Unmanaged Internet Protocol
Taming the Edge Network Management Crisis

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“Ubiquitous Networking”

- What is it?
- Why isn't it here yet?
- How can we make it work?
A Ubiquitous Networking Scenario
A Ubiquitous Networking Scenario
A Ubiquitous Networking Scenario
A Ubiquitous Networking Scenario

DSL/Cable Internet

Ethernet

Computer

Person

Router
A Ubiquitous Networking Scenario

- Ethernet
- DSL/Cable Internet
- DSL/Cable Internet to Ethernet
- Ethernet to Internet

Diagram: Laptop connected to DSL/Cable Internet router, which also connects to a desktop computer.
A Ubiquitous Networking Scenario

802.11

DSL/Cable Internet

Ethernet
A Ubiquitous Networking Scenario
A Ubiquitous Networking Scenario
A Ubiquitous Networking Scenario
A Ubiquitous Networking Scenario

Internet

Joe

Jim
A Ubiquitous Networking Scenario
A Ubiquitous Networking Scenario
A Ubiquitous Networking Scenario

“NAT?”
A Ubiquitous Networking Scenario

“NAT?”
“Dynamic DNS?”
A Ubiquitous Networking Scenario

“NAT?”

“Dynamic DNS?”

“Mobile IP?”
A Ubiquitous Networking Scenario
A Ubiquitous Networking Scenario

Joe

Jim
A Ubiquitous Networking Scenario

Joe

Jim
A Ubiquitous Networking Scenario

Joe

Jim
A Ubiquitous Networking Scenario

“Ad-hoc mode?”

Joe

Jim
A Ubiquitous Networking Scenario

“Ad-hoc mode?”

“DHCP?”

Joe

Jim
A Ubiquitous Networking Scenario

“Ad-hoc mode?”

“DHCP?”

“Static IP addresses?”
A Ubiquitous Networking Scenario

Joe

Jim
The Problem

Getting “ubiquitous networking” devices to \textit{ubiquitously network} is way too complicated, even when the technology is available.
Outline

- Motivation: What's wrong?
  - Why doesn't ubiquitous networking work?
    - *Answer:* hierarchical address-based routing (ABR).
  - How do we fix it?
    - *Answer:* scalable identity-based routing (IBR).
- A proposed identity-based routing architecture
- Conclusion
Why IP is Wrong for Edge Networks

- Hierarchical address architecture
  - Routable addresses must be allocated from central administrative authorities
  - Each node must be assigned an address:
    - Static assignment ⇒ inconvenient, requires knowledge
    - DHCP ⇒ nodes can't talk at all without DHCP server
  - Address hierarchy must reflect topology
    - Node mobility ⇒ address instability, broken connections
  - Good for scalability, bad for useability
What about ad-hoc routing protocols?

- Landmark, DSR, DSDV, AODV, etc.
- A big step in the right direction, *but*:
  - Not scalable beyond local area (≈hundreds of nodes)
- Good for outdoor geek parties
- Useless for Joe and Jim
We need ad-hoc routing

at Internet-Wide Scale
We need ad-hoc routing at Internet-Wide Scale
A Proposed Identity-Based Routing Protocol Architecture
UIP: “Unmanaged Internet Protocol”

- **Transport Layer**: TCP, UDP, SCTP
- **Network Layer**:
  - **Identity-Based Routing**: UIP
  - **Address-Based Routing**: IPv4, IPv6, GRID, etc.
- **Link Layer**: Ethernet, 802.11, Bluetooth, PPP, etc.
Key Properties of UIP

• “Unmanaged” = “Manages Itself”
  - No central authority required to hand out addresses
  - No explicit maintenance of routing and forwarding
  - No futzing or broken connections when nodes move

• Operates both:
  - Over IPv4/IPv6 as a scalable overlay network
  - Directly over Ethernet and other link layers
UIP Node Identifiers

Cryptographic hash of node's public key (ala HIP):

- **Automatically generated** by node itself
- **Stable** for as long as owner of node desires
- **Self-authenticating** for privacy and integrity
- **Topology-independent** for host mobility
- **Globally unique, cryptographically unforgeable**
Why This Is Hard

- Must give up hierarchical address architecture, but still get scalability to millions of nodes!
- Can't require each node to maintain and propagate state about every other node
- ...But theoretically feasible: Arias et al. “Compact Routing with Name Independence,” SPAA 2003
Idea!

What about adapting Peer-to-Peer Distributed Hash Table (DHT) lookup algorithms?
The Intuition

- DHTs provide:
  - Lookup on topology-independent keys
  - $O(\log n)$ state, maint. traffic per node
The Intuition

- DHTs *don't*:
- Forward around discontinuities
- Traverse NATs (usually)
- Route between Internet & Ad-hoc Networks
A First Approximation

- Two-level stratification
- “Core” nodes maintain DHT
- “Edge” nodes reachable thru core nodes
- Example: i3
A First Approximation

- Limitations:
  - Must configure whether node is "core" or "edge"
  - Discontinuities in "core" network
  - Disconnected edge nodes can't talk
What We Want

- Unstratified
What We Want

- Unstratified
- Forwarding around holes (RON)
What We Want

- Unstratified
- Forwarding around holes (RON)
What We Want

- Unstratified
- Forwarding around holes (RON)
- ...thru NATs
What We Want

- Unstratified
- Forwarding around holes (RON)
- ...thru NATs
- Autonomous ad-hoc rings
What We Want

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What We Want

- Unstratified
- Forwarding around holes (RON)
- ...thru NATs
- Autonomous ad-hoc rings
- Inter-domain routing
Forwarding Mechanisms

- **Source Routing**
  - Nodes can store source routes, not just IP addresses, in their DHT neighbor tables.
  - Source routes not usually very long, because UIP sees Internet as “one big link.”

- **Virtual Link Forwarding**
  - Source routes restricted to two hops, but recursively composable
  - Distributes routing information throughout path
Source Routing
Source Routing

New node
Source Routing

Z's Neighbor Table

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New node
Source Routing

Z's Neighbor Table

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Initial (Direct) Neighbor
Source Routing

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Direct Neighbors

A → B, C, D, E
C → B, D, E, G
D → A, C, E
E → A, C, D, Z
Z → E, H, A
Source Routing

Indirect Neighbors

Z's Neighbor Table

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Source Routing

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Indirect Neighbors:

- H: [C → H]
- G: [C → H → G]
What We Have
What We Have

Virtual Ring

Physical Rings

NAT
What We Have

Virtual Ring

Physical Rings

NAT
What We Have

Virtual Ring

Physical Rings

NAT
What We Have

Virtual Ring

Physical Rings

NAT
What We Have

Virtual Ring

Physical Rings

NAT
Source Routing

Z's Neighbor Table

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Challenges

- Forwarding path optimization
- Healing efficiently after arbitrary partitions
- Incentives for good behavior, resistance to denial-of-service attacks
Implementation Status

• Algorithm works under simulation
  – Up to 10,000 nodes, “Internet-like” networks
  – $\approx O(\log n)$ state and maintenance traffic observed
  – Heals quickly after partitions

• In progress:
  – Further algorithm refinement
  – Real-world prototype
Conclusion

• To get ubiquitous networking:
  – Edge nodes must be able to operate without centralized address assignment:  
    *Address-Based Routing* $\Rightarrow$ *Identity-Based Routing*
  – Edge routing protocols must be self-managing at global Internet-wide scales, not just locally

• Scalable IBR is hard, but should be feasible