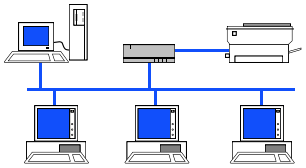


Distributed Systems
600.437
Wireless Mesh Networks

Department of Computer Science
The Johns Hopkins University

Wireless Mesh Networks

Lecture 10

Further reading:

www.dsn.jhu.edu/publications/

The Wireless Revolution

- Wide use of wireless 802.11 networks.
- The norm for Internet connectivity.

- Current practice:
  - The access point paradigm
    - Client – server in nature.
- Academic research:
  - A lot of focus on the ad-hoc paradigm since the 90s
    - Peer 2 peer in nature.
  - The Mesh paradigm introduced in the last few years

What We Were Missing

- The Access Point paradigm is great
  - Until I move away from mine
    - East Coast schools have massive walls …
- So:
  - Put more access points
    - Connect them all to the Internet
- However:
  - As I move between access points
    - Some interruption in connectivity, potential loss of sessions.
  - Connecting only few of the access points to the Internet could be useful:
    - First responders, lack of infrastructure, etc.
- In parallel: VoIP is becoming popular.
  - Skype.
  - Cell phones with 802.11.

The Mesh Paradigm

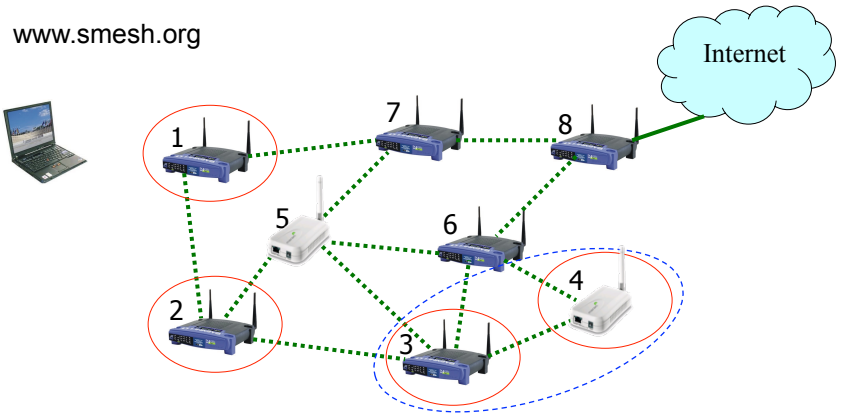
- Two classes of participants
  - Mesh nodes and clients
    - Some of the mesh nodes, the **Internet Gateways**, are connected to the Internet.
    - Other mesh nodes forward packets over multiple wireless hops.
  - Clients are mobile
  - Mesh nodes are relatively stationary
- In between the Access Point and the Ad-hoc paradigms
  - Different optimization considerations

Challenges

- Not changing the client
  - No special software or hardware
  - The client should feel as if there is one omni-present access point
- Fast, lossless handoff
  - Handoff between access points fast enough for VoIP and video
  - The responsibility of the mesh and not the client
- Multi-homed mesh environment
  - Multiple Internet gateways
    - Potentially on different networks
    - How to utilize to our advantage
  - Handoff between Internet gateways
    - How to keep connectivity alive on different networks

Introducing SMesh

www.smesh.org



Related Work

- Handoff on Wireless Networks
  - Mobile IP [C. Perkins, IP Mobility Support, RFC2002, 1996]
  - Handoff in Cellular Wireless Networks [Seshan, Balakrishnan and Katz, Kluwer Journal on Wireless Personal Communications, 1996]
  - An Empirical Analysis of 802.11 Handoff [Mishra, Shin and Arbaugh, SIGCOMM, 2003]
  - SyncScan [Ramani and Savage, INFOCOM, 2005]
- Wireless Mesh Networks
  - Metricom Ricochet, MIT Roofnet, Microsoft MCL, Rice TAPS, UCSB/Bell labs MeshCluster, SUNY Stony Brook iMesh, Purdue MAP, UIUC Net-X, Tropos, ...

Outline

- Introduction
- Related work
- The SMesh Architecture
  - **Generic overlay network**
  - **Seamless client access**
  - **Multi-homed environment**
- Intra-domain Handoff
  - **How it works**
  - **Experimental results**
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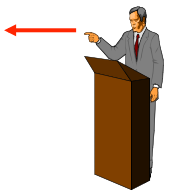
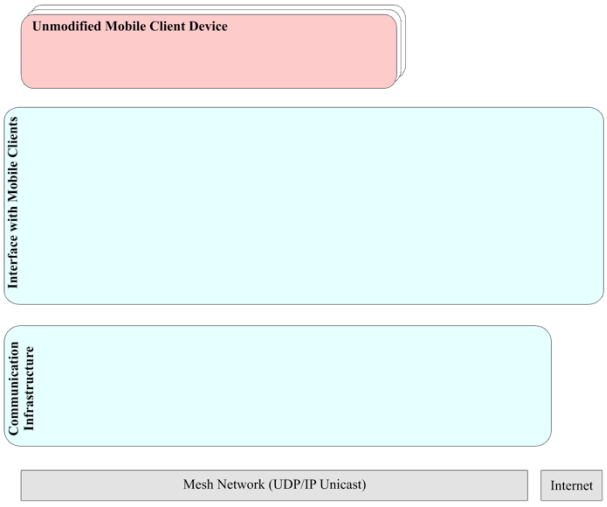


The SMesh Architecture



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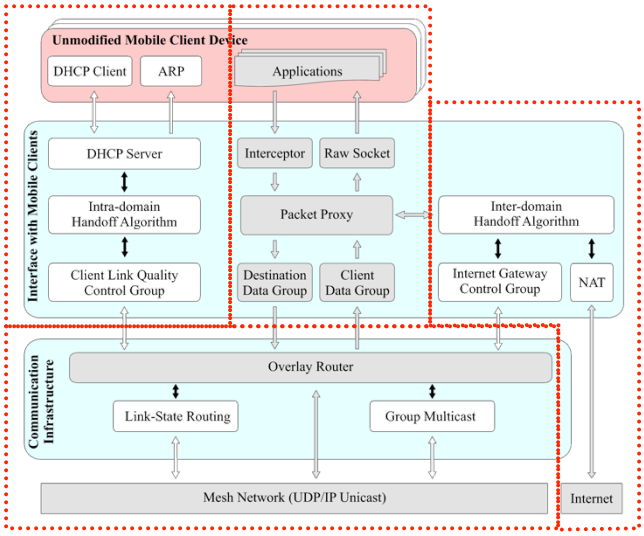
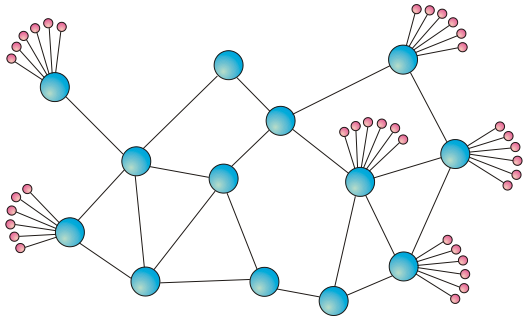


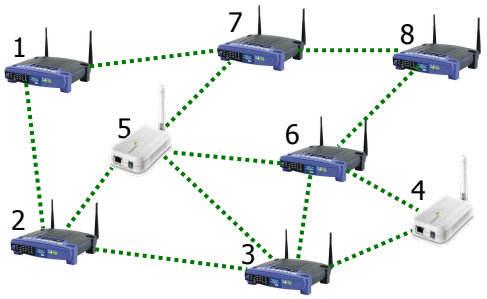
The Spines Messaging System



[DSN03, NOSSDAV05, TOM06]

- Daemons create an overlay network on the fly
- Clients are identified by the IP address of their daemon and a port ID
- Clients feel they are working with UDP and TCP using their IP and port identifiers
- Efficient support for unicast, multicast and anycast

The Spines Messaging System



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- Efficient support for unicast, multicast and anycast

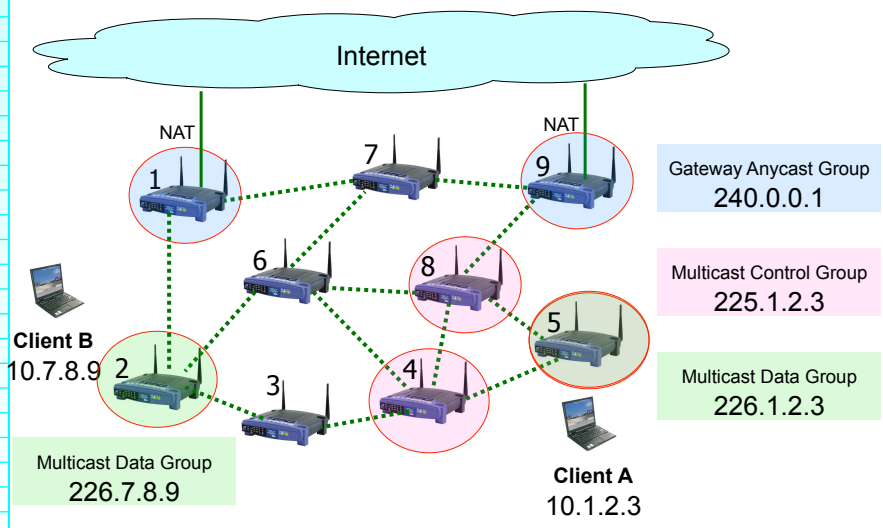
Seamless Client Access

- Standard DHCP Protocol

- Client always gets the same IP address
  - Assign IP based on MAC address (10.x.y.z)
- Client routes all packets through a Virtual Default Gateway
  - Default Gateway: 10.20.30.40
  - Netmask: 255.255.255.254

- Client gets Gratuitous ARP to associate Default Gateway IP address with the currently serving access point.

A Routing Approach for Lossless Handoff



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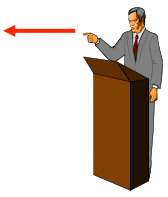


Intra-Domain Handoff

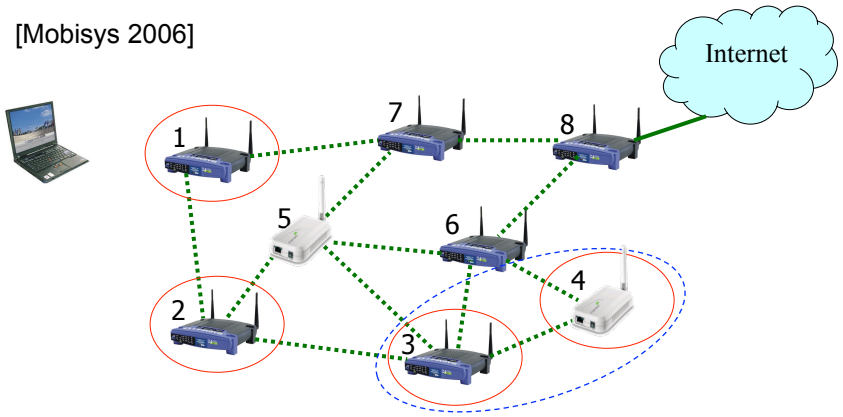
- Use DHCP to make the client send heartbeats
  - Tuning DHCP T1 and T2 timers.
  - Sending ARP request for client address.
  - Heartbeat is broadcast every 2 seconds.
    - Broadcast is less reliable than unicast.
- Nearby access points:
  - Join client control group.
  - Constantly measure client connection quality.
    - A decay function based on loss rate of monitored DHCP requests.
    - Signal strength (RSSI) as well.
  - Periodically advertise connection quality on client control group.

Fast Lossless Handoff

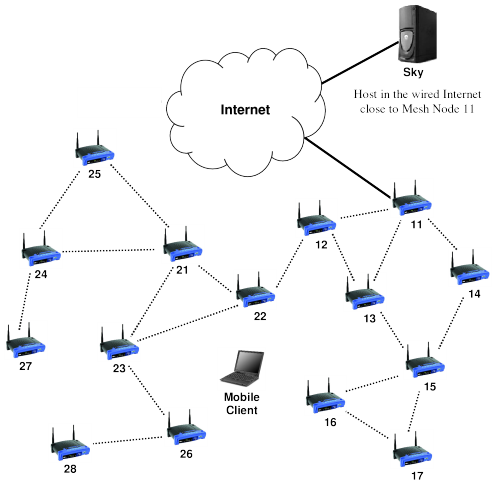
- Packets to client are sent to client data group.
- Access point with best connection quality.
  - Joins client data group.
  - Sends Gratuitous ARP to mobile client.
- At least one access point in client data group.
  - When no longer think it is the best, can request to leave client data group by sending request on client control group.
  - Can leave only when another access point acknowledges it is the best on client control group.
- Therefore, multiple access points in client data group during handoff.
  - Duplicates are the price of lossless handoff !

Intra-Domain Handoff

[Mobisys 2006]



Intra-domain Testbed



Test

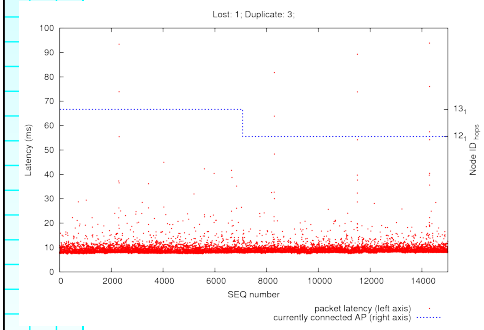
Full Duplex VoIP
Internet <==> Client

Each Stream

G.711
64 Kbps
160 bytes / 20 ms

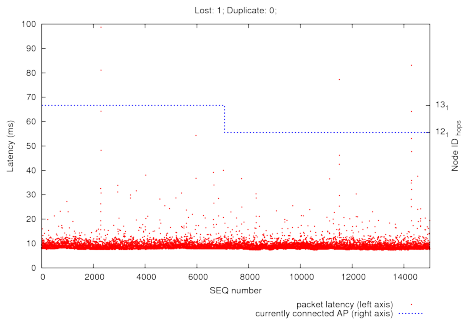
Stationary Client: Latency

Internet -> Mobile Client



Packets delayed over 100ms
4 packets

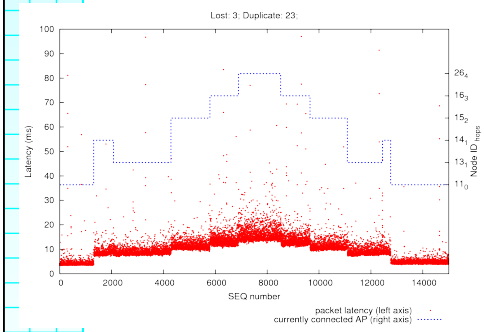
Mobile Client -> Internet



Packets delayed over 100ms
1 packets

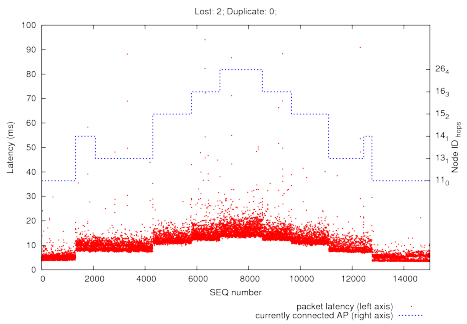
Moving Client: Latency

Internet -> Mobile Client



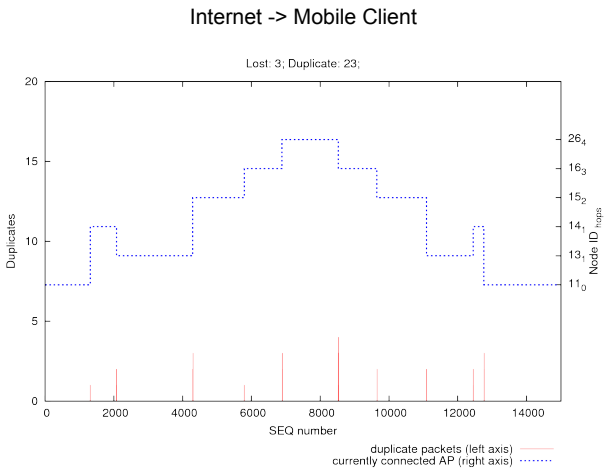
Packets delayed over 100ms
25 packets

Mobile Client -> Internet

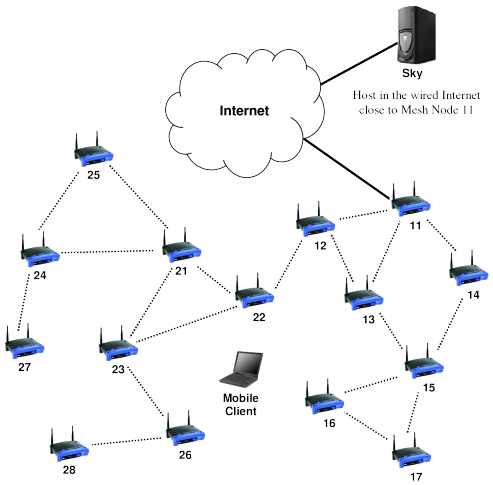


Packets delayed over 100ms
13 packets

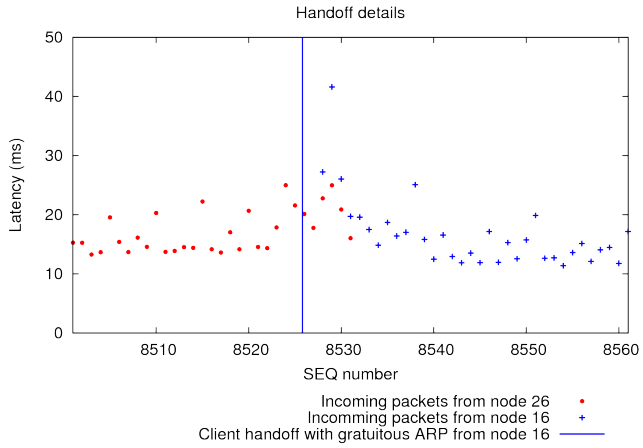
Moving Client: Duplicates



Intra-domain Testbed

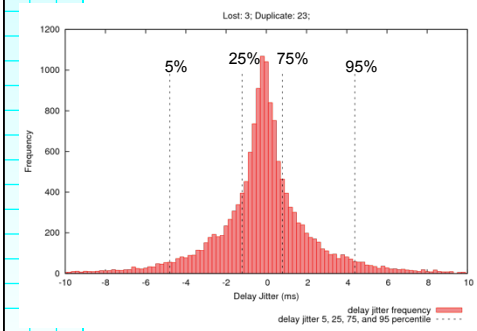


Zooming on the Handoff

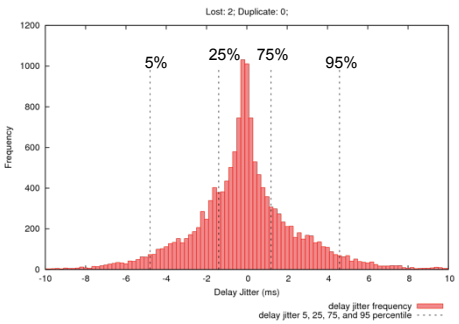


Delay Jitter

Internet -> Mobile Client

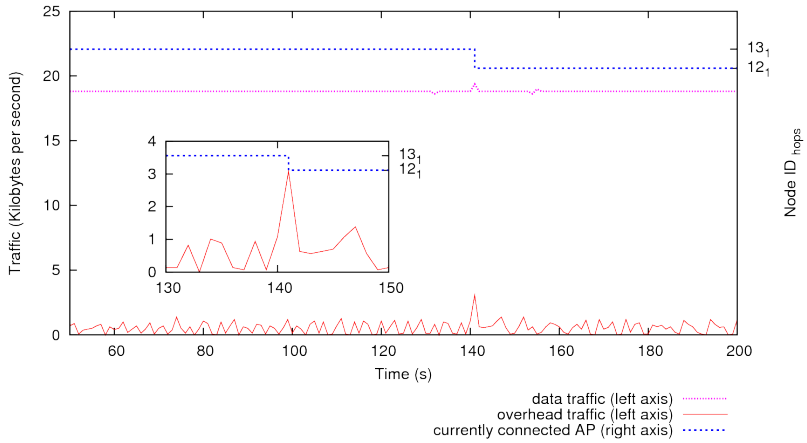


Mobile Client -> Internet



Delay Jitter between 5% to 95% was < 10ms

Overhead



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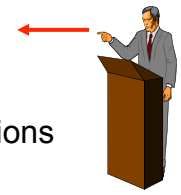
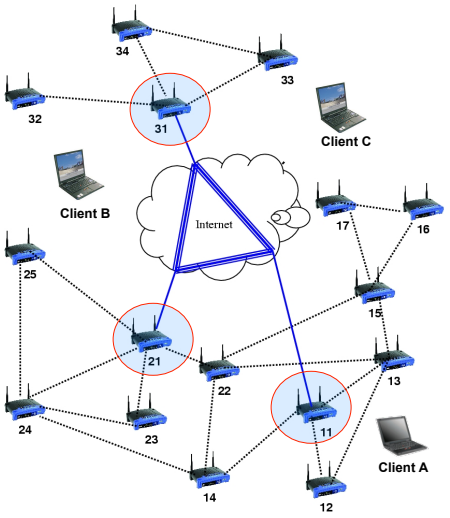


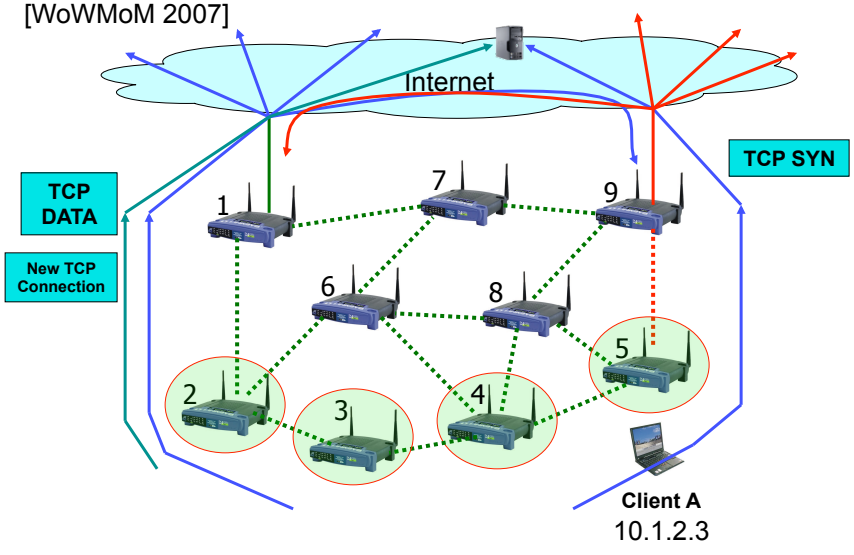
Inter-domain Environment

- Wireless Auto-discovery defines wireless topology
- Internet Gateways potentially on different networks
- Internet Gateways need to be pre-configured to form an initial connected graph
- Internet Gateways advertise their existence on gateway multicast group.
- All Internet Gateways eventually form a fully connected graph



Inter-Domain Handoff

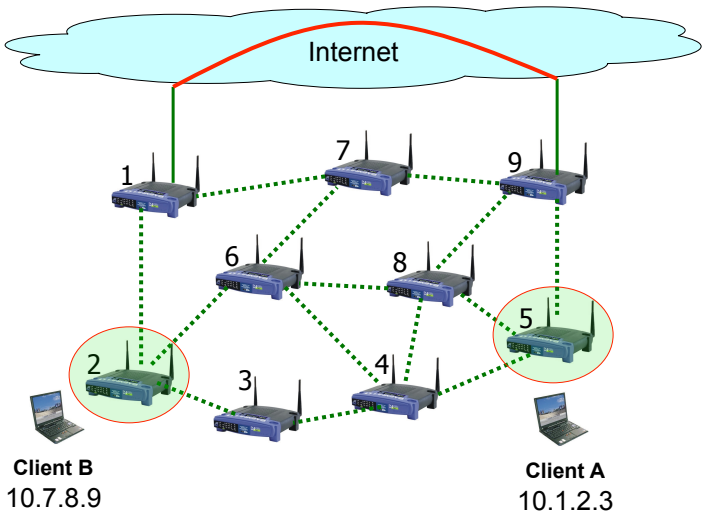
[WoWMoM 2007]



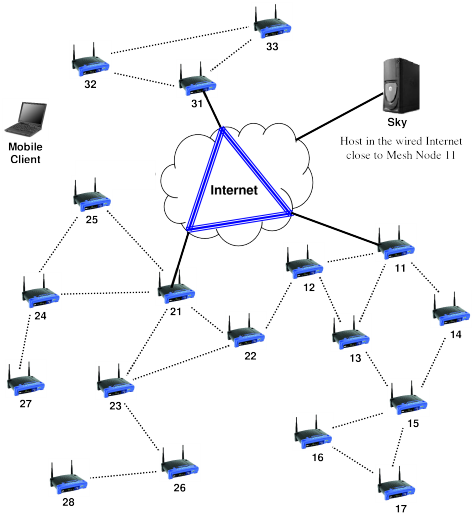
UDP Inter-domain handoff

- No SYN Packet to identify connection establishment
- When hearing a stream packet without a known owner, forward to destination AND to Internet Gateway Multicast Group
- If a data packet is received on the Internet Gateway Multicast Group, and I am the owner, forward the packet to the destination, and announce on the Internet Gateway Multicast group that I am the owner
- If no owner announcement is heard, forwarding node will assume ownership after some time (i.e. 200ms)
- Any non-owner will eventually forward stream packets to owner
- Caveat: More than one Internet gateway may assume ownership if stream fluctuates between two Internet gateways. We use reverse traffic from destination and lowest IP address to break such ties.

By Product: Optimized P2P Routing

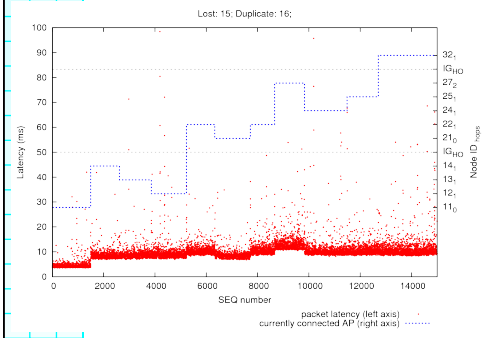


Inter-domain Testbed



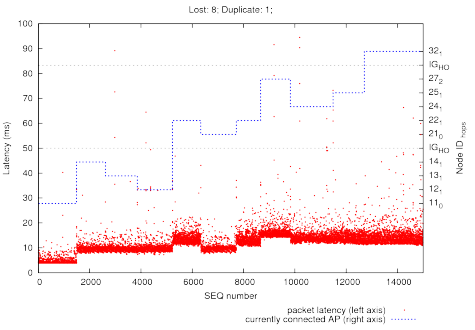
Inter-domain Handoff Latency

Internet -> Mobile Client



Latency

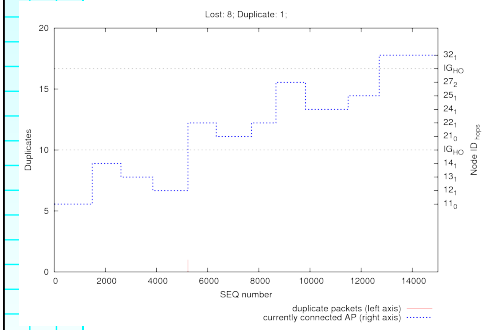
Mobile Client -> Internet



Latency

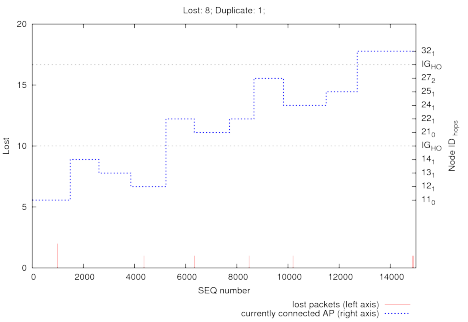
Inter-domain Handoff Performance

Mobile Client -> Internet



Duplicates

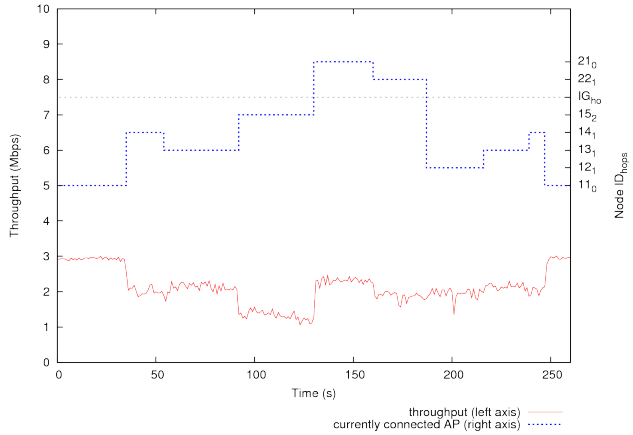
Mobile Client -> Internet



Loss

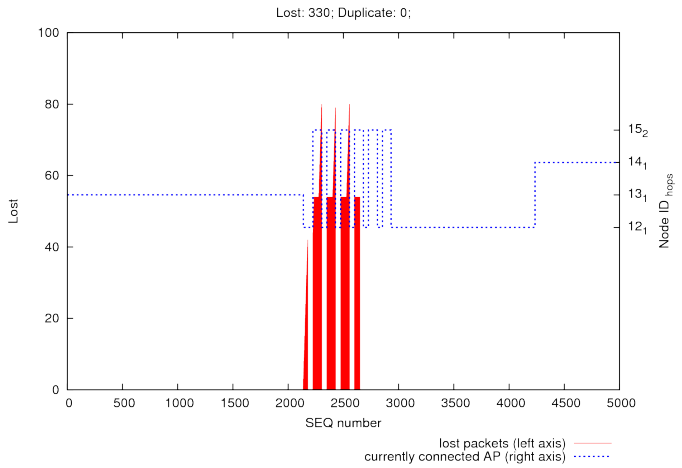
TCP Throughput

TCP Stream

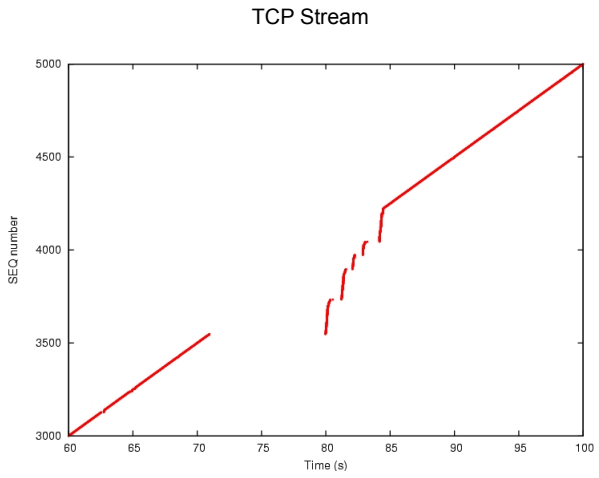


What about Failures / Crashes?

Mesh Node Failover



Non-Owner Internet Gateway Failover



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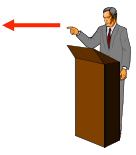


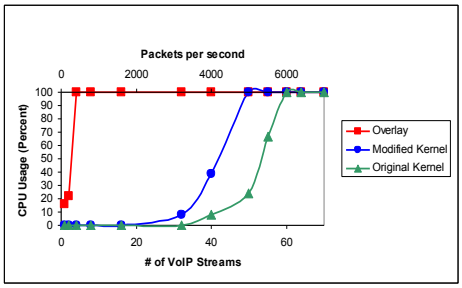
Low Cost Routers Limitations

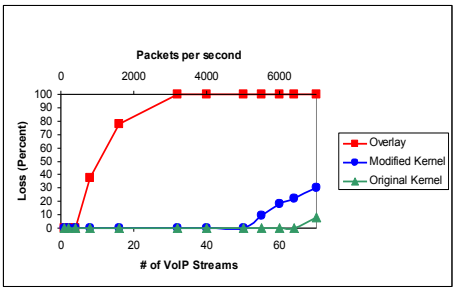
- Cost effective deployment requires low-cost mesh nodes.
- Performance bottleneck
  - Overlay routing saturates off-the-shelf, low cost ($50-$200) wireless routers
- Solution approach:
  - Overlay architecture for control and monitoring
  - Kernel-level routing for data packets
  - Loadable kernel modules to support overlay multicast routing using kernel redundant multipath (unicast) routing.

Performance Impact

[WiMesh 2008]

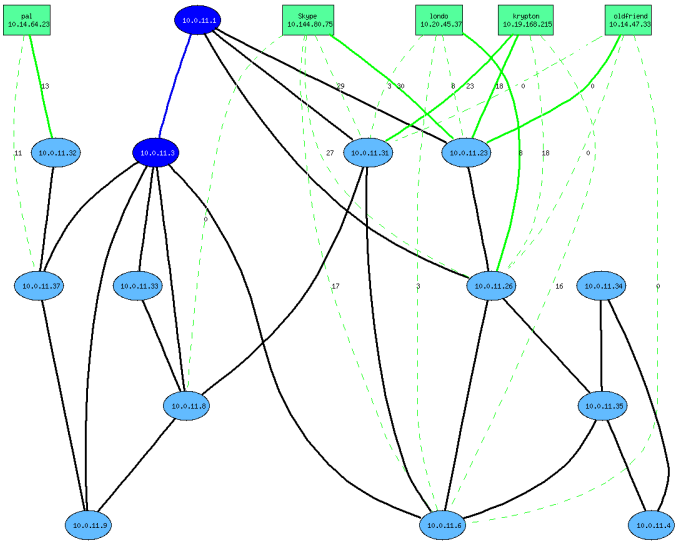
- Ability to support a much higher number of streams with cheap boxes.
- Overall throughput close to the native box's ability to route.
- In addition:
- Latency reduction of 60% - 75%.





Real-Time Monitoring

www.smesh.org



Summary

- Smesh as a wireless mesh network www.smesh.org
  - The first seamless 802.11 mesh with fast handoff
  - Inter-domain handoff for multi-home support
  - Optimized hybrid, wired-wireless routing
- Mesh environments become increasingly complex
  - A few access points with a single Internet connection
  - Inter-domain environments with a few networks and tens of access points
  - Neighborhoods to metropolitan areas ?
- Can it be a reality, and if so, reality for what ?
  - Encouraging signs: first responders, relatively small scale rapid deployments
  - Beyond that?

Open Questions

- Overlay networks paradigm
  - Importance as a new paradigm of networking
  - The future of the Internet?
  - Pros and Cons compared with a clean-slate approach.
- Wireless mesh networks
  - Is it here to stay?
  - Will it wash away with better alternatives (cellular, provider-based solutions) ?