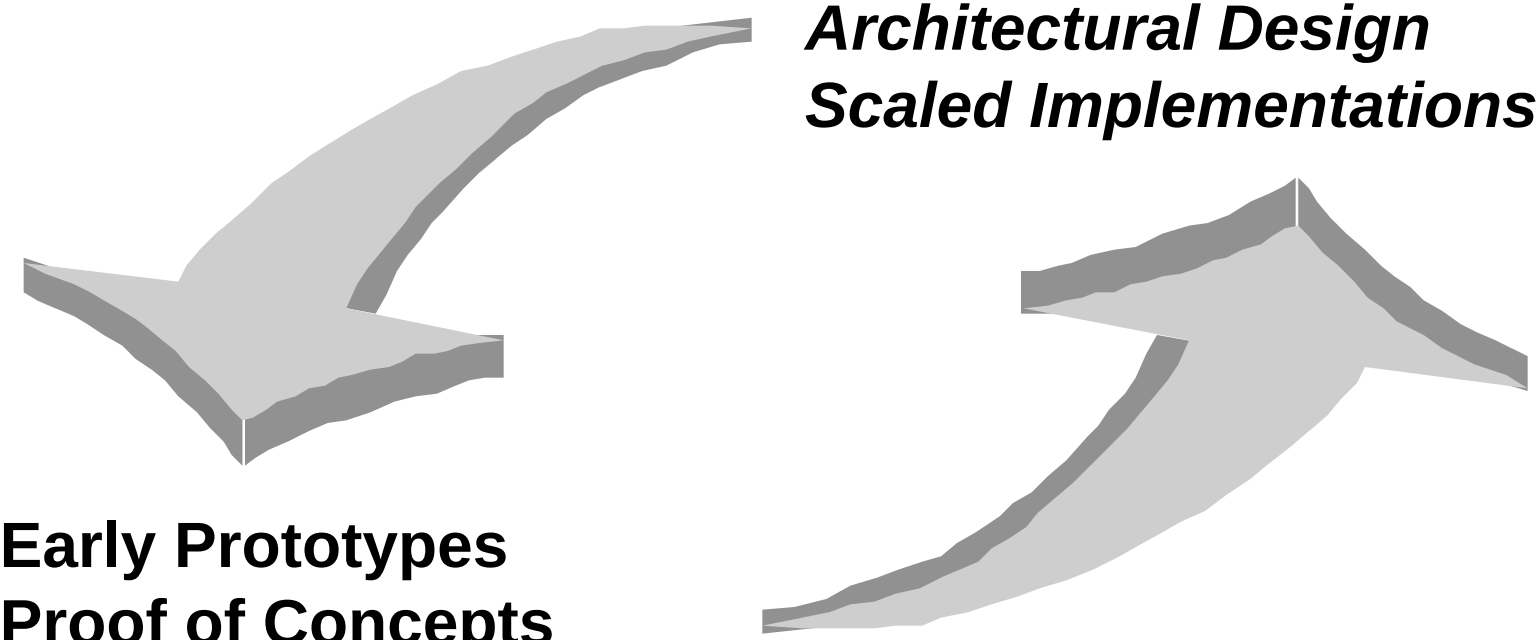
# Spanning Space of Wireless Network Technologies




**Figures of Merit:**

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

# Project Strategy

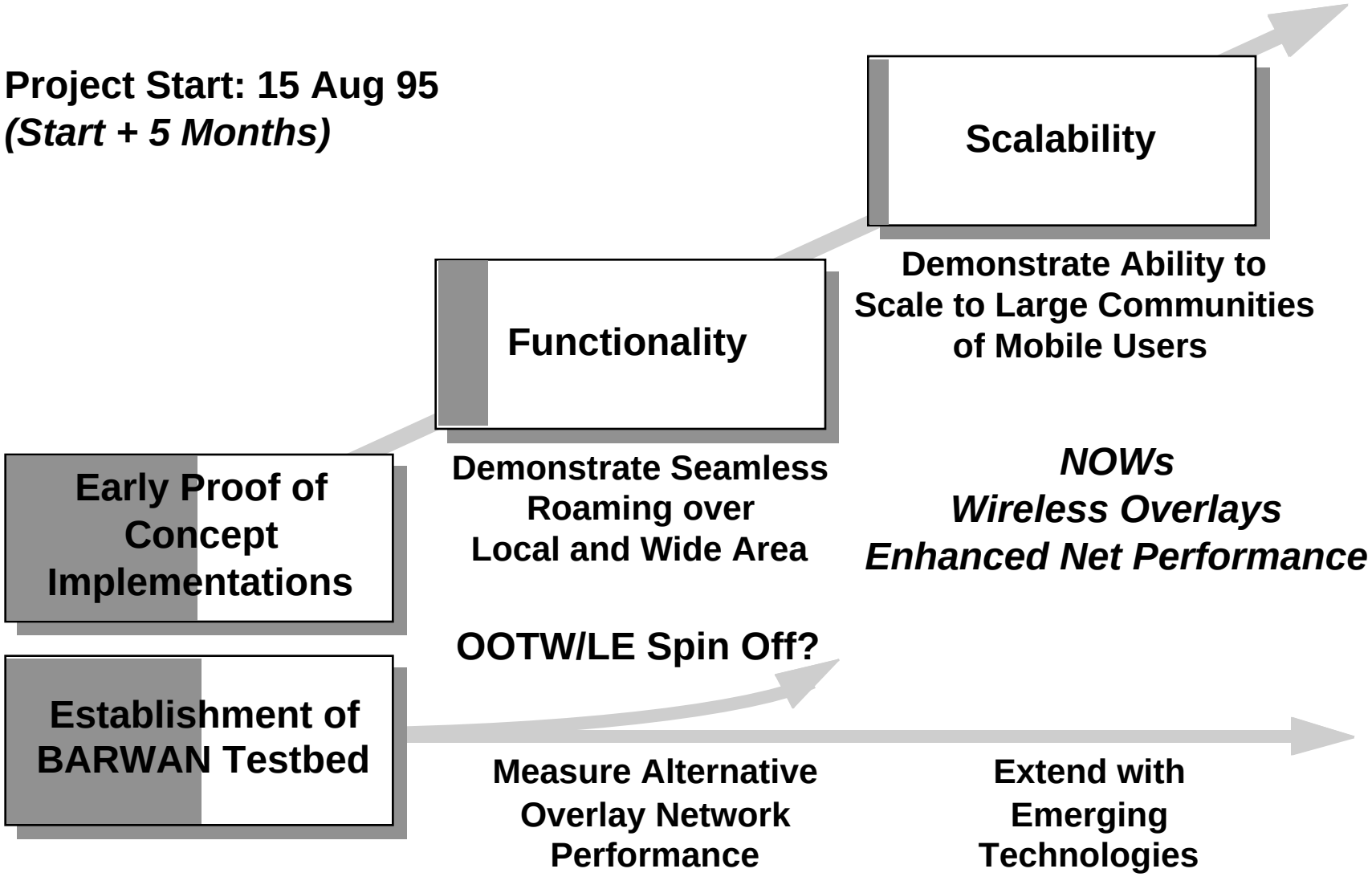


***Architectural Design***
***Scaled Implementations***

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

# Project Plan and Status

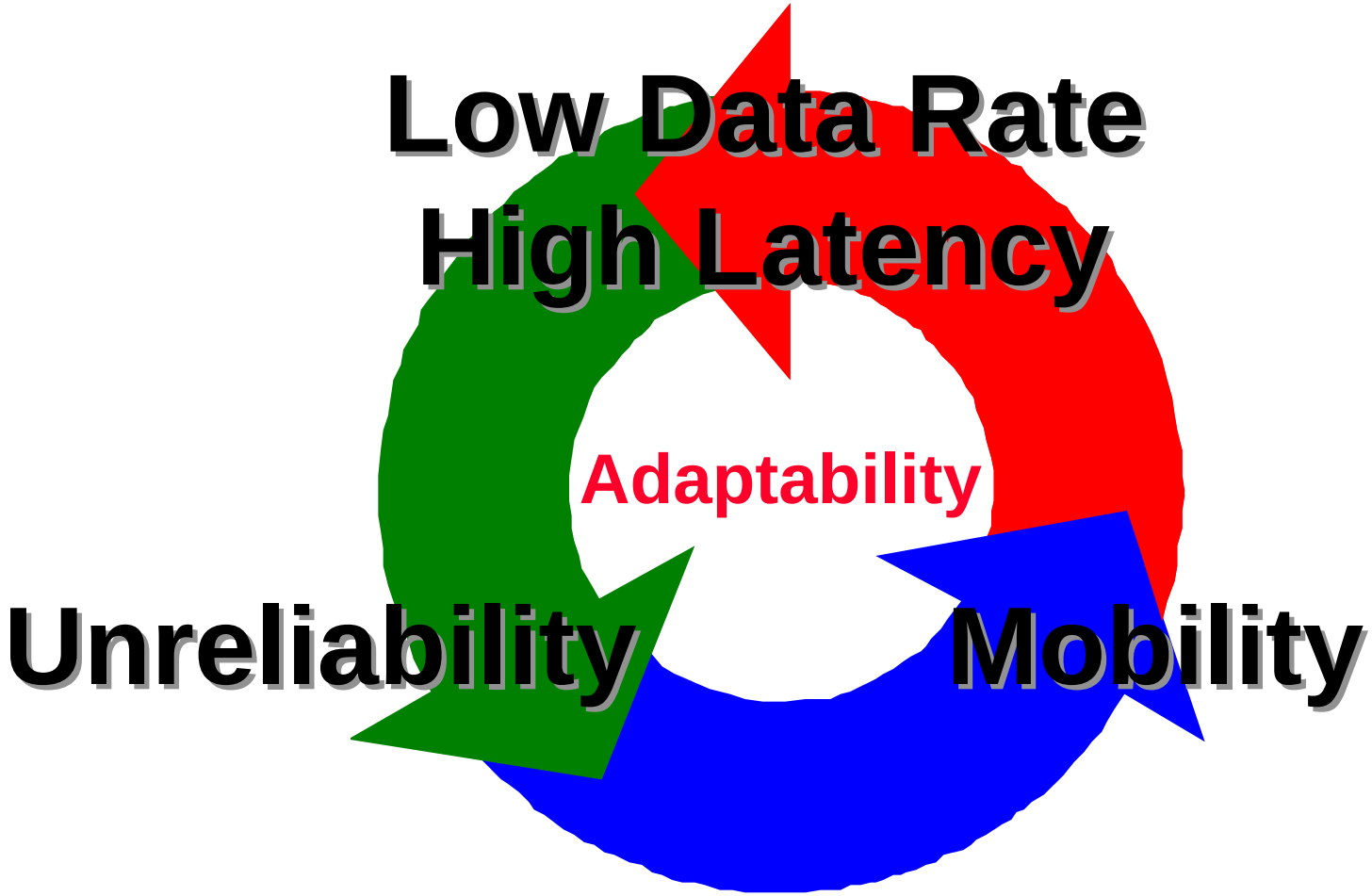
**Project Start: 15 Aug 95**
***(Start + 5 Months)***



# 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

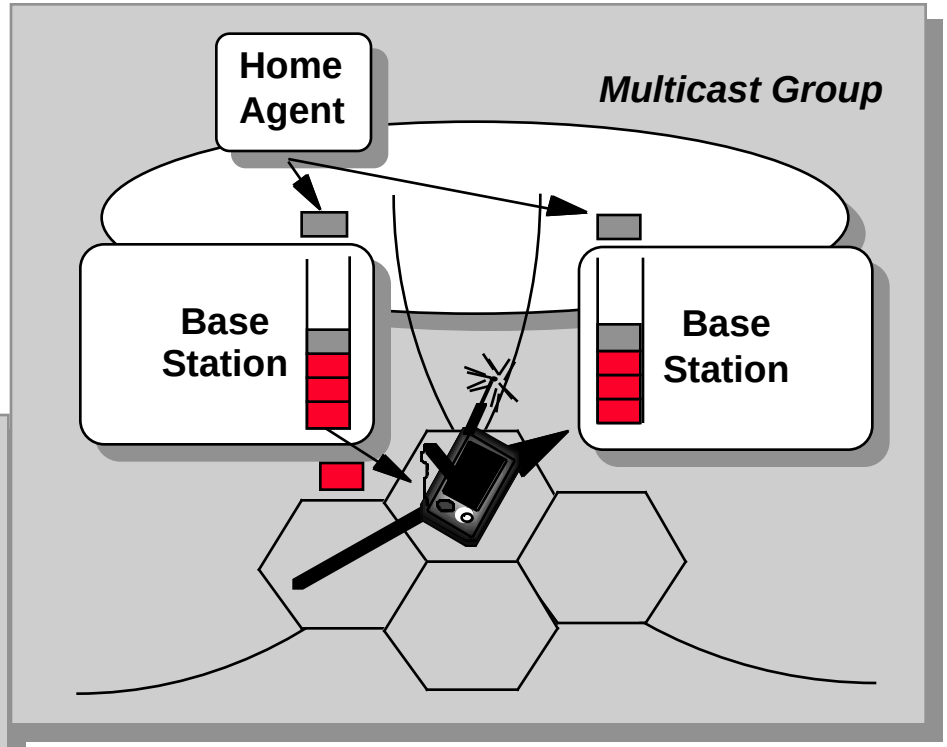
# Mobile Computing Challenges

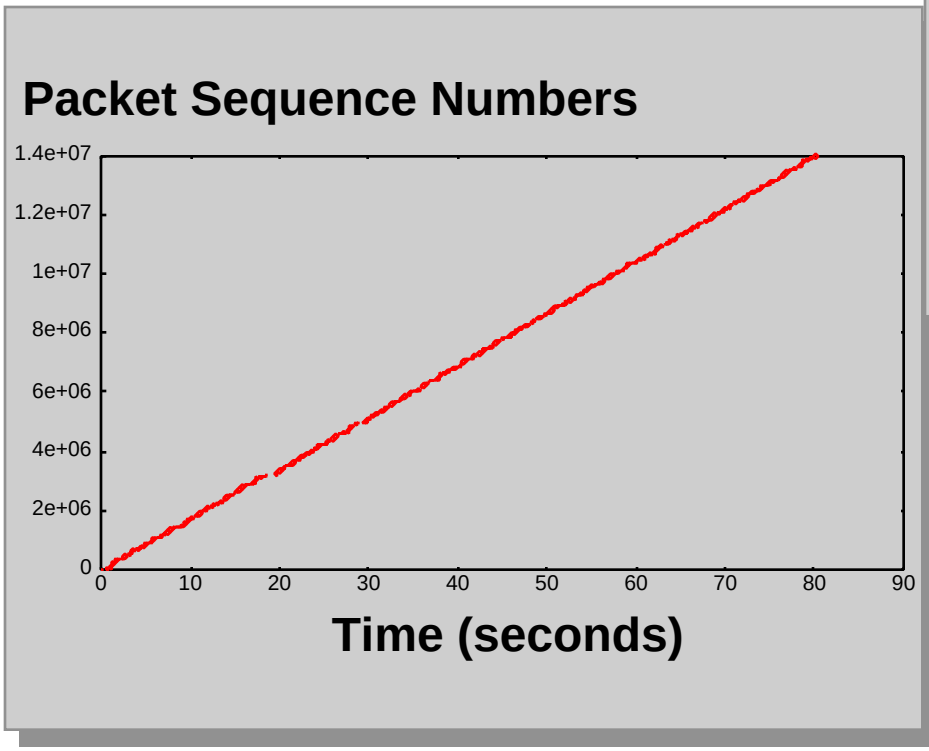



**Early Proof of Concepts in all of these areas**

# Mobility Meets Multimedia: Low Latency Handoff

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



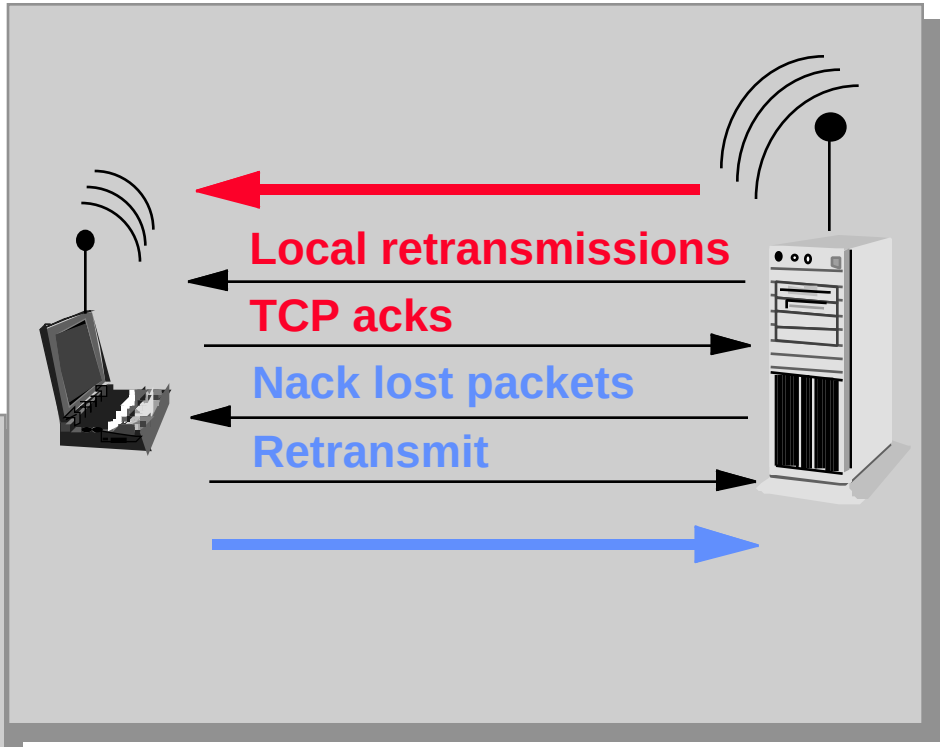



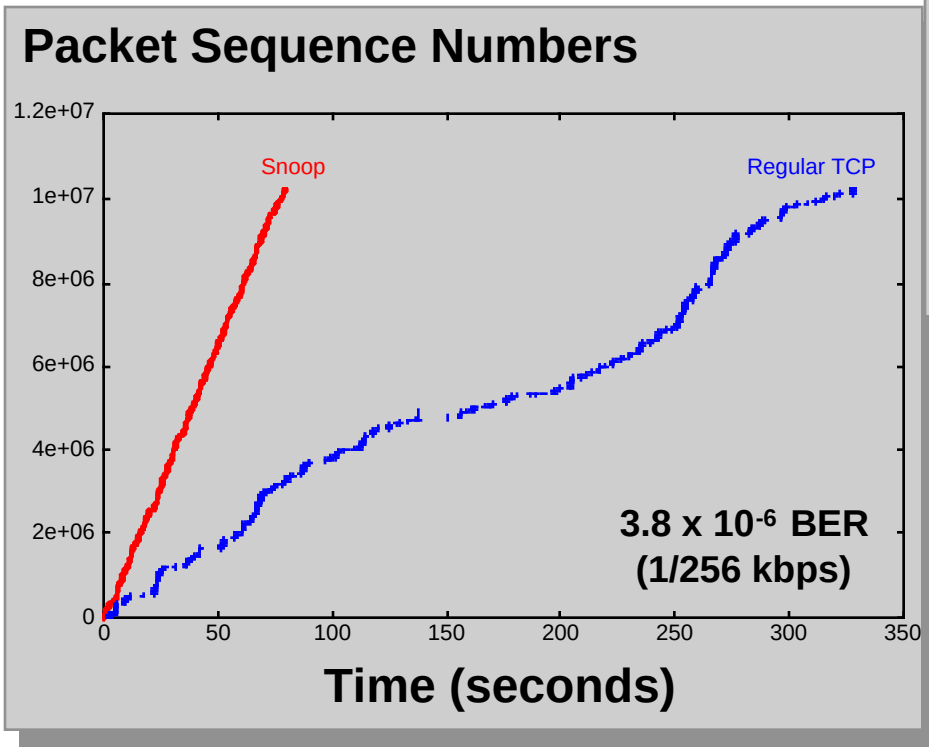

**Handoffs every 10 seconds**

**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**

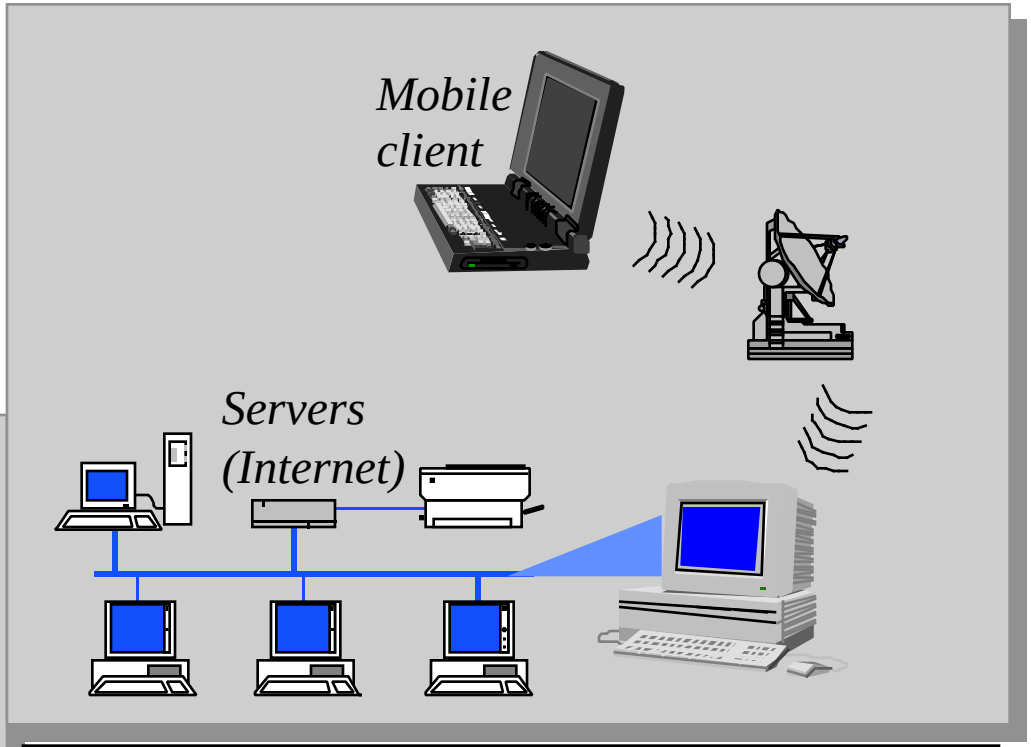
# Proxy Architecture: Image Proxy

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

*78 colors, 49K bytes*

*~2 sec.*

*4 grays, 530 bytes*

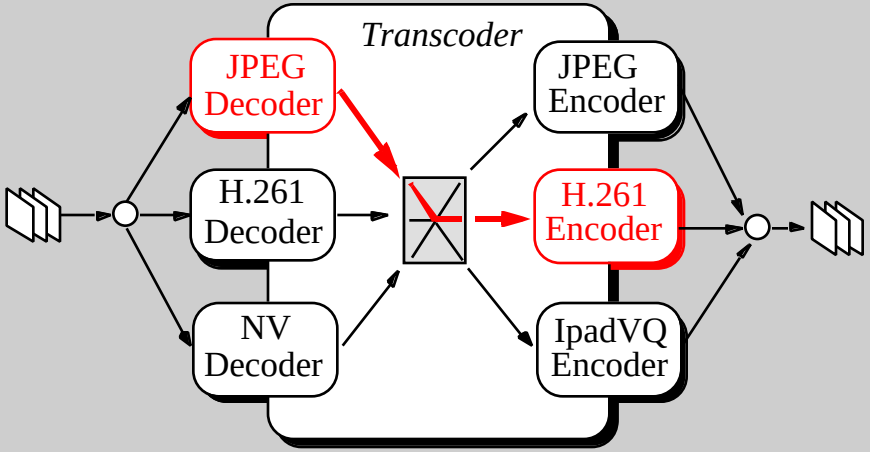



| Orig. size (bytes) | New size | New size as % of original | Pixel dimensions | Scaled by | Time (sec.) |
|---|---|---|---|---|---|
| 34K | 2022 | 0.058 | 320x200 | 2 | 1 |
| 848K | 5938 | 0.007 | 1280x1024 | 4 | 13 |
| 848K | 1676 | 0.002 | 1280x1024 | 8 | 10 |
| 361K | 24311 | 0.066 | 1022x703 | 2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

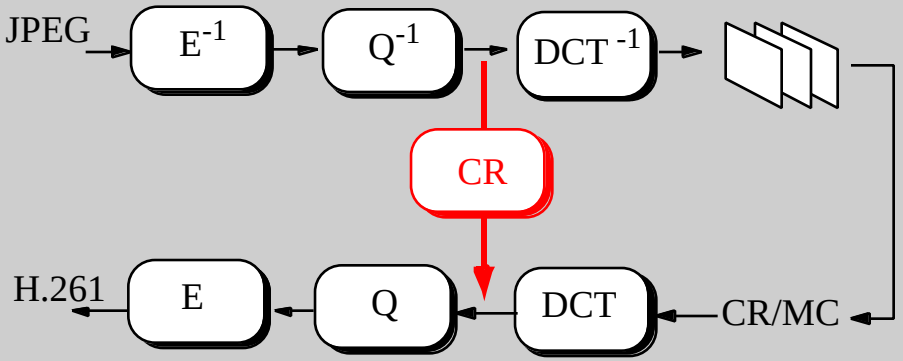
# Proxy Architecture: Video Gateway

- 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

## Gateway Architecture




## JPEG to H.261 Transcoder




| 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)***