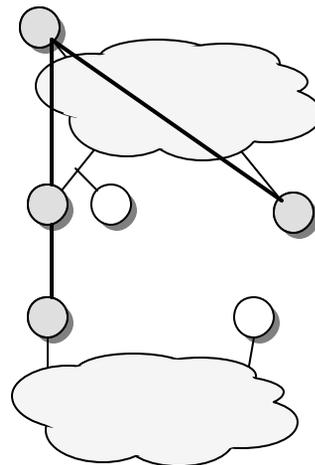


Overlay Networks

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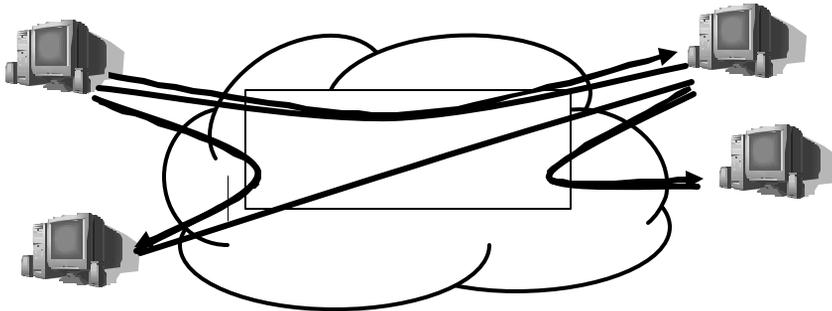
Definition

- Network
 - defines addressing, routing, and service model for communication between hosts
- Overlay network
 - A network built on top of one or more existing networks
 - adds an additional layer of indirection/virtualization
 - changes properties in one or more areas of underlying network
- Alternative
 - change an existing network layer



Definition

- An overlay network is a virtual network of nodes and logical links that is built on top of an existing network with the purpose to implement a network service that is not available in the existing network.



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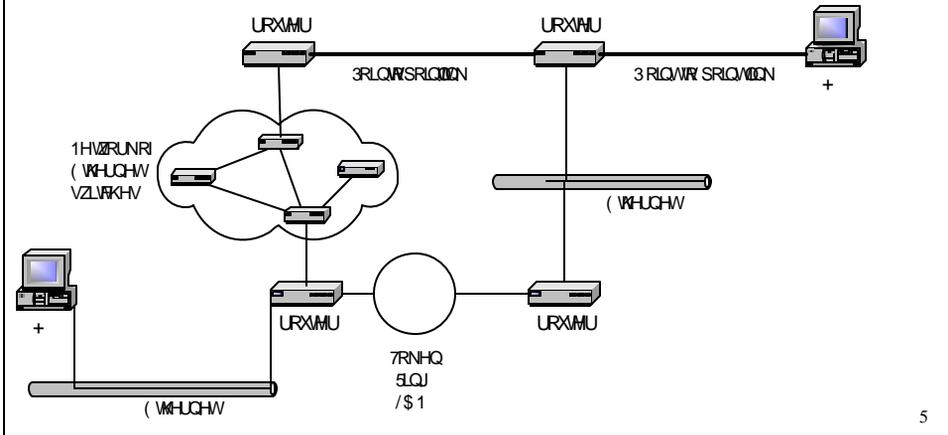
A Historical Example

- **The Internet is an overlay network**
 - goal: connect local area networks
 - built on local area networks (e.g., Ethernet), phone lines
 - add an Internet Protocol header to all packets

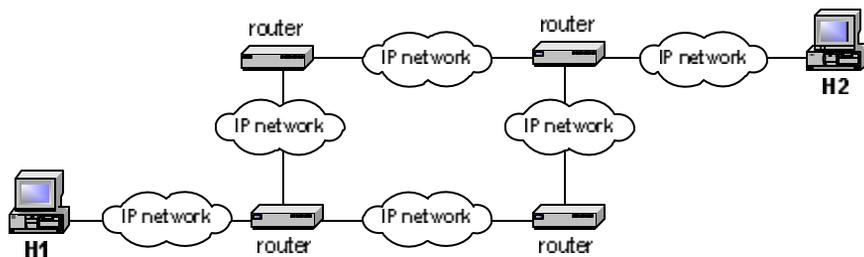
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Delivery of an IP datagram

- At data link layer :
each data link network can transfer frames, but not delivery across multiple LANs



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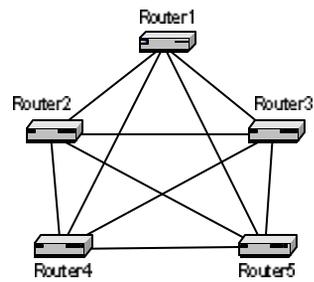
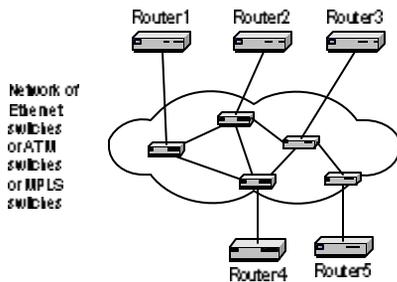
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IP network as an overlay network

A set of routers that are all connected to a network of Layer 2 switches (ATM, Ethernet)

... can be configured to be a full mesh at the IP layer.

How?



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Applications of Overlays

- Routing
- Addressing
- Security
- Multicast
- Mobility

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Benefits

- Do not have to deploy new equipment, or modify existing software/protocols
 - probably have to deploy new software on top of existing software
 - e.g., adding IP on top of Ethernet does not require modifying Ethernet protocol or driver
 - allows bootstrapping
 - expensive to develop entirely new networking hardware/software
 - all networks after the telephone have begun as overlay networks

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Benefits

- Do not have to deploy at every node
 - Not every node needs/wants overlay network service all the time
 - e.g., QoS guarantees for best-effort traffic
 - Overlay network may be too heavyweight for some nodes
 - e.g., consumes too much memory, cycles, or bandwidth
 - Overlay network may have unclear security properties
 - e.g., may be used for service denial attack
 - Overlay network may not scale (not exactly a benefit)
 - e.g. may require n^2 state or communication

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Costs

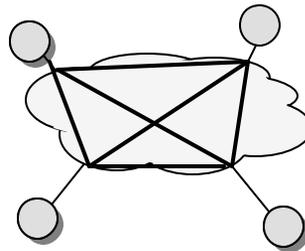
- Adds overhead
 - Adds a layer in networking stack
 - Additional packet headers, processing
 - Sometimes, additional work is redundant
 - E.g., an IP packet contains both Ethernet (48 + 48 bits) and IP addresses (32 + 32 bits)
 - Eliminate Ethernet addresses from Ethernet header and assume IP header(?)
- Adds complexity
 - Layering does not eliminate complexity, it only manages it
 - More layers of functionality → more possible unintended interaction between layers
 - E.g., corruption drops on wireless interpreted as congestion drops by TCP

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Applications: Increasing Routing Robustness

- **Resilient Overlay Networks (RONs)**
[Anderson et al 2001]
 - Overlay nodes form a complete graph
 - Nodes probe other nodes for lowest latency
 - Knowledge of complete graph → lower latency routing than IP, faster recovery from faults

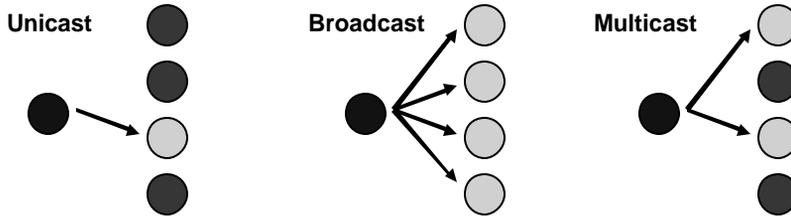


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Case Study: Multicasting

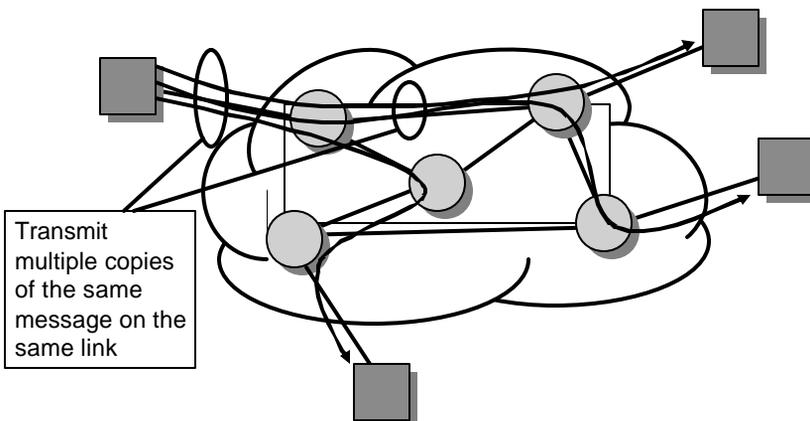
- Multicast communications refers to one-to-many or many-to-many communications.
- Multicast implements a one-to-many send operation:



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Case Study: Need for multicast

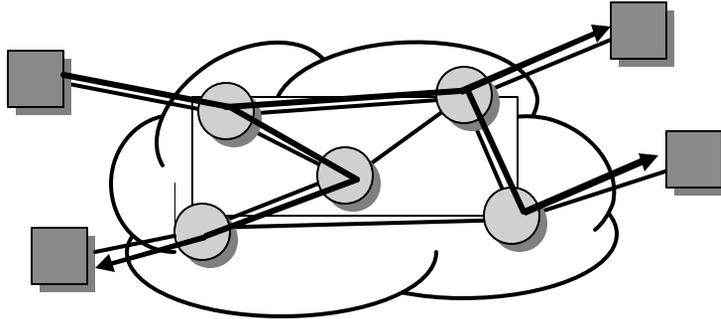
- Without support for multicast at the network layer:



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Multicasting at the network layer

- With support for multicast at the network layer:



Requires a set of mechanisms at the network layer:

- (1) Routers must be able to send multiple copies of same packet
- (2) Multicast routing algorithms needed to build up a dissemination tree

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How does multicast work with IP?

- IP multicast addresses are allocated a certain range:

Class D

1	1	1	0	multicast group id
---	---	---	---	--------------------

28 bits

Class	From	To
D	224.0.0.0	239.255.255.255

- Each multicast group designates a “multicast group”.
- Hosts can “join” a multicast group.
- An IP datagram sent to a multicast address is forwarded to everyone who has joined the multicast group.

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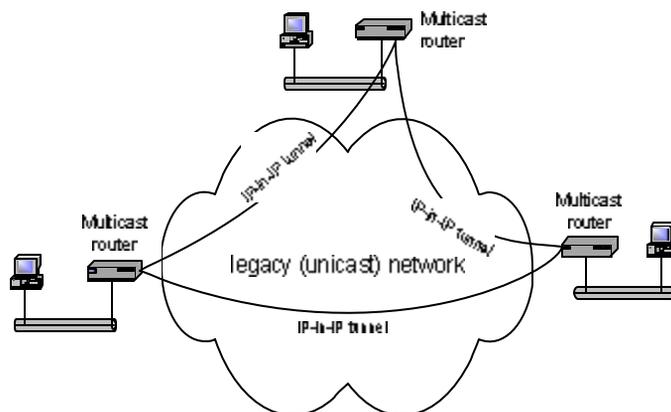
MBONE: An overlay network for incremental IP multicast deployment

- IP multicast deployment in the Internet began in early 1990s with the creation of the Multicast Backbone (MBONE)
- MBONE solved the problem of wide-area IP multicast routing on the Internet where only few routers were capable of IP multicast routing, by setting up a virtual network of multicast routers that are connected by unicast path.
- MBONE uses the concept of IP tunneling (IP-in-IP encapsulation)

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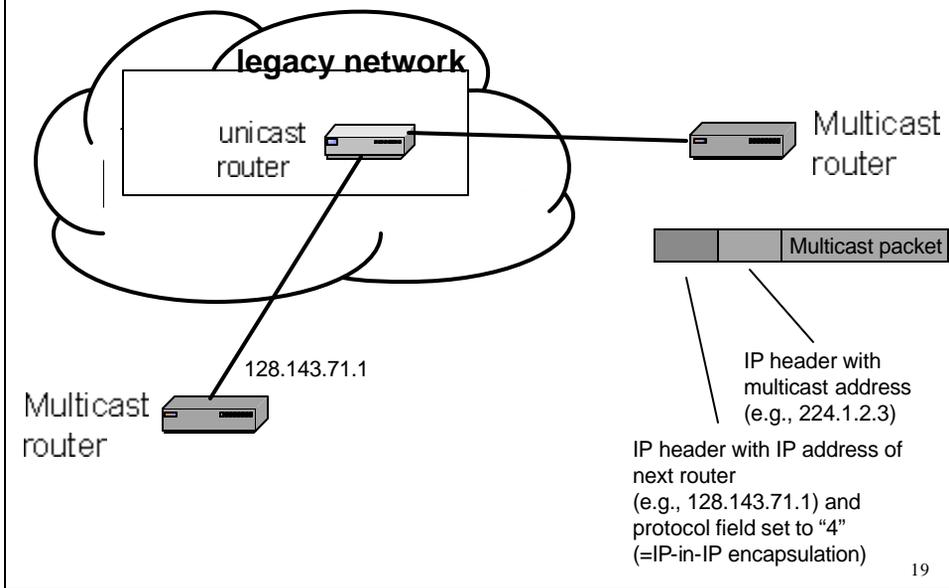
MBONE: Overlay Network of multicast routers

- MBONE is the set of all of multicast routers
- MBONE is an overlay network at the IP layer that provides multicast service



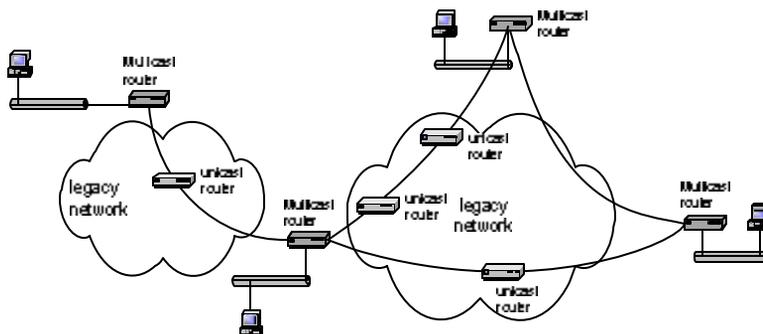
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IP Tunneling



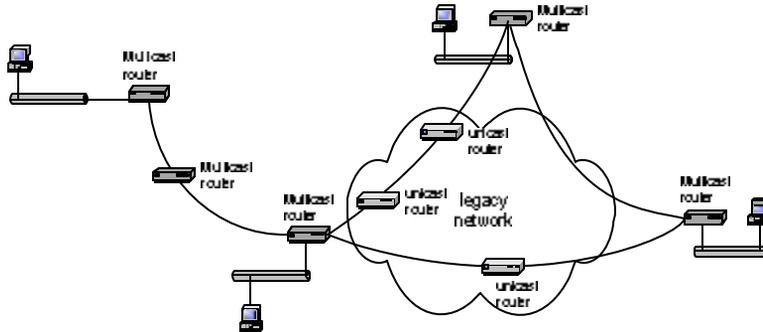
Incremental deployment with IP tunneling

- IP tunneling in MBONE permits gradual deployment of a service (here: multicast service)
- **Phase 1: multicast enabled routers only at edges**



Incremental deployment with IP tunneling

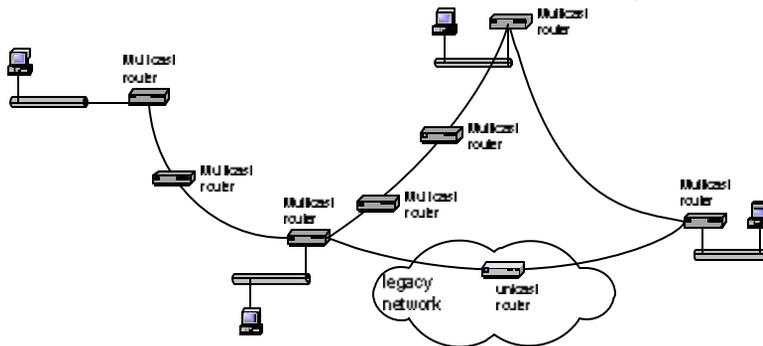
- Phase 2: some routers in backbone are multicast capable



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Incremental deployment with IP tunneling

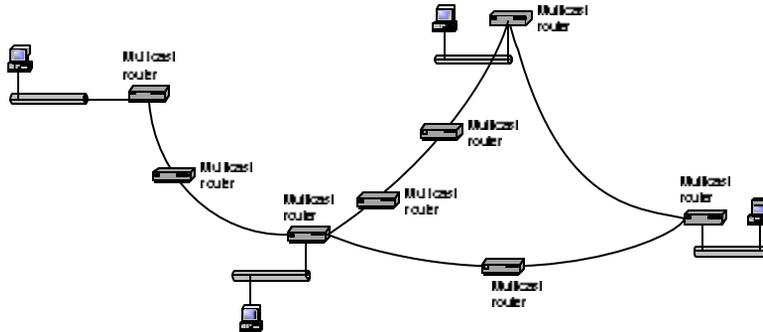
- Phase 3: more routers in backbone are multicast capable



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Incremental deployment with IP tunneling

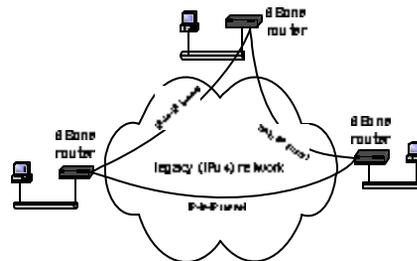
- Finally, when all routers are multicast enabled, the MBONE overlay has been replaced by an infrastructure
- **Phase 4: entire network is multicast enabled**



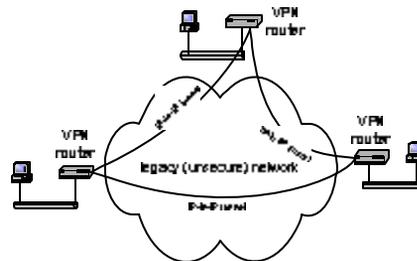
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Other networks with tunneling: 6Bone, VPN

- 6Bone is an IPv6 overlay that can be used to transmit IPv6 packets over an IPv4 network



- Virtual Private Networks (VPNs) encrypt and encapsulate IPv4 traffic.
- Encryption and encapsulation is done by VPN routers



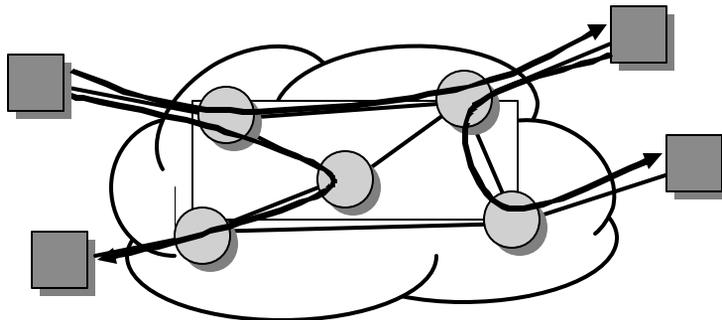
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The evolution of IP multicast

- **Early 1990s:** MBONE routers were developed and deployed
- **Mid-1990s:**
 - MBONE has thousands of MBONE routers
 - IP routers increasingly support multicast routing
- **End-1990s:**
 - Most routers can support multicasting
 - **But IP multicast is not turned on most routers because of concerns pertaining to scalability, network management, deployment and support for error, flow and congestion control**
- **Since early 2000s:**
 - Multicast through application layer overlays

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Application-layer multicasting



- Provide multicast functionality above IP layer
- Data is transmitted between neighbors in the overlay
- No multicast needed in overlay network

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Potential Benefits

- Scalability
 - Routers do not maintain per-group state
 - End systems do, but they participate in very few groups
- Easier to deploy
 - Only requires adding software to end hosts
- Potentially simplifies support for higher level functionality
 - Use hop-by-hop approach, but end hosts are routers
 - Leverage computation and storage of end systems
 - E.g., packet buffering, transcoding of media streams, ACK aggregation
 - Leverage solutions for unicast congestion control and reliability

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Overlay Construction Problems

- Dynamic changes in group membership
 - Members may join and leave dynamically
 - Members may die
- Dynamic changes in network conditions and topology
 - Delay between members may vary over time due to congestion, routing changes
- Knowledge of network conditions is member specific
 - Each member must determine network conditions for itself

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What is the best overlay?

Evaluation criteria:

1. Properties of the overlay graph
2. Mapping of the overlay to the layer-3 network
3. Properties of protocol that maintains the overlay topology

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Overlay-based approaches for multicasting

- Build an overlay mesh network and embed trees into the mesh:
- Build a shared tree:
- Build a graph with well-known properties
 - N-dimensional torus: CAN (see reading list)
 - Hypercube inspired: Chord (see reading list)
 - Triangulation: Delaunay Triangulation (see reading list)

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1. Properties of the overlay graph

- **Number of neighbors (routing table size)**
 - Many DHTs, hypercubes: $O(\log N)$ (*max.*)
 - Triangulation graphs: $O(N)$ (*max.*), 6 (*avg.*)
 - Meshes, trees: no *a priori* bound, but bounds can be enforced
- **Path lengths in the overlay**
 - Many DHTs, hypercubes: $O(\log N)$ (*max.*)
 - Triangulation graphs: $O(N)$ (*max.*), $O(\sqrt{N})$ (*best case avg.*)
 - Meshes, trees: no *a priori* bound

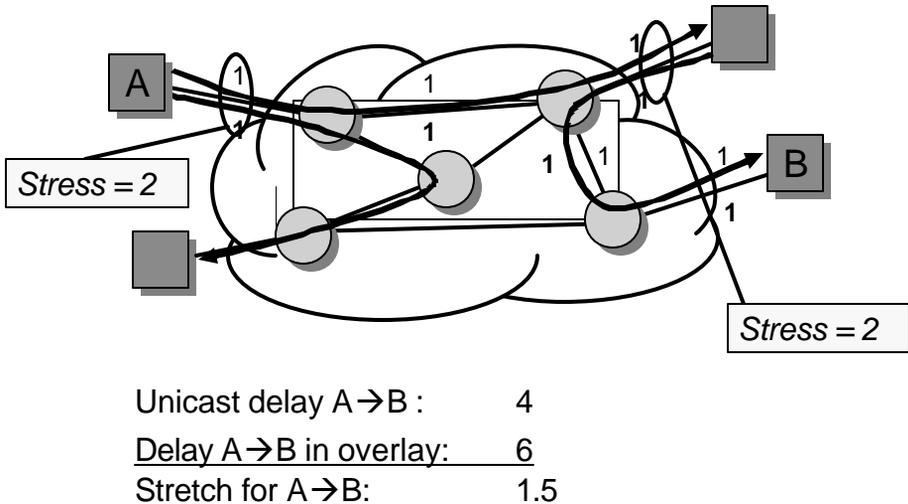
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2. Mapping of the overlay to the layer-3 network

- **Compare overlay multicast to network-layer multicast:**
 - “**Stretch**”: Ratio of delay to shortest path delay
 - “**Stress**”: Number of duplicate transmissions over a physical link
- Overlays that provide a good mapping need to be aware of the underlying layer-3 network

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Illustration of “Stress” and “Stretch”



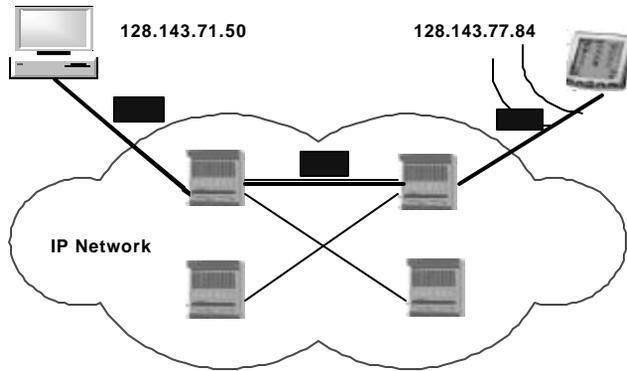
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Case Study: Mobile IP

- **Goal:** Provide access to the Internet to mobile IP hosts
- Reconnection occurs automatically
- Mobility transparent to applications and higher level protocols such as TCP

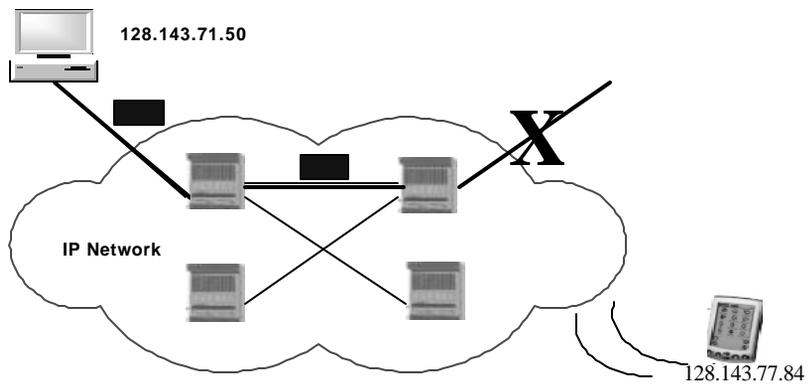
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Mobile Networking problem



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Mobile Networking problem



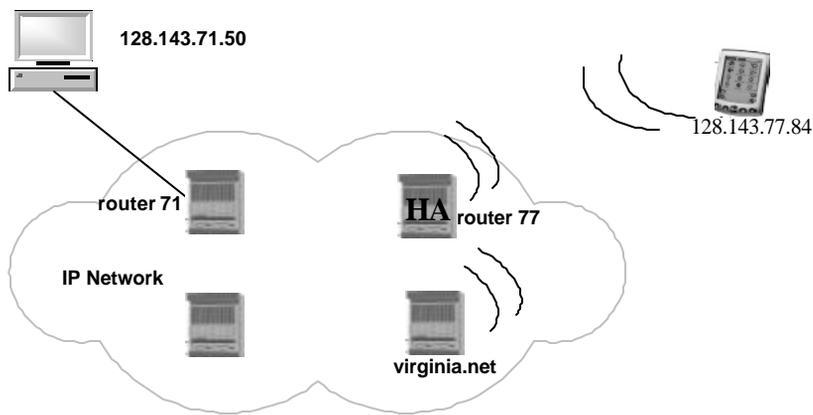
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Mobile IP Approach

- Mobile IP uses two IP addresses :
 - **Home address:** The IP address assigned to the *mobile node*, making it logically appear attached to its *home network*.
 - **Care-of address:** An IP address at the *mobile node's* current point of attachment to the Internet, when the mobile node is not attached to the *home network*.
- **Home network:** The network at which the *mobile node* seems reachable, to the rest of the Internet, by virtue of its assigned IP address.
- **Foreign network:** The network to which the *mobile node* is attached when it is not attached to its *home network*, and on which the *care-of address* is reachable from the rest of the Internet.
- **Home agent:** A router on the *home network* that effectively causes the mobile node to be reachable at its home address even when the mobile node is not attached to its home network.
- **Foreign agent:** A router on the foreign network that can assist the mobile node in receiving datagrams delivered to the care-of address.

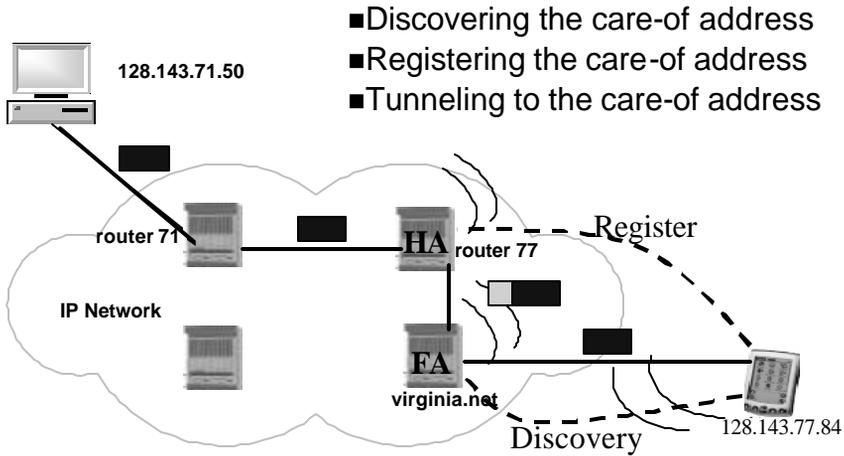
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How Mobile IP Works



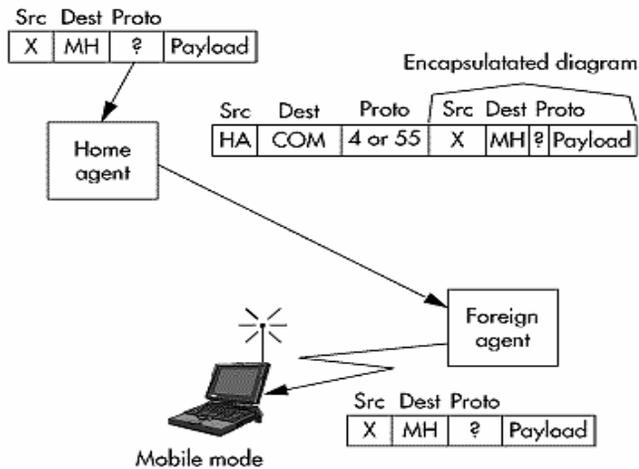
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How Mobile IP Works



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Tunneling to the Care of Address



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