Routing beyond unicast

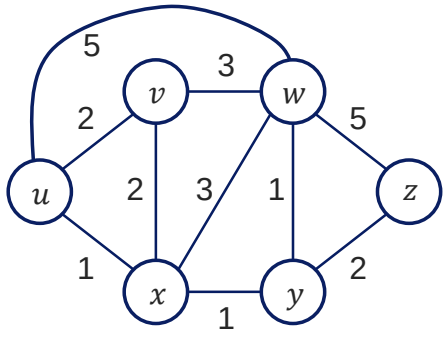
- Data forwarding between two endpoints
  - Unicast
    - One-to-one
- Other modes of data forwarding?
  - Broadcast
    - One-to-all
  - Multicast
    - One-to-many (a group)
    - Open and closed groups
  - Anycast
    - One-to-one-of-many
  - Geocast
    - One-to-area

- Applications

Broadcast delivery

Design an algorithm to broadcast a packet from node u to the other nodes in the network

- Unicast
  - Source unicasts packet to all recipients
  - But, source duplication is inefficient
- Flooding
  - Routers forward packet on all outgoing links
  - But, multiple packets arrive at routers and are retransmitted! → *broadcast storm*
- Controlled flooding
  - Use sequence numbers, routers forward each packet only once (on all outgoing links)
  - But, still multiple arrivals at each router
- Minimum spanning tree
  - Spanning tree $G' = (V, E')$, where $E' \subseteq E$ and G' connected, acyclic
  - Controlled flooding over lower cost G'
  - Downsides?

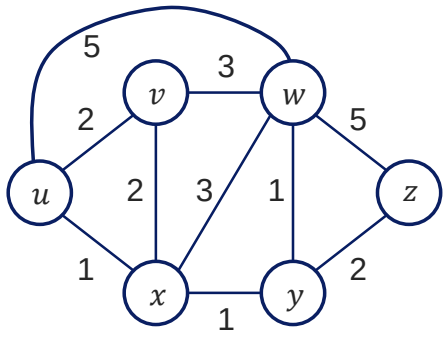


- Network model
  - Graph $G = (V, E)$
    - $V = \{u, v, w, x, y, z\}$
    - $E = \{(u, v), (u, x), (v, x), \dots\}$
  - Link cost $c(x, y)$
    - $c(x, y) = c(y, x)$
    - If $(x, y) \notin E$ then $c(x, y) = \infty$

Spanning tree construction

Design an algorithm to build a minimum cost spanning tree from node u to the other nodes in the network

- LS approach
  - Source node knows network topology
  - Centralized calculation
- DV approach
  - Destination nodes unicast *tree join* message to source (also *rendezvous point*, or *core*)
  - Forwarded to core, or until arrives at node already in tree
  - Path of tree join messages define branches
  - Could be inefficient for asymmetric links!



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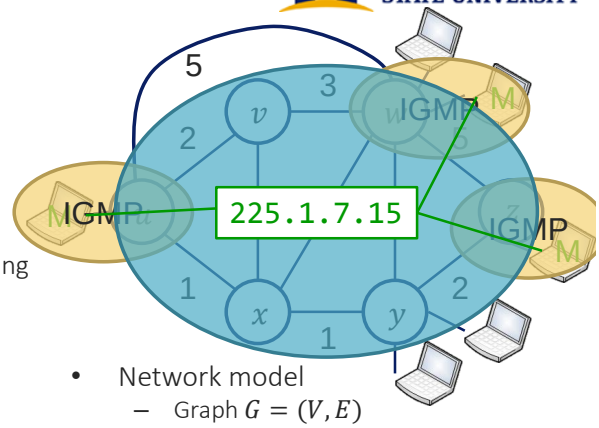
IP Multicast

- Challenges
  - How to identify group members (M)?
  - How to address packets?
  - How to build multicast spanning trees?
- Group membership maintenance
  - End hosts communicate with edge routers using Internet Group Management Protocol (IGMP)
  - IGMP coordinates with multicast routing protocols: DVMRP, PIM, SSM, MSDP
- Address indirection
  - Class D address space 224/4
  - Packets sent to a multicast address delivered to all group members



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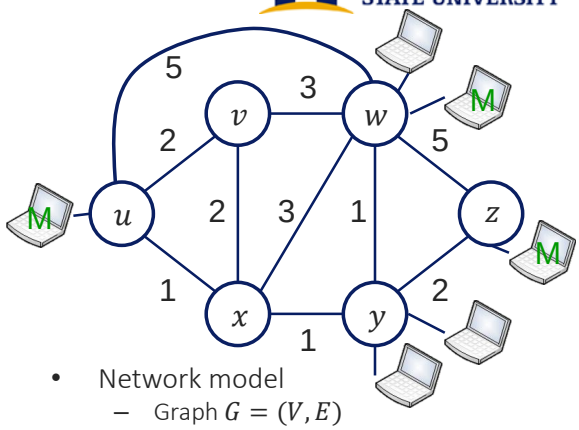
Multicast trees

- Group-based trees (Steiner tree)
  - Minimum cost tree connecting all routers with attached group members
  - Problem is NP-complete, heuristics exist, but too complex in practice
- Source trees (DVMRP)
  - Controlled network flood
  - Routers accept traffic only from shortest path to source upstream nodes
  - Routers reject traffic (*prune*) if no downstream recipients
  - Soft state: prune state times out
- Group-based trees (MSDP)
  - Edge routers send tree join requests
  - Forwarded between ISPs by BGP



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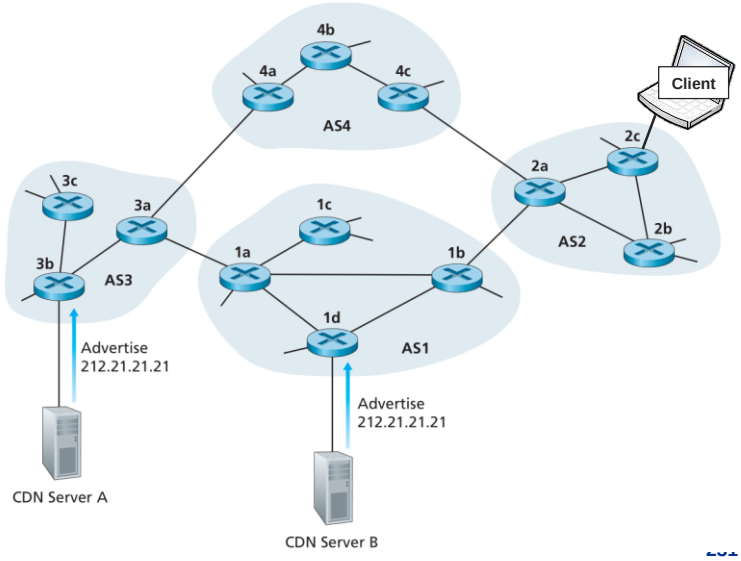
Anycast

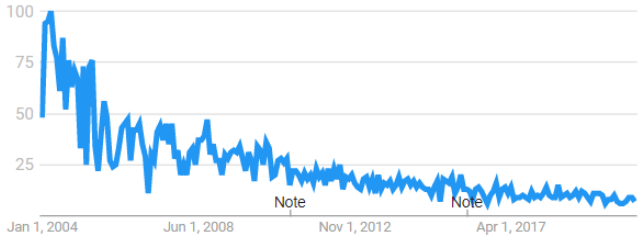
- Get routing to chose the closest cluster of content servers
- Assign *the same* IP to multiple servers
- Advertise reachability through BGP
- Router receiving an advertisements
  - Sees them as multiple routes to the same address
  - Picks the shortest one

What path do packets take from the client to 212.21.21.21?



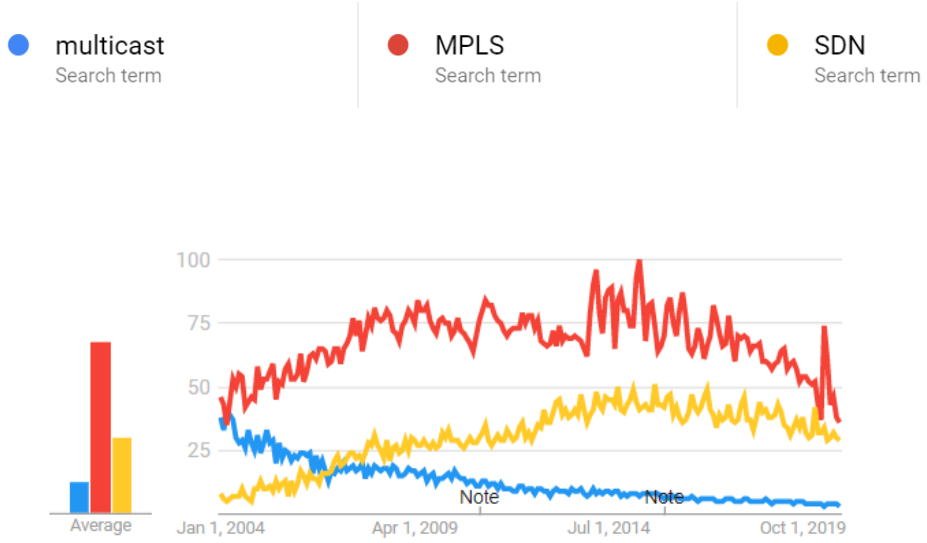
Future of IP multicast

- Why is IP multicast not being adopted?
  - Higher load on routers
  - Difficulties in accounting for multicast traffic between ISPs
  - Cost of network complexity
  - Application layer solutions
    - Make load accounting easier



Source: Google Trends

More Technology Trends



More Technology Trends