

## More on IP and the Network Layer

Kai Shen

10/3/2011

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## The Internet Protocol

- Addressing, LAN grouping of addresses
- Packet format
- Hierarchical routing:
  - intra-AS (RIP, OSPF)
  - inter-AS (BGP)

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## IPv6

- **A key motivation:** address depletion
  - 128-bit addresses
- **Additional motivation:**
  - simplification help speed processing/forwarding
    - fixed-length 40 byte header
    - no fragmentation allowed in intermediate routers
  - header changes to facilitate QoS
    - flow label
  - new "anycast" address: route to one of a set of several servers

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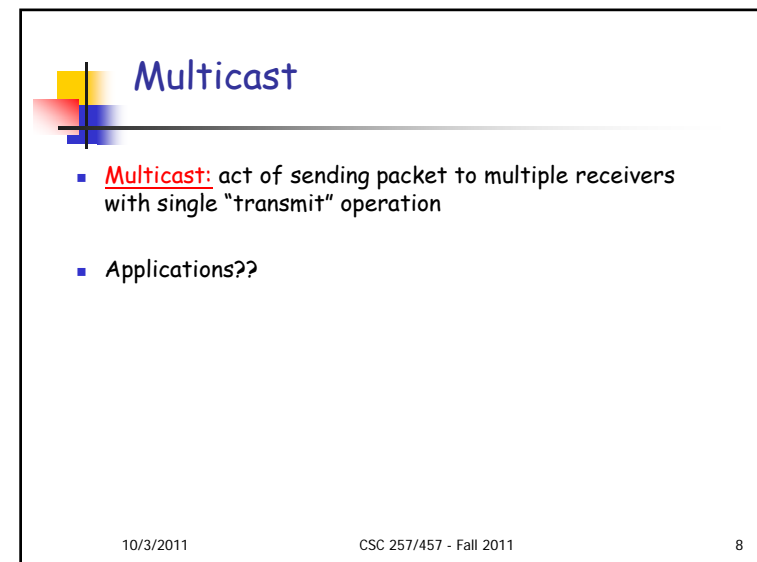
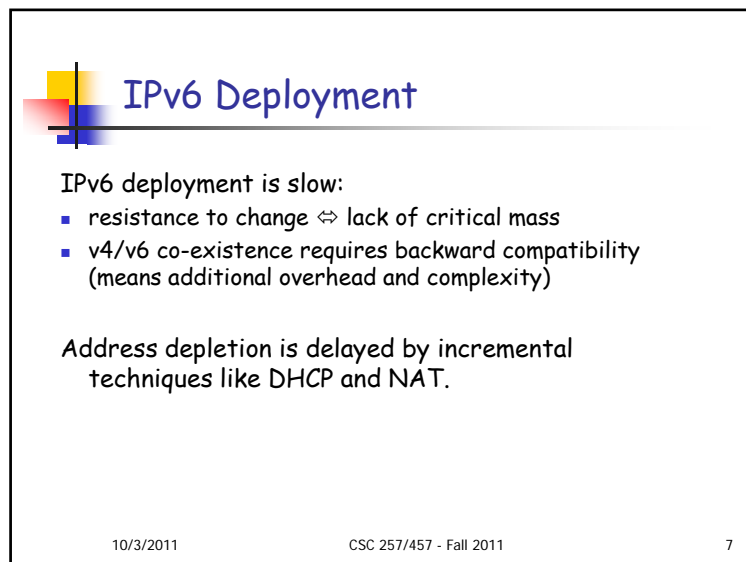
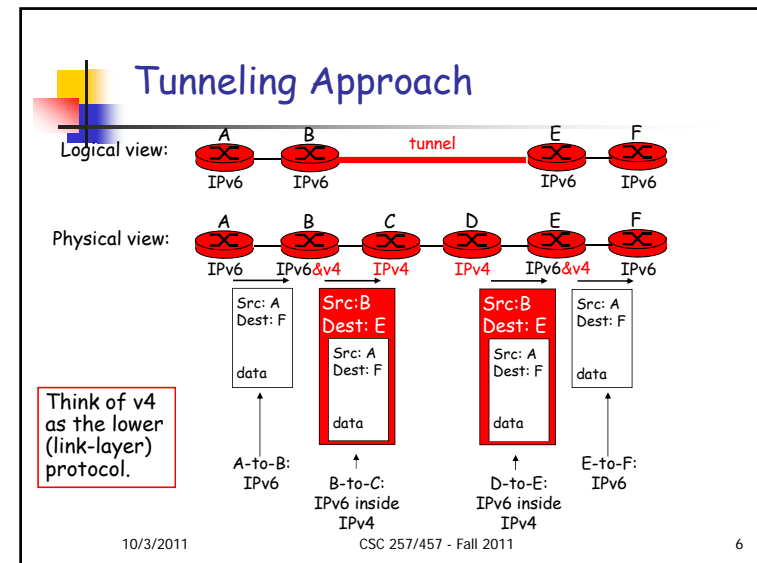
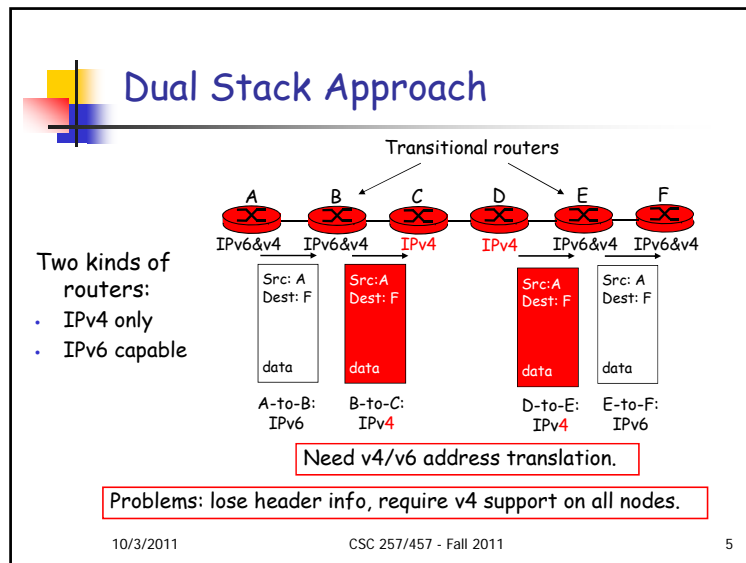
## Transition From IPv4 To IPv6

- It is difficult to change the network layer protocol
  - The large number of routers and administrative autonomy makes simultaneous change impossible.
  - Routers speaking different protocols do not naturally work together.
- Two proposed approaches:
  - **Dual Stack:** some routers with dual stack (v6, v4) can "translate" between formats.
  - **Tunneling:** IPv6 carried as payload in IPv4 packet among IPv4 routers.

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## Multicast via Multiple Unicasts

Multicast via unicast

- source sends N unicast packets, one addressed to each of N receivers
- no change on routers
- problem?

routers forward unicast packets

multicast receiver (red) not a multicast receiver

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## Ideal Network Multicast

Router actively participate in multicast, making copies of packets as needed and forwarding towards multicast receivers

Multicast routers (red) duplicate and forward multicast packets

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## Local and Wide-Area Multicast Management

- local: host informs local mcast router of desire to join group
  - IGMP (Internet Group Management Protocol)
- wide area: local router interacts with other routers to receive mcast packet flow

IGMP

IGMP

wide area multicast routing

IGMP

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## Shortest Path Tree

- Goal: find path/paths (tree) connecting multicast routers having local mcast group members
- Tree of shortest path routes from source to all receivers
  - Dijkstra's algorithm

S: source

R1

R2

R3

R4

R5

R6

R7

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## Reverse Path Forwarding

What if we don't have global network information?

Goal is to forward along shortest paths. **Heuristic:**

- not to forward when packets clearly have deviated from the shortest paths;
- rely on router's knowledge of unicast routing table.

**if** (mcast packet received on incoming link on shortest path back to source)  
**then** flood packet onto all outgoing links  
**else** ignore packet

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## Reverse Path Forwarding: Example

**LEGEND**

- router with attached group member
- router with no attached group member
- packet will be forwarded
- packet will not be forwarded

- result is a source-specific *reverse SPT*
- problem: reaching routers that are not in the group

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## Reverse Path Forwarding: Pruning

- forwarding tree contains subtrees with no mcast group members
  - "prune" msgs sent upstream by router with no downstream group members

**LEGEND**

- router with attached group member
- router with no attached group member
- P prune message
- links with multicast forwarding

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## Wide-area Multicast Routing

**Goal:** find path/paths (tree) connecting multicast routers.

- **source-based tree:** one tree per source
  - shortest path trees, reverse path forwarding
- **group-shared tree:** group uses one tree

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## Shared-Tree Multicast

- Assume complete global network information is available, derive minimum cost tree connecting all relevant routers
  - Steiner tree
  - problem is NP-complete

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## A Distributed Solution: Center-based Tree

- One router identified as "*center*" of tree
- To join:
  - edge router sends unicast *join-msg* addressed to center router
  - *join-msg* "processed" by intermediate routers and forwarded towards center
  - *join-msg* either hits existing tree branch for this center, or arrives at center
  - path taken by *join-msg* becomes new branch of tree for this router

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## Comparison

Compare reverse path forwarding with center-based tree

- Better multicast delivery along shortest paths produced by reverse path forwarding
- Too much pruning in a "sparse" system with relatively few interested routers

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## Internet Multicasting Routing

- **DVMRP**
  - distance vector multicast routing protocol, based on reverse path forwarding and pruning
- **PIM**
  - in a **sparse** mode where DVMRP doesn't do well, it uses Center-based Trees
- IP multicast deployment?

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