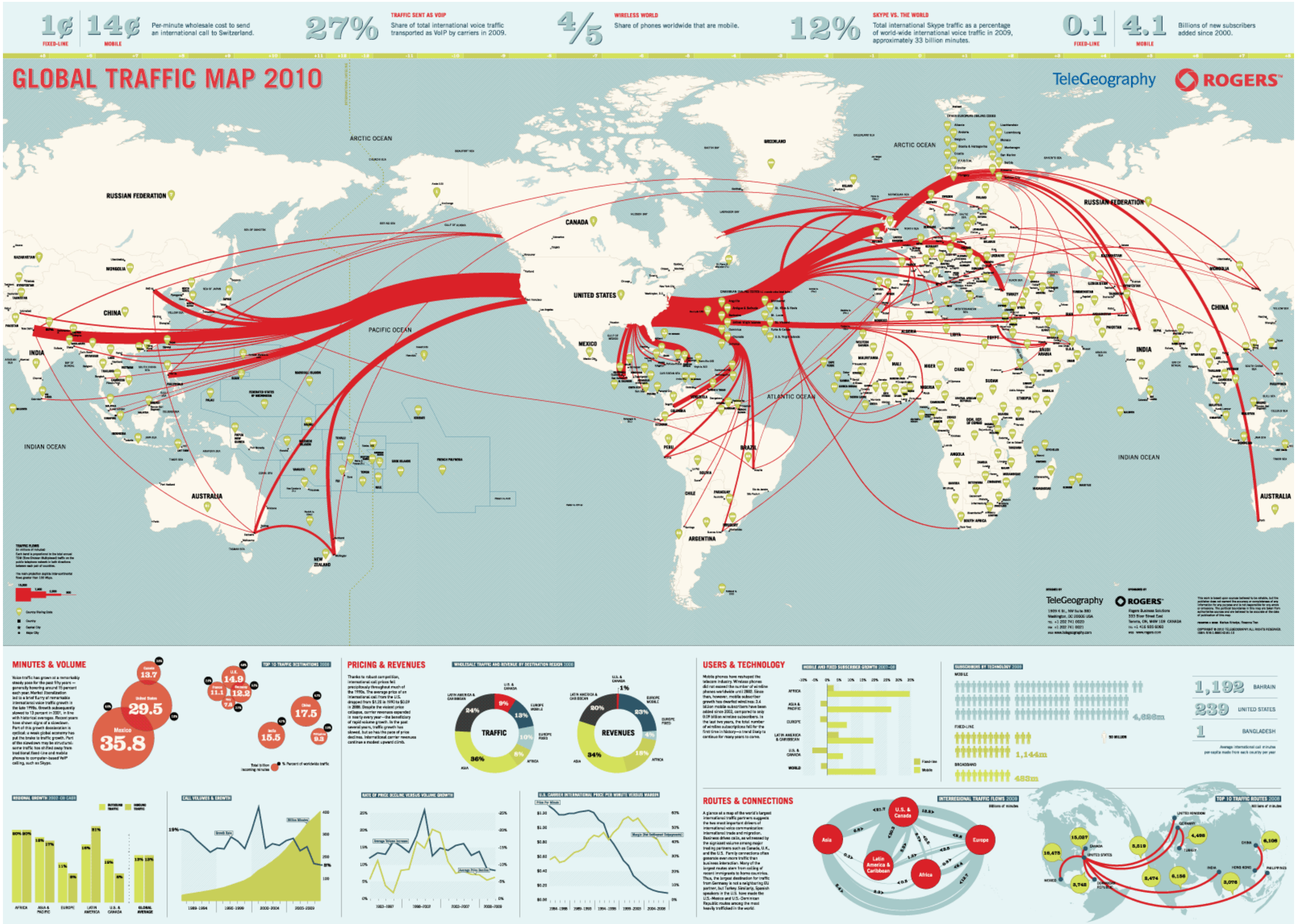
CS5412: NETWORKS AND THE CLOUD

Lecture III

Ken Birman

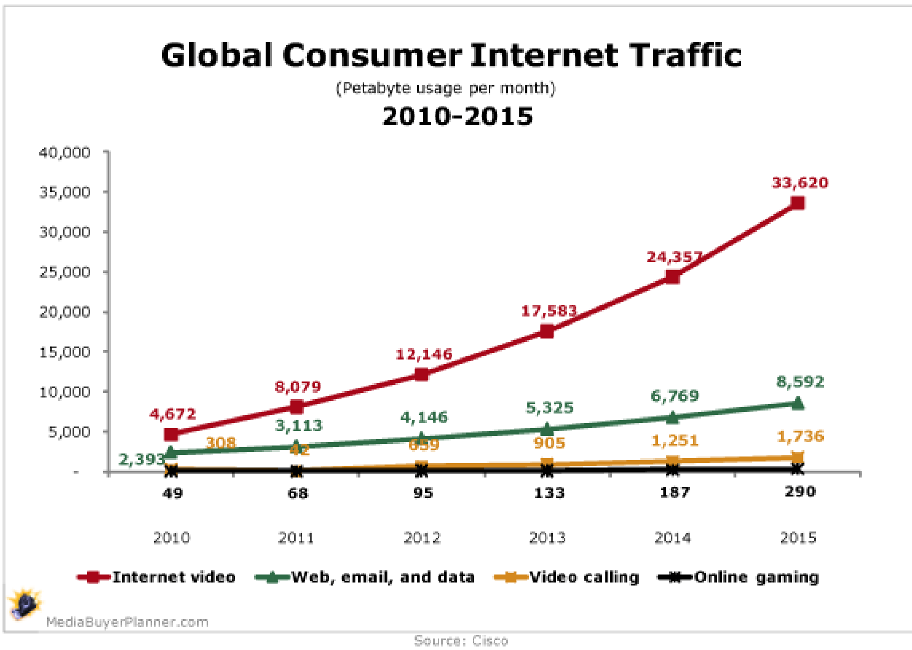
The Internet and the Cloud

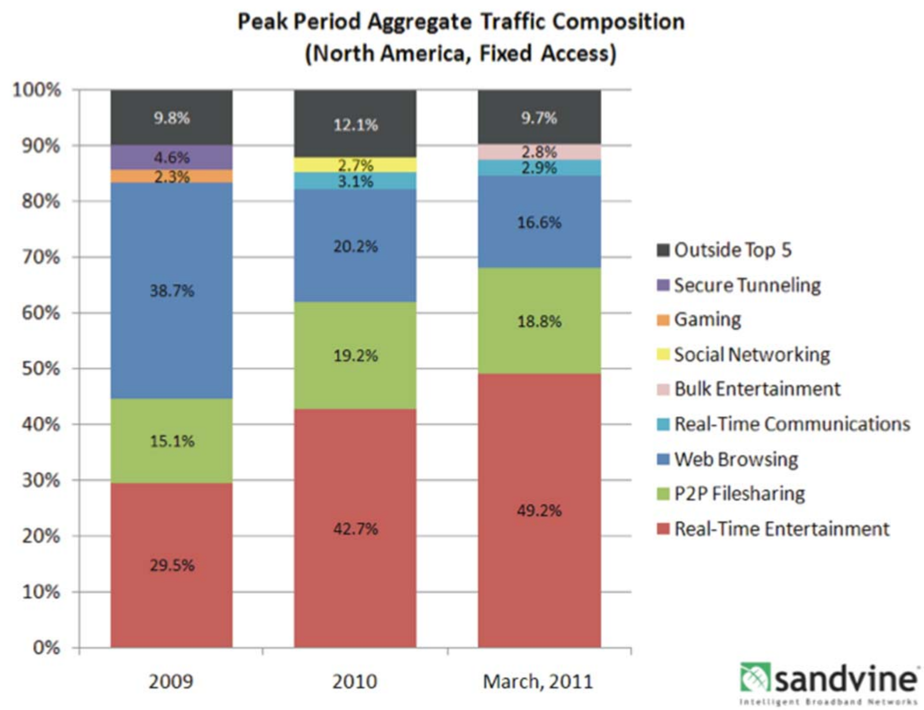
- Cloud computing is transforming the Internet!
  - Mix of traffic has changed dramatically
  - Demand for networking of all kinds is soaring
  - Cloud computing systems want "control" over network routing, want better availability and performance
  - ISPs want more efficiency, and also a cut of the action
- Early Internet: "Don't try to be the phone system"
- Now: "Be everything". A universal critical resource
  - Like electric power (which increasingly, depends on networked control systems!)



1¢
FIXED-LINE
14¢
MOBILE
Per-minute wholesale cost to send an international call to Switzerland.
27%
TRAFFIC SENT AS VOIP
Share of total international voice traffic transported as VoIP by carriers in 2009.
4/5
WIRELESS WORLD
Share of phones worldwide that are mobile.
12%
SKYPE VS. THE WORLD
Total international Skype traffic as a percentage of world-wide international voice traffic in 2009, approximately 33 billion minutes.
0.1
FIXED-LINE
4.1
MOBILE
Billions of new subscribers added since 2000.
GLOBAL TRAFFIC MAP 2010
TeleGeography
ROGERS
ARCTIC OCEAN
PACIFIC OCEAN
ATLANTIC OCEAN
INDIAN OCEAN
RUSSIAN FEDERATION
CANADA
UNITED STATES
MEXICO
CHINA
INDIA
AUSTRALIA
BRAZIL
ARGENTINA
MINUTES & VOLUME
PRICING & REVENUES
USERS & TECHNOLOGY
ROUTES & CONNECTIONS
TRAFFIC
REVENUES
1,192
BAHRAIN
239
UNITED STATES
1
BANGLADESH

Current Internet loads





Source: Cisco

Source: Sandvine's Fall 2010 report on global Internet trends

Looking closer

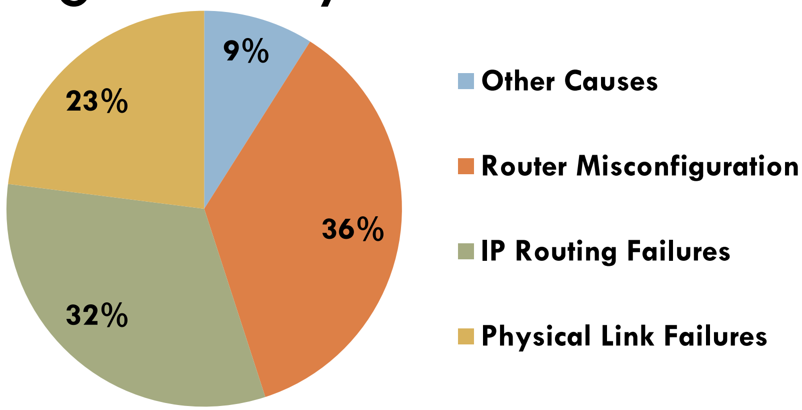
- As of 2010:
  - 42.7% of all traffic on North American “fixed access” networks was attributable to real-time media
  - Netflix was responsible for 20.6% of peak traffic
  - YouTube was associated with 9.9% of peak traffic
  - iTunes was generating 2.6% of downstream traffic
- By late 2011
  - Absolute data volumes continuing rapid rise
  - Amazon “market share”, and that of others, increasing

Implications of these trends?

- Internet is replacing voice telephony, television… will be the dominant transport technology for everything
- Properties that previously only mattered for telephones will matter for the Internet too
- Quality of routing is emerging as a dominent cost issue
  - If traffic is routed to the "wrong" data center, and must be redirected (or goes further than needed), everyone suffers
  - Complication: Only the cloud knows which route is the "right" or the "best" one!

Cloud needs from the network

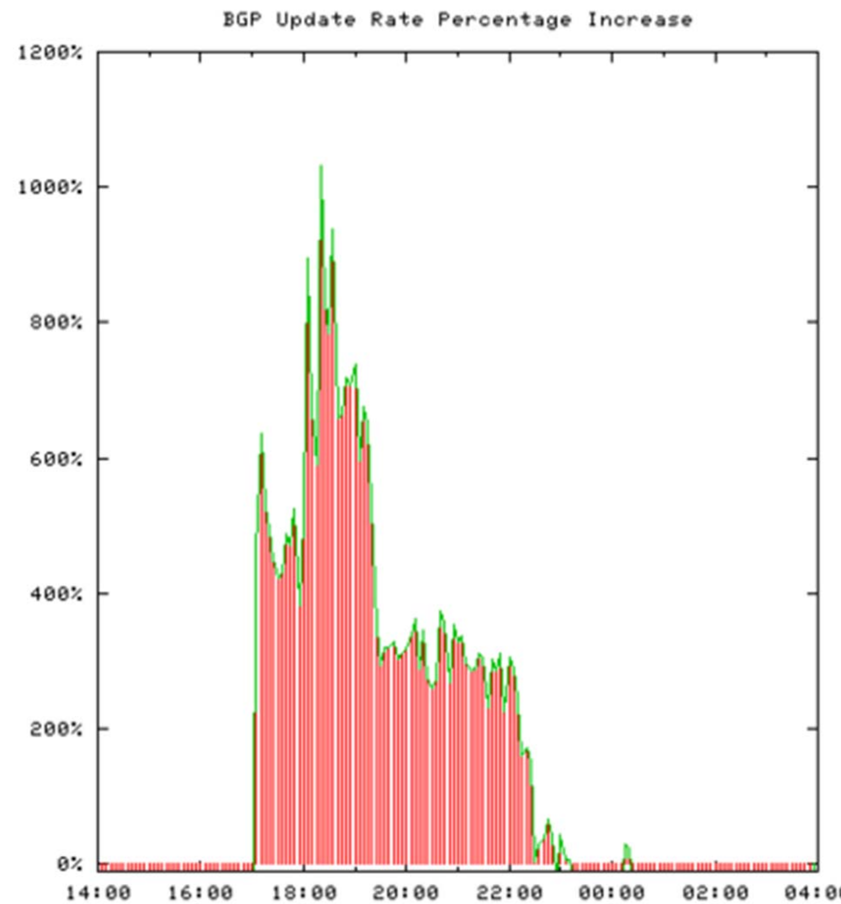
- Continuous operation of routers is key to stream quality and hence to VOIP or VOD quality
- A *high availability* router is one that has redundant components and masks failures, adapts quickly
- 2004 U. Michigan study of router availability:



Source: University of Michigan and Sprint, October 2004

Minor BGP bugs cause big headaches

- In this example, a small ISP in Japan sent 3 minor but incorrect BGP updates
- Certain BGP programs crashed when processing these misreported routes
- Triggers a global wave of incorrect BGP activity that lasts for four hours
- Software patch required to fix issue!



What is BGP and how does it work?

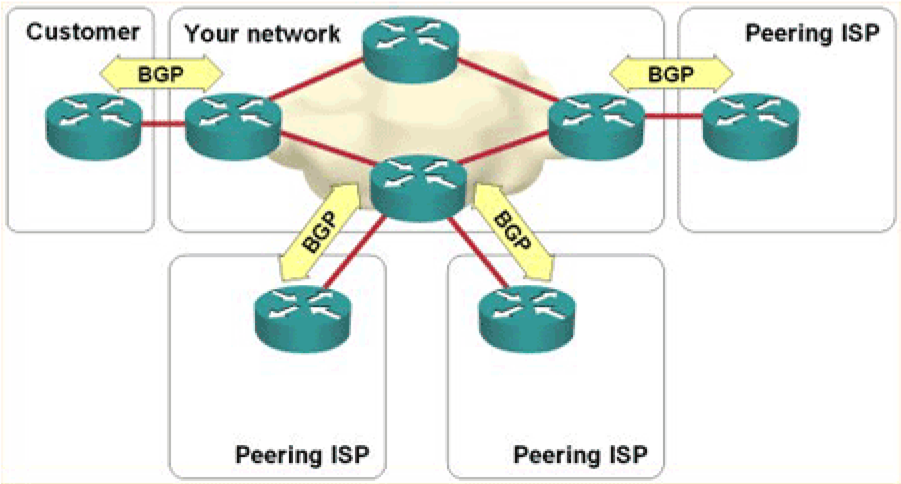
- Modern routers are
  - Hardware platforms that shunt packets between lines
  - But also computers that run "routing software"
- BGP is one of many common routing protocols
  - Border Gateway Protocol
  - Defined by an IETF standard
- Other common routing protocols include OSPF, IS-IS, and these are just three of a long list

What is BGP and how does it work?

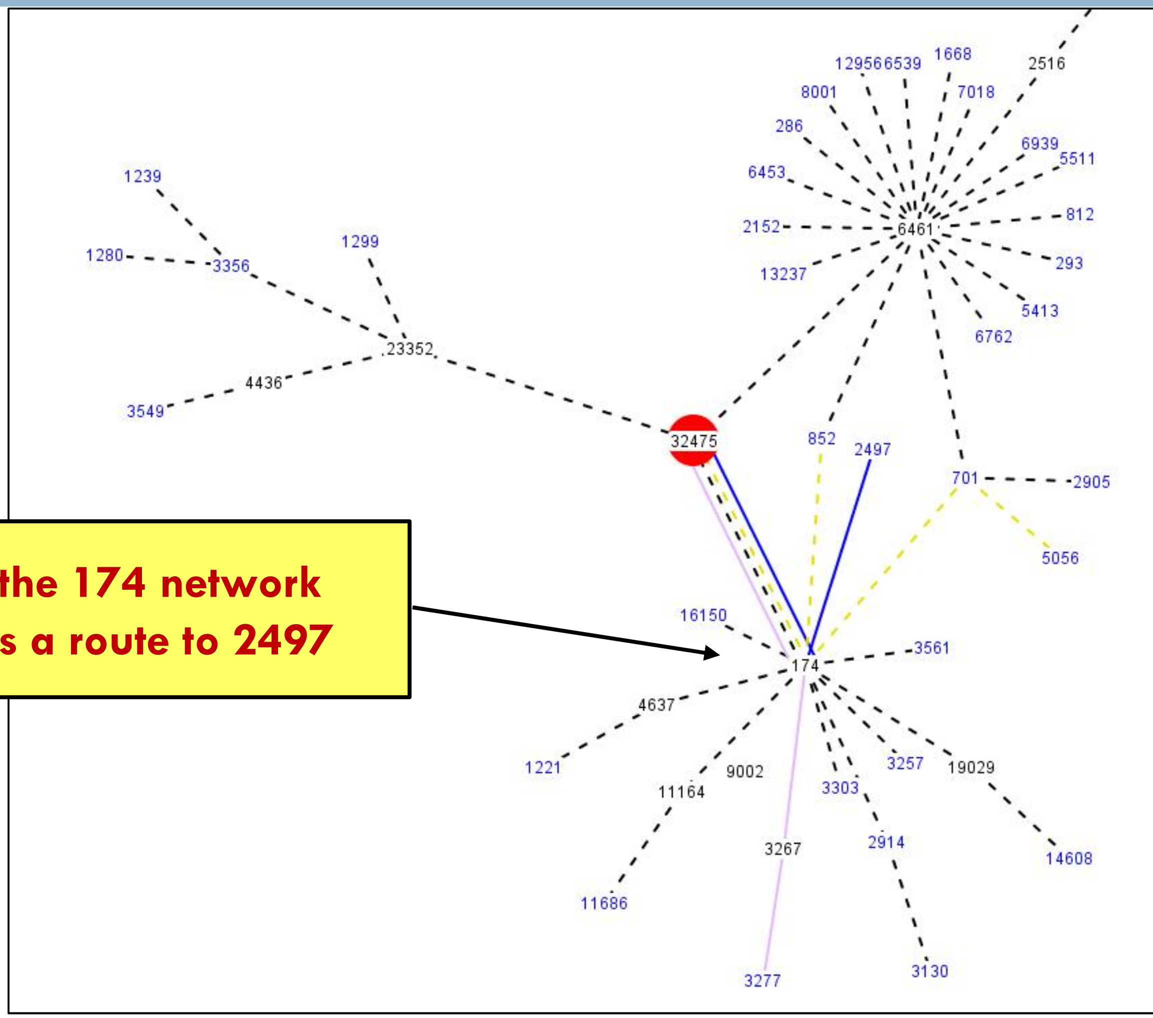
- BGP is implemented by router programs such as the widely popular Quagga routing system, Cisco's proprietary BGP for their core Internet routers, etc
- Each implementation
  - ... follows the basic IETF rules and specifications
  - ... but can extend the BGP protocol by taking advantage of what are called "options"

What is BGP and how does it work?

- Any particular router that hosts BGP:
  - Would need to run some BGP program on one of its nodes ("one" because many routers are clusters)
  - Configure it by telling it which routers are its neighbors (the term "BGP peers" is common)
  - BGP peers advertise routes to one-another
  - For example, "I have a route to 172.23.*.*"

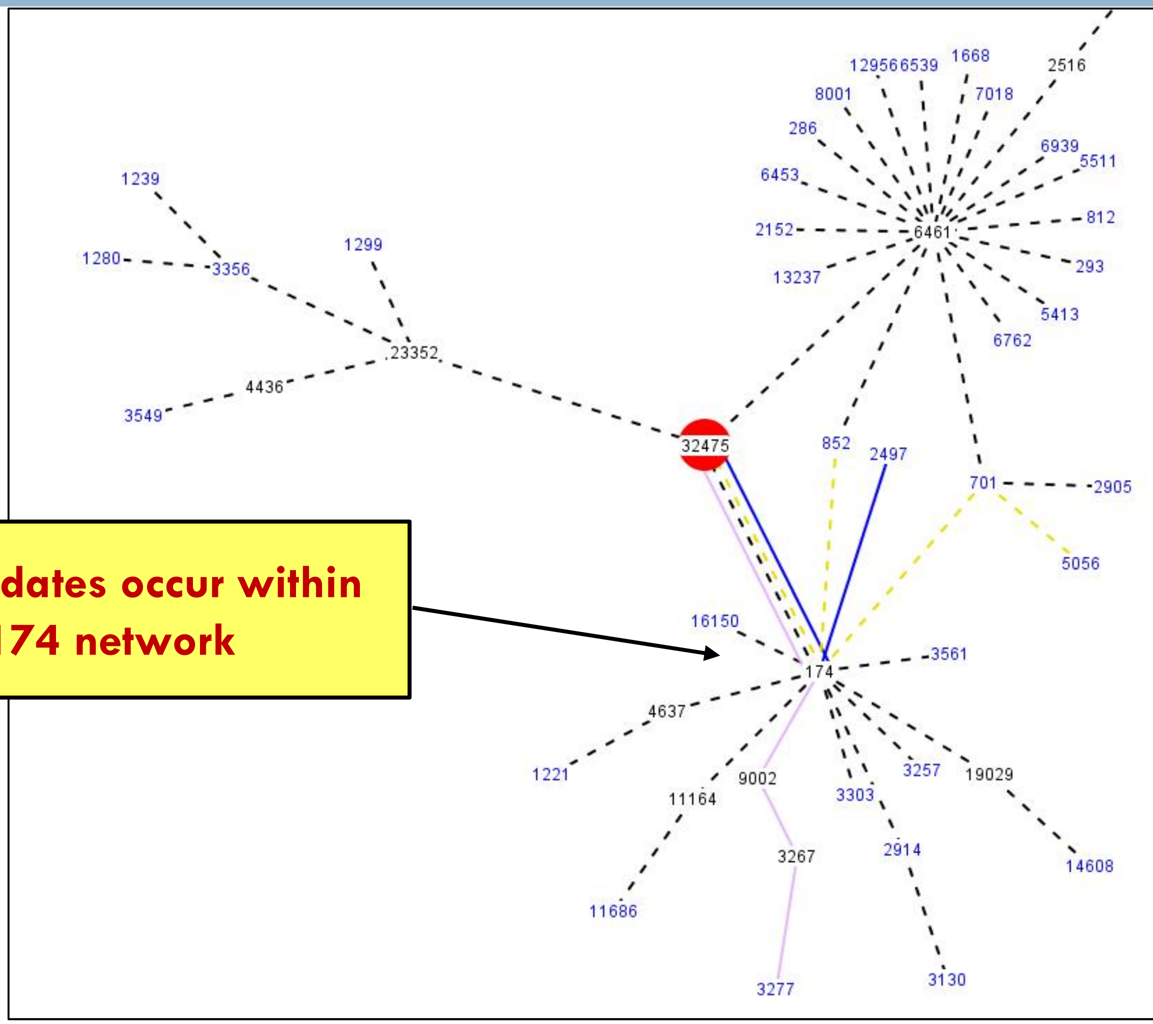


BGP in action (provided by Cogent.com)



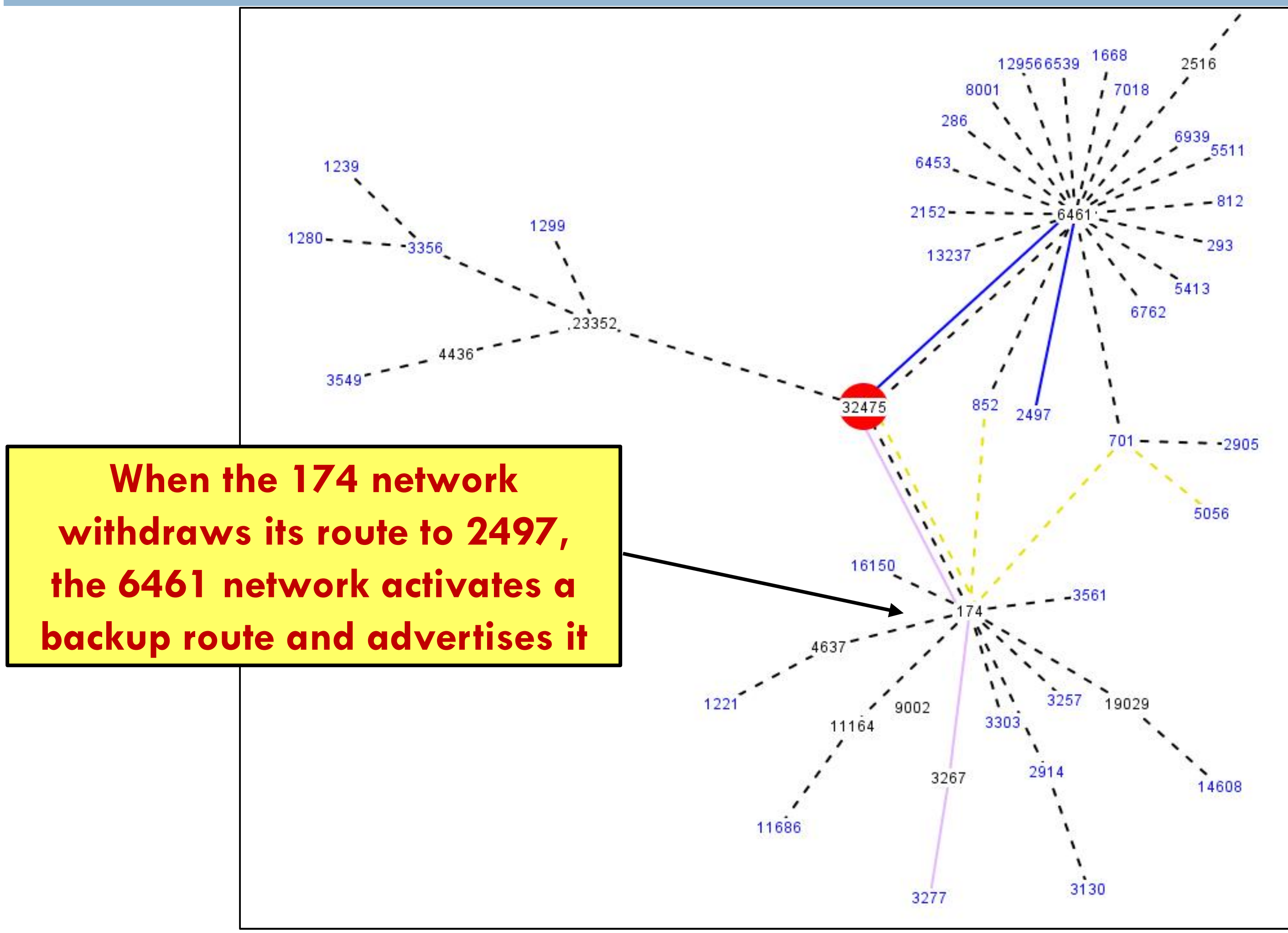
Initially, the 174 network advertises a route to 2497

BGP in action (provided by Cogent.com)



Routing updates occur within the 174 network

BGP in action (provided by Cogent.com)



Notations for IP addresses

- IP addresses are just strings of bits
  - IPv4 uses 32-bit addresses
  - In IPv6 these become 64-bit addresses
  - Otherwise IPv4 and IPv6 are similar
- BGP uses “IP address prefixes”
  - Some string of bits that must match
  - Plus an indication of how many bits are in the match part
  - Common IPv4 notations: 172.23.*.*, or 172.23.0.0/7
  - IPv6 usually shown in hex: 0F.AE.17.31.6D.DD.EA.A0
  - The Cogent slide simply omitted the standard “a.b.c.d” notation, but this is purely a question of preferences

BGP routing table

- Basic idea is that BGP computes a *routing table*
- Loads it into the router, which is often a piece of hardware because line speeds are too fast for any kind of software action
- Router finds the "first match" and forwards packet

Routers in 2004... versus today

- In 2004 most routers were a single machine controlling one line-card per peer
- In 2012, most core Internet routers are clusters with multiple computers, dual line-cards per peer, dual links per peering relationship
- In principle, a 2012 router can "ride out" a failure that would have caused problems in 2004!
- But what about BGP?

Worst case problems

- Suppose our router has many processors but BGP is running on processor A
  - After all, BGP is just a program, like Quagga-BGP
  - You could have written it yourself!
- Now we need BGP to move to processor B
  - Perhaps A crashes
  - Perhaps we're installing a patch to BGP
  - Or we might be doing routine hardware maintenance

Remote peers connect over TCP

- BGP talks to other BGPs over TCP connections
  - So we had a connection from, say, London to New York and it was a TCP connection from X to A.
  - Now we want it to be a connection from X to B.
- BGP doesn't have any kind of "migration" feature in its protocols hence this is a disruptive event
  - BGP will terminate on A, or crash
  - BGP' starts running on B
  - Makes connection to X. Old connection "breaks"

How BGP handles broken connections

- If BGP in New York is seen to have crashed, BGP in London assumes the New York router is down!
  - So it switches to other routes "around" New York
  - Perhaps very inefficient. And the change takes a long time to propagate, and could impact the whole Internet
- Later when BGP restarts, this happens again
- So one small event can have a lasting impact!
  - How lasting? Cisco estimated a 3 to 5 minute disruption when we asked them!

What happens in those 3 minutes?

- When BGP "restarts" on node B, London assumes it has no memory at all of the prior routing table
  - So London sends the entire current routing table, then sends any updates
  - This happens with all the BGP peers, and there could be many of them!
- Copying these big tables and processing them takes time, which is why the disruption is long

BGP "graceful restart"

- An IETF protocol that reduces the delay, somewhat
- With this feature, BGP B basically says "I'm on a new node with amnesia, *but the hardware router still is using the old routing table.*"
  - Same recovery is required, but London continues to route packets via New York. Like a plane on autopilot, the hardware keeps routing
  - However, that routing table will quickly become stale because updates won't be applied until BGP' on B has caught up with current state (still takes 3-5 minutes)

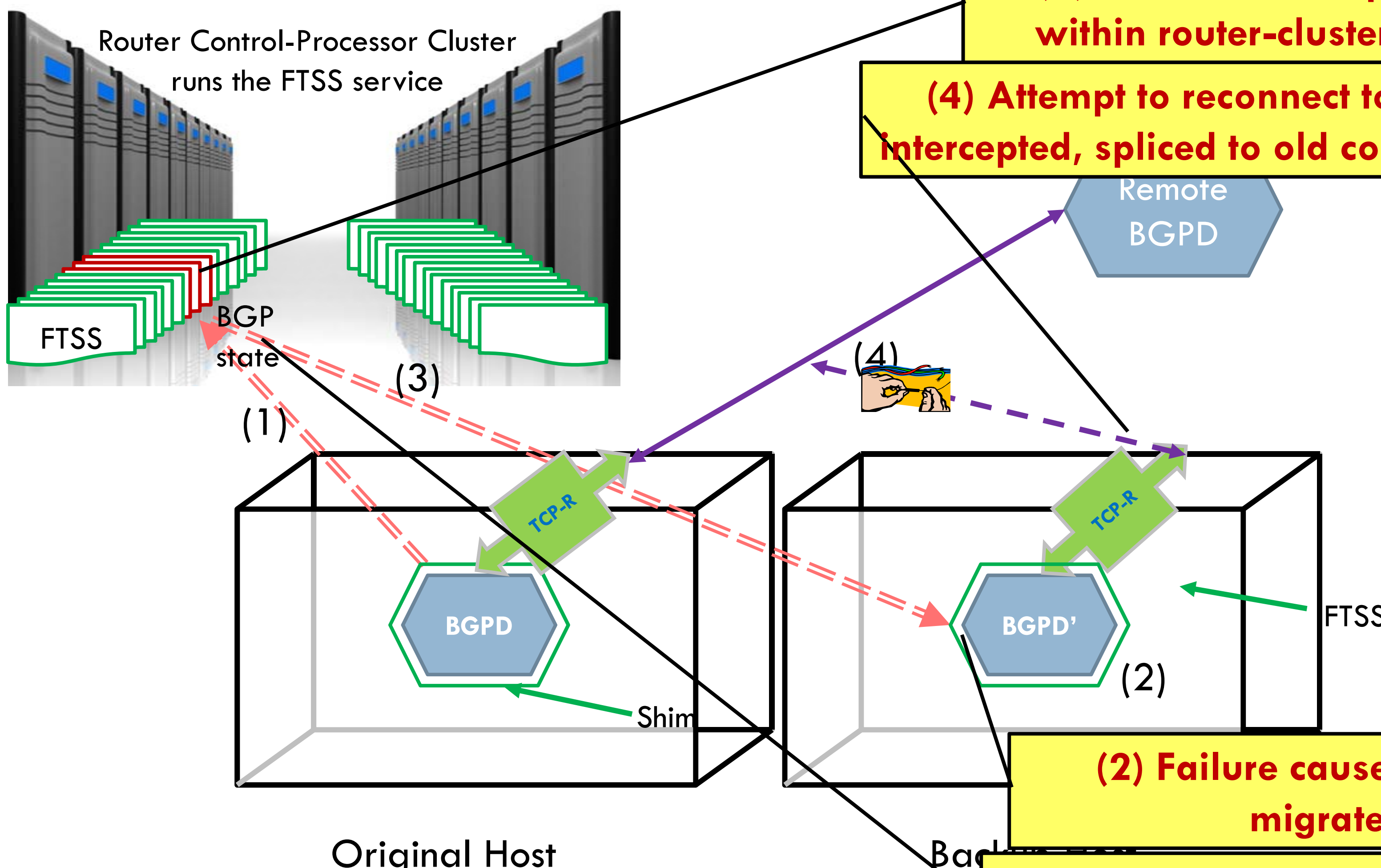
High assurance for BGP?

- We need a BGP that is up and in sync again with no visible disruption at all!
- Steps to building one
  - Replicate the BGP state so that BGP' on B can recover the state very quickly
    - We'll do this by replicating data within memory in the nodes of our cluster-style router
    - BGP' on B loads state from the replicas extremely rapidly
  - Splice the new TCP connections from BGP' on B to peers to the old connections that went to BGP on A
    - They don't see anything happen at all!

Picture of high-availability BGP

(1) State of BGP replicated within router-cluster nodes

(4) Attempt to reconnect to peer intercepted, spliced to old connection



(2) Failure causes BGP to migrate

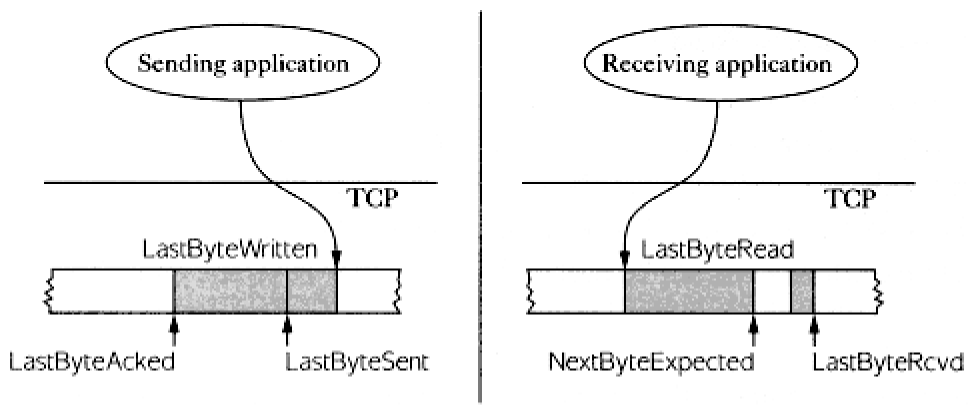
(3) Reload state from replicas

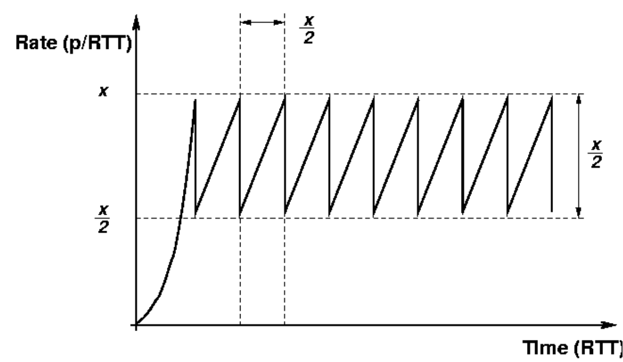
How does TCP-R work?

- Role of TCPR is to
  - Detect an attempt to reconnect to the same peer
  - Connect the new TCP endpoint on node B to the old TCP session that was active between London and node A!
  - Can this be done? Can BGP operate over the resulting half-old, half-new connection?
- Need to understand how TCP works to answer these questions

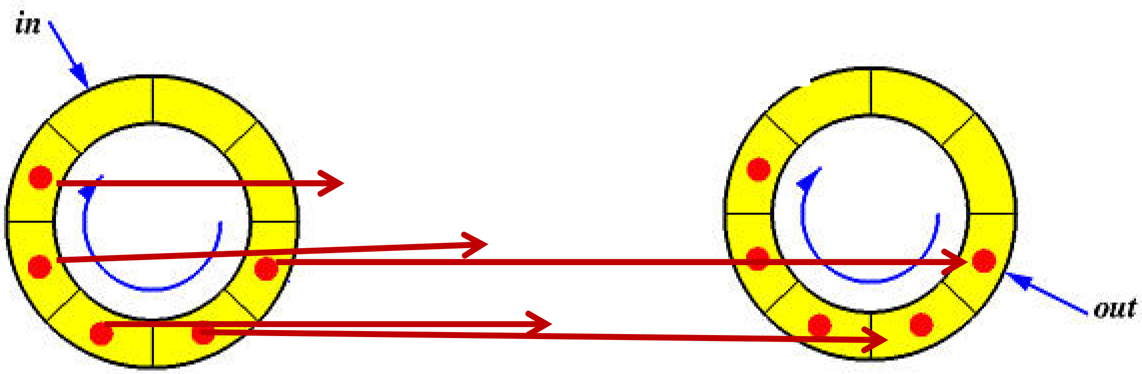
TCP protocol in action

- TCP has a pair of “windows” within which it sends data “segments” numbered by byte offsets
- Varies window size to match data rate network and receiver can handle





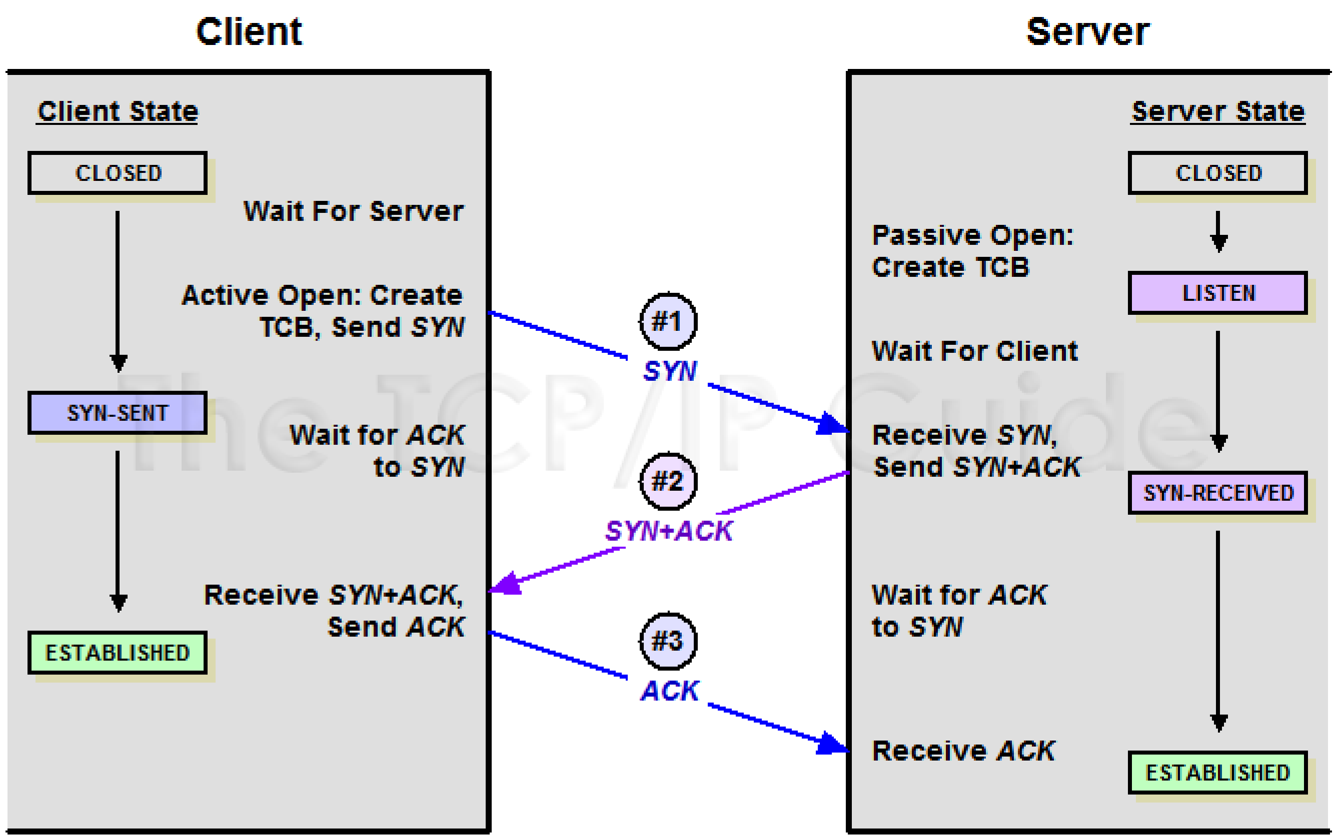
TCP windows are like a pair of bounded buffers



Sequence numbers established in initial handshake

- Connection creator (say, A) says to B:
  - I want to make a connection to you using initial sequence number A→B 1234 (a random number)
  - B replies I will accept your connection using initial sequence number from B→A 9171 (also random)
  - A responds "our connection is established"
- Notice that both numbers start at random values
- This protects against confusion if msg redelivered
- Called a "three-way handshake"

Sequence numbers established in initial handshake



Basic TCP-R idea

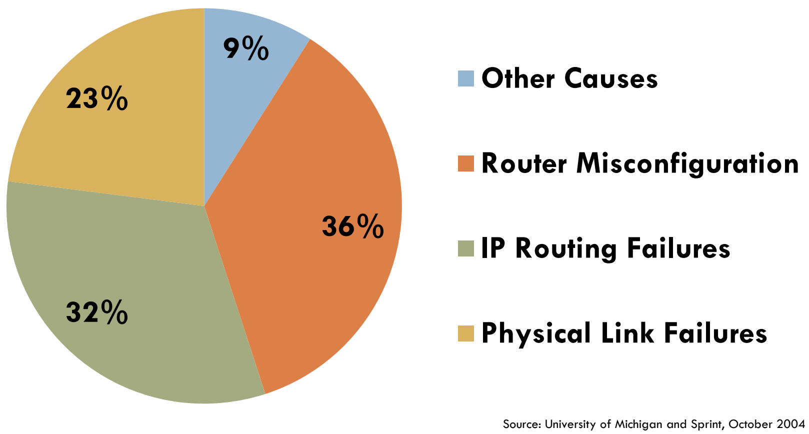
- TCP-R just notes the old sequence pair
  - When BGP B tries to connect to the old peer, TCPR intercepts the handshake and runs it “locally”, noting the delta between old and new sequence numbers
  - Now on each packet, TCPR can “translate” from new numbering to old and back, fooling the old TCP stack into accepting the new packets
  - Updates the TCP checksum field on packet headers
- This splices the connections together

FT-BGP

- FT-BGP has a bit more work to do
  - Old BGP just accepted updates and processed them
  - FT-BGP must log any updates it sends or receives before TCP acknowledges the incoming update, or sends the outgoing one
  - FT-BGP must also complete any receive or send that was disrupted by the failover from node A to B
- But these are easy to do
- Total time for failover: milliseconds!

Thus we've made our router more available

- Goal was to improve on the 2004 situation:



- … every element of the picture has been "fixed"!
  - Replicated links and line cards
  - FT-BGP for failover
  - Better management tools to reduce risk of misconfiguration

How available can the network be?

- Today's Internet achieves between 2 and 3 "nines" of availability
  - Means that over a period of X seconds, would expect to see between 99% and 99.9% of "good behavior"
  - Between 1% and 0.1% of time, something is seriously wrong
- Hubble project at UW: finds that on a national scale Internet has large numbers of black holes, slow patches, terrible choices of routes, etc at all times
- With work like what we've seen could probably push towards a "5-nines" Internet, comparable to voice telephony but at Internet data rates

Could we go further?

- Same idea can harden other routing protocols
- But what about other kinds of router problems?
  - For example, “distributed denial of service attacks” that overload links with garbage data or overwhelm a web site with junk packets?
- Also, how could cloud providers “customize” routing?
  - Cloud operators want a degree of routing control
  - Ideally would want to look inside the packets

These are active research topics...

- Ideas include:
  - Better control over routing within entire regions
  - Some way to support end-to-end "circuits" with pre-authentication between sender and receiever
  - New routing ideas aimed at better support for media streams
  - Monitoring BGP to notice if something very wrong occurs
- Leads to the vision of a collection of "SuperNets" each specialized in different ways, but sharing routers

SuperNet examples

- Google might want to build a Google+ net optimized for its social networking applications
- Netflix would imagine a NetFlixNet ideally tuned for transport of media data
- The smart power grid might want a "grid net" that has security and other assurance features, for use in monitoring the power grid and controlling it

Sharing resources

- The idea is very much like sharing a machine using virtual machines!
  - With VMs user thinks she “owns” the machine but in reality one computer might host many VMs
  - With SuperNet idea, Google thinks it “owns” the GoogleNet but the routers actually “host” many nets
- Could definitely be done today
  - Probably would use the OpenFlow standards to define behaviors of these SuperNets.

Can we “secure” the Internet?

- End-to-end route path security would help…
- … but if routers are just clusters of computers, must still worry about attacks that deliberately disrupt the router itself
  - Like a virus or worm but one that infects routers!
  - This is a genuine risk today
  - Must also worry about disruption of BGP, or the DNS or other critical services

A secured router

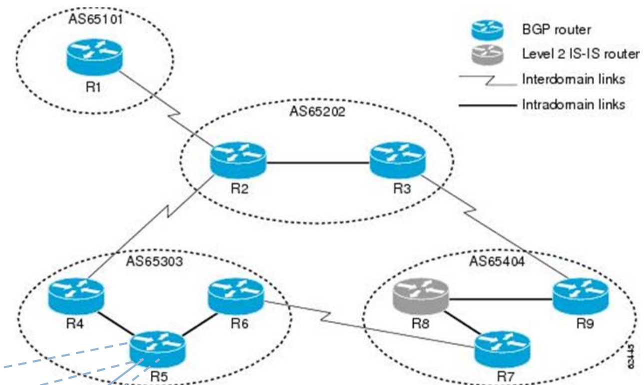
- We would need a way to know precisely what we're running on it
  - Can be done using "trusted platform modules" (TPM is a kind of hardware repository for security keys)
  - Would need to run trustworthy code (use best development techniques, theorem provers)
  - Then "model check" by monitoring behavior against model of what code does and rules for how network operates
- Entails a way of securely replicating those control rules, but this is a topic we'll "solve" later in the course

A secured network

NOC, this is the network topology I want you to use.

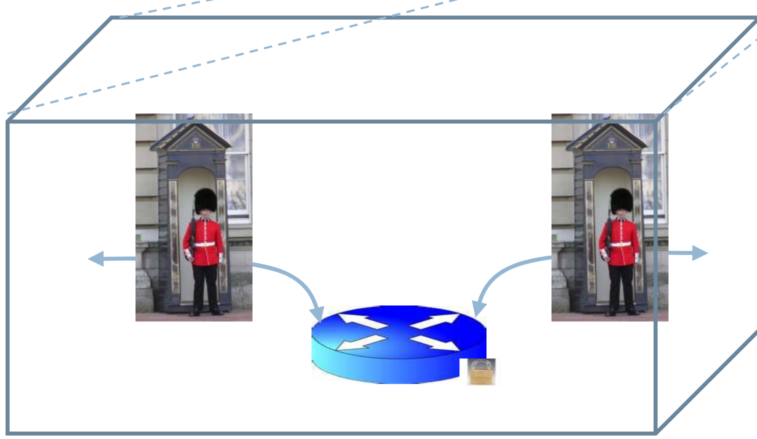
A securely replicated command

Central command controls routing for a region, and sets the policy for BGP updates



Guards supervise router communication but can't create fake router packets: Lack signature authority (TPM keys)

Use a hardware-security feature called the TPM to offer hardened virtual machines

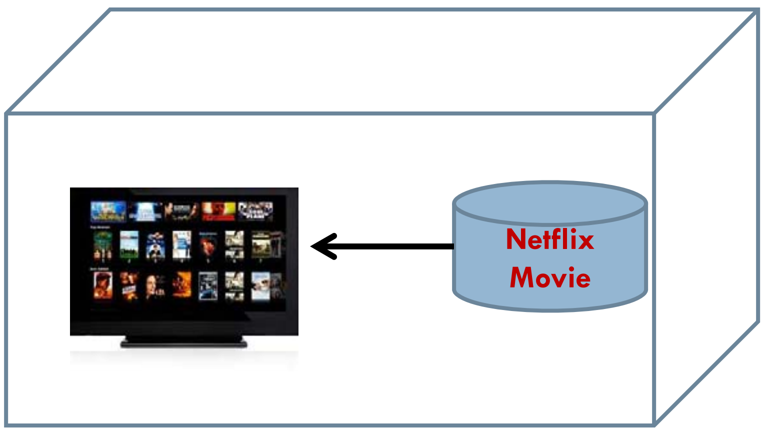


Safe router in a box

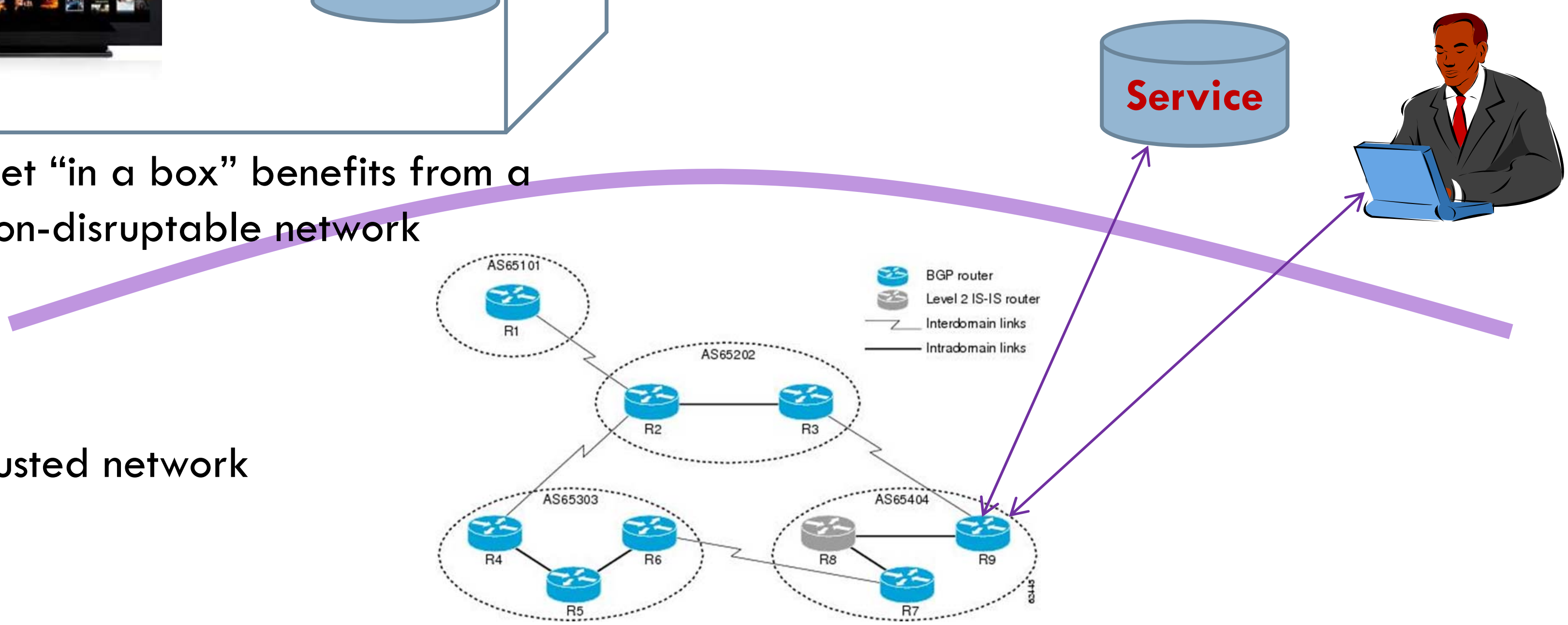
A monitored router can only behave in ways the policy permits

Hosting a SuperNet on a SecureNet

- Secure net is an infrastructure on which the SuperNet runs with no means to disrupt other users!
- SuperNet controls its own virtual resources (maybe even dedicated links)



SuperNet "in a box" benefits from a non-disruptable network



Trusted network

Conclusions?

- Cloud is encouraging rapid evolution of the Internet

- Different cloud "use cases" will want to customize routing and security in different ways

- Nobody wants to be disrupted by other users or by hackers, and this is a big issue for cloud providers

- Tomorrow's network will probably have features that allow each provider to create its own super-net specialized in just the ways it wishes. They will share physical infrastructure.