

# CS5412: NETWORKS AND THE CLOUD

Lecture III

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# 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!)
  - ▣ And the phone system (which now runs over the Internet)

**1¢** **14¢** Per-minute wholesale cost to send an international call to Switzerland.  
FIXED-LINE MOBILE

**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** **4.1** Billions of new subscribers added since 2000.  
FIXED-LINE MOBILE

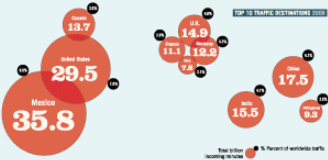
# GLOBAL TRAFFIC MAP 2010

TeleGeography **ROGERS**



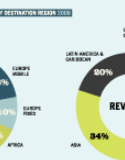
### MINUTES & VOLUME

Minutes traffic has grown as a remarkably steady pace in the past five years — generally between 5 to 10 percent each year. Mobile traffic growth is a lot faster. The total volume of international minutes has grown at an average of 12 percent in 2009, in line with historical averages. Fixed-line minutes have shown signs of a rebound. Part of it is a result of a steady decline in minutes, as well as a steady increase in mobile minutes. Part of it is a result of a steady increase in minutes, as well as a steady increase in mobile minutes.



### PRICING & REVENUES

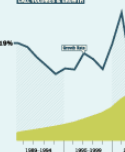
Thanks to robust competition, international rates have fallen precipitously throughout most of the 1990s. The average price of a minute has fallen from \$1.10 in 1990 to \$0.10 in 2009. Despite the steady decline in rates, carrier revenues reported in 2009 were up 1 percent from 2008. This is due to a combination of factors, including a steady decline in rates, as well as a steady increase in mobile minutes.



### REGIONAL GROWTH (2000-2009)



### CALL VOLUMES & GROWTH



### RATE OF PRICE DECLINE VERSUS VOLUME GROWTH



### U.S. CHANGE IN INTERNATIONAL PRICES PER MINUTE VERSUS MARKET



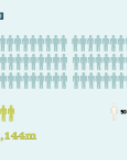
### USERS & TECHNOLOGY

Mobile phones have reshaped the international market. Wireless phones do not need the same level of infrastructure as fixed-line phones. This has led to a steady increase in mobile phone usage, particularly in developing countries. The growth in mobile phone usage has led to a steady increase in international minutes, particularly in developing countries.



### IMPACT OF TECHNOLOGY

Mobile phones have reshaped the international market. Wireless phones do not need the same level of infrastructure as fixed-line phones. This has led to a steady increase in mobile phone usage, particularly in developing countries. The growth in mobile phone usage has led to a steady increase in international minutes, particularly in developing countries.



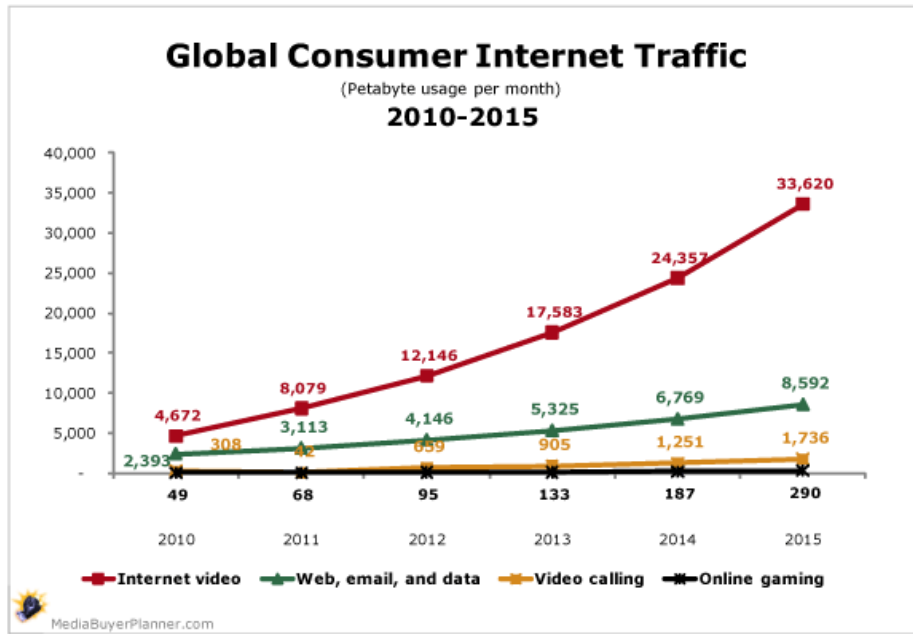
### ROUTES & CONNECTIONS

A global network of world's largest telecommunications providers suggests that the world's largest international voice connections are between North America and Europe. This is due to a combination of factors, including a steady decline in rates, as well as a steady increase in mobile minutes.

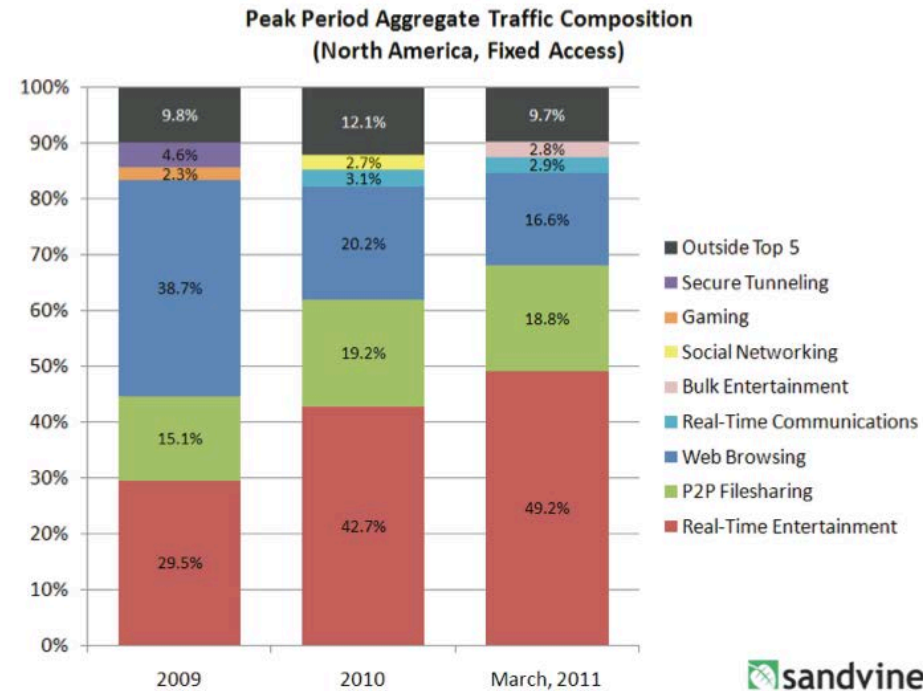


# Current Internet loads

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Source: Cisco



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

# Looking closer

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- 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?

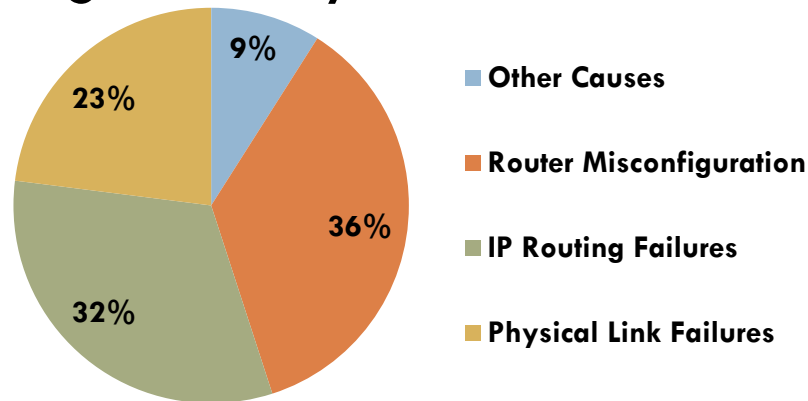
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- Internet is replacing voice telephony, television... will be the dominant transport technology for everything
- Properties that previously only mattered for telephones will matter for the Internet too
- Quality of routing is emerging as a dominant 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

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- 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:

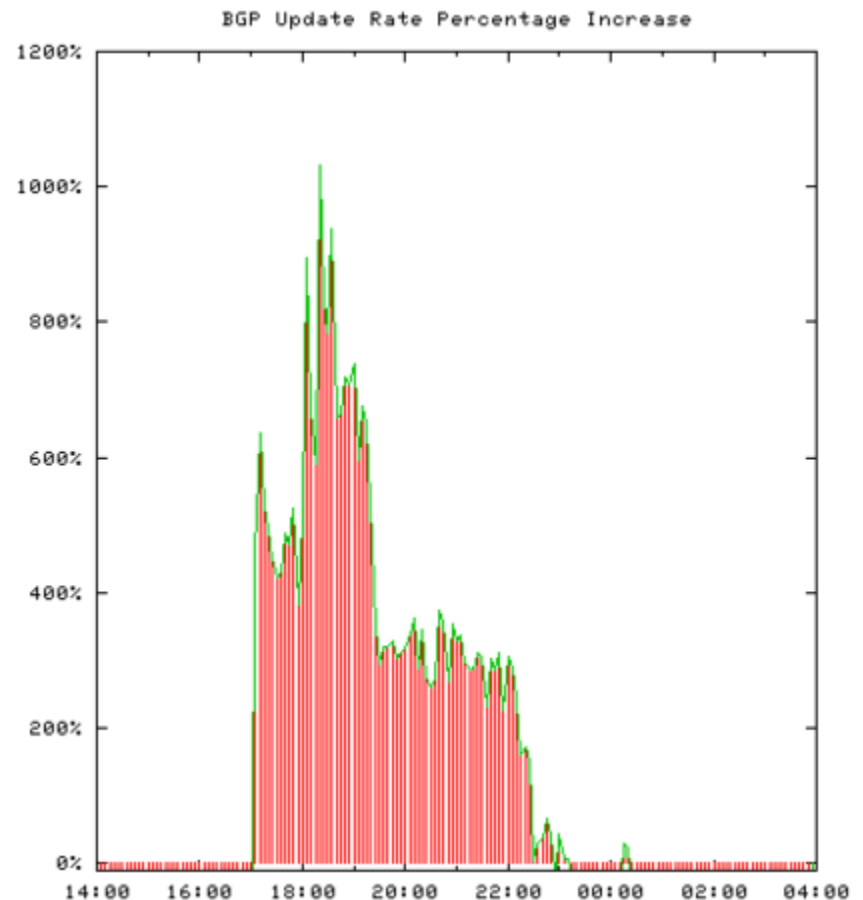


Source: University of Michigan and Sprint, October 2004

# Minor BGP bugs cause big headaches

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- 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!





# Minor BGP bugs cause big headaches

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A typo in a BGP  
configuration file...  
**... major consequences!**



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## How the Chinese Internet ended up in Cheyenne, Wyoming

BY BRIAN FUNG [✉](#) January 22 at 11:01 am

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The building on Pioneer Ave. that houses Sophidea, the company that received a deluge of Chinese Internet traffic Tuesday. (Google Streetview)

# What is BGP and how does it work?

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- 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

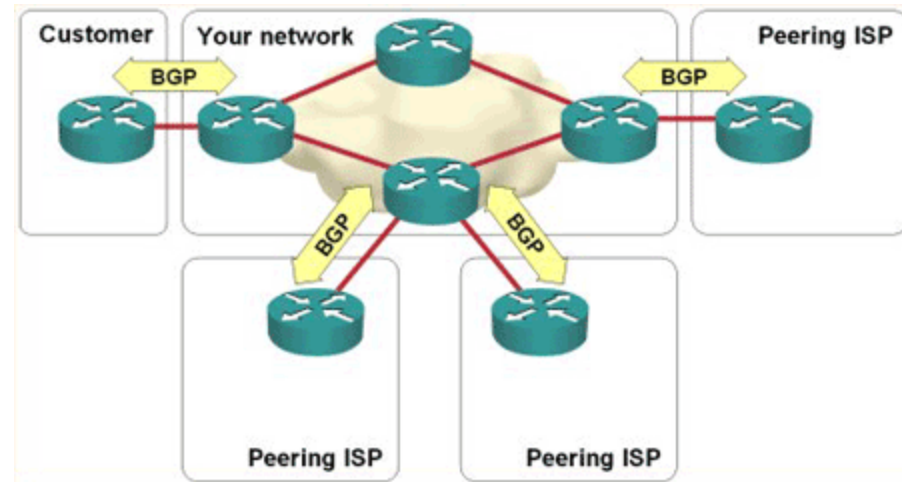
# What is BGP and how does it work?

- 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?

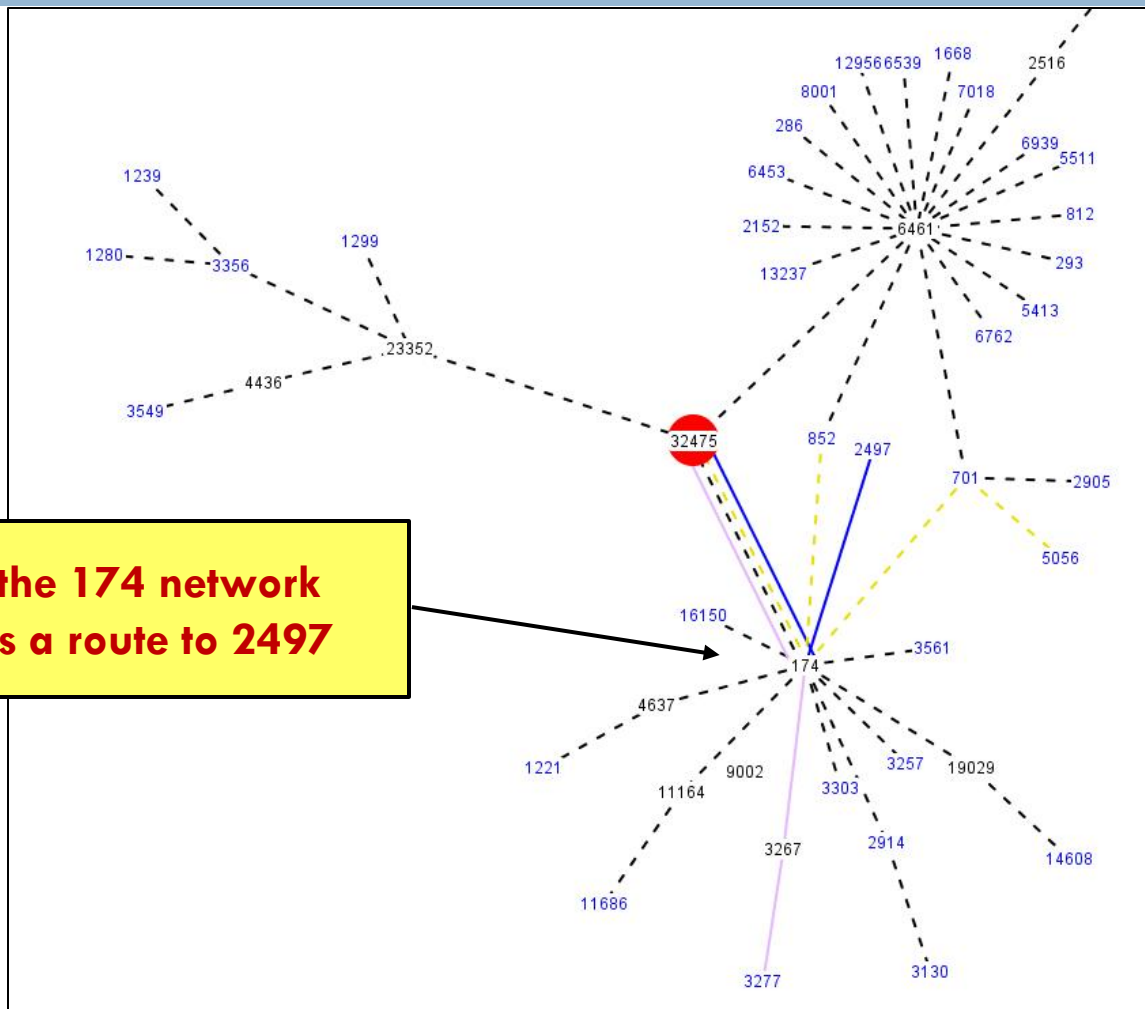
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- Any particular router that hosts BGP:
  - ▣ Would need to run some BGP program on one of its nodes (“one” because many routers are clusters)
  - ▣ Configure it by telling it which routers are its neighbors (the term “BGP peers” is common)
  - ▣ BGP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



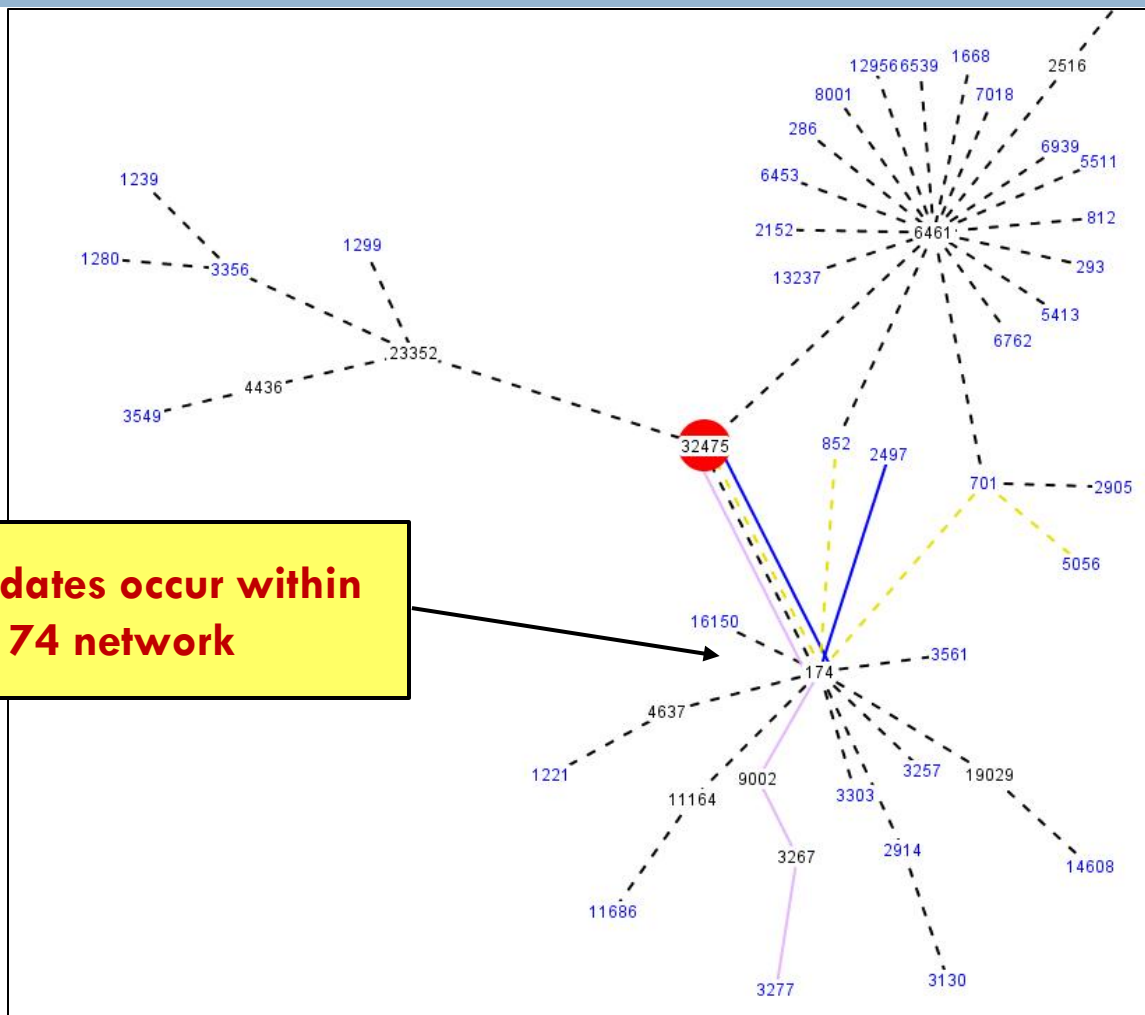
# BGP in action (provided by Cogent.com)

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# BGP in action (provided by Cogent.com)

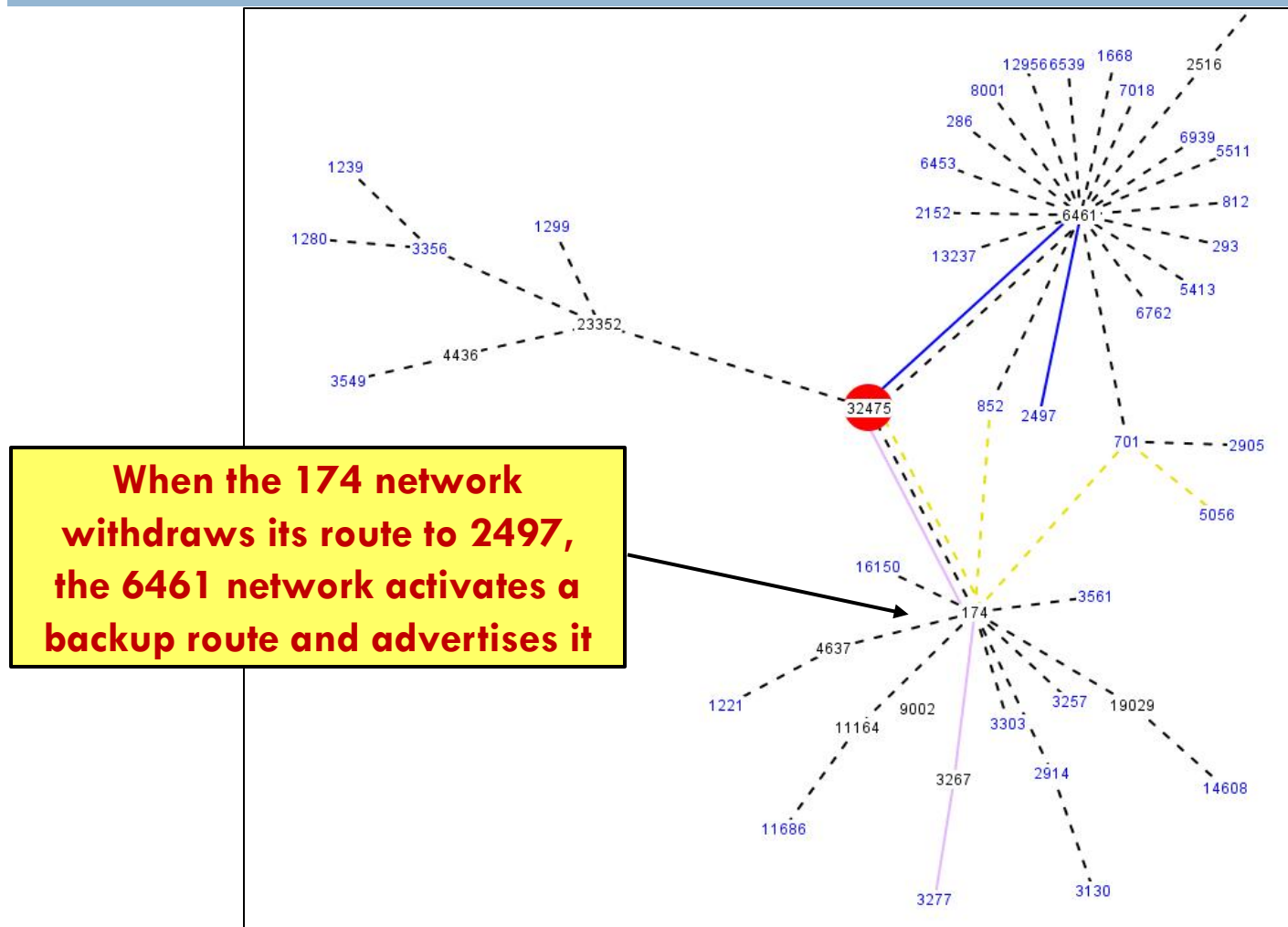
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**Routing updates occur within the 174 network**

# BGP in action (provided by Cogent.com)

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# Notations for IP addresses

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- 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

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- 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

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- 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

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- 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

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- 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

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- 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?

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- 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”

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- 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?

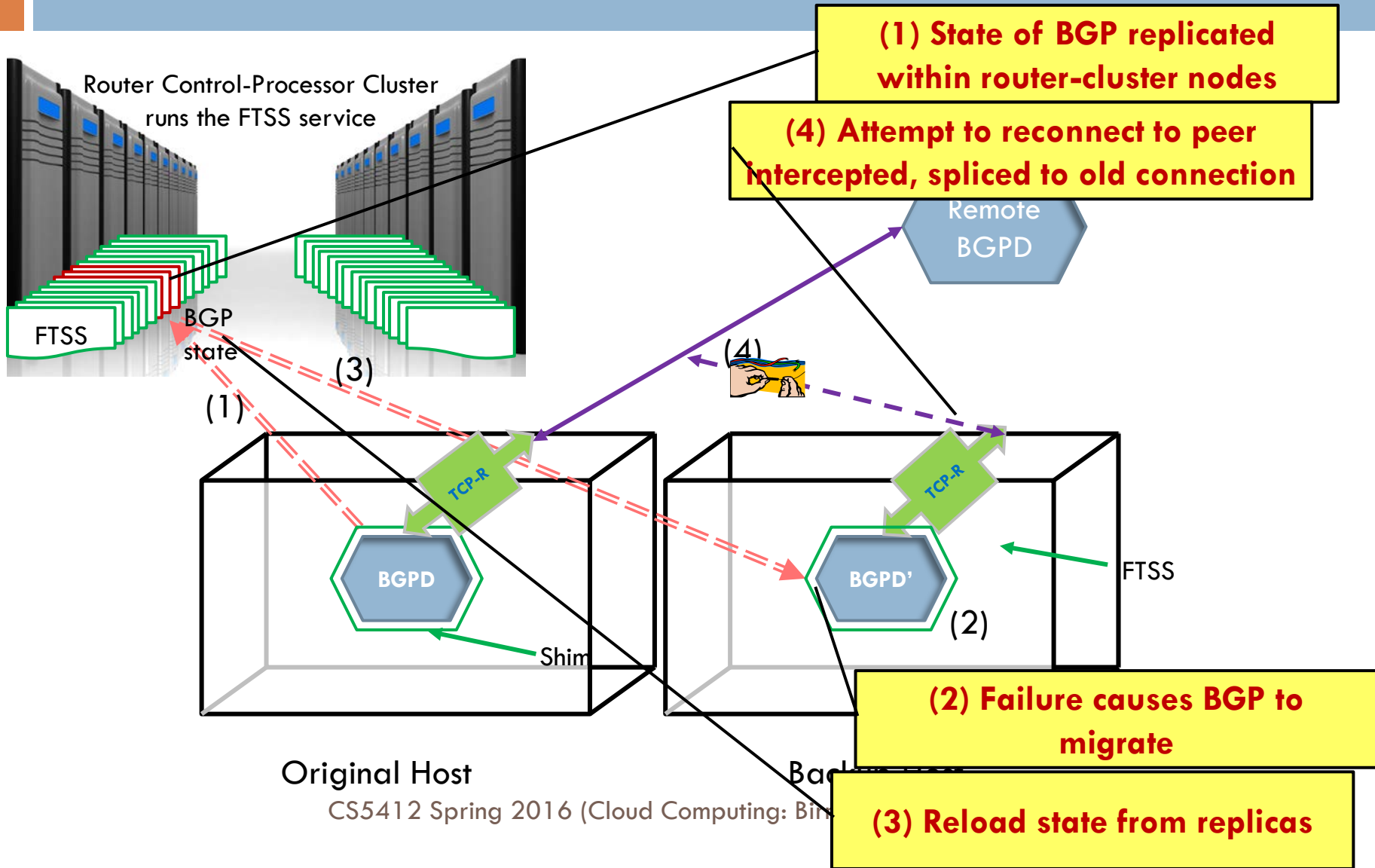
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- We need a BGP that is up and in sync again with no visible disruption at all!
- Steps to building one
  - ▣ Replicate the BGP state so that BGP' on B can recover the state very quickly
    - We'll do this by replicating data within memory in the 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

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Original Host

Backup Host

# How does TCP-R work?

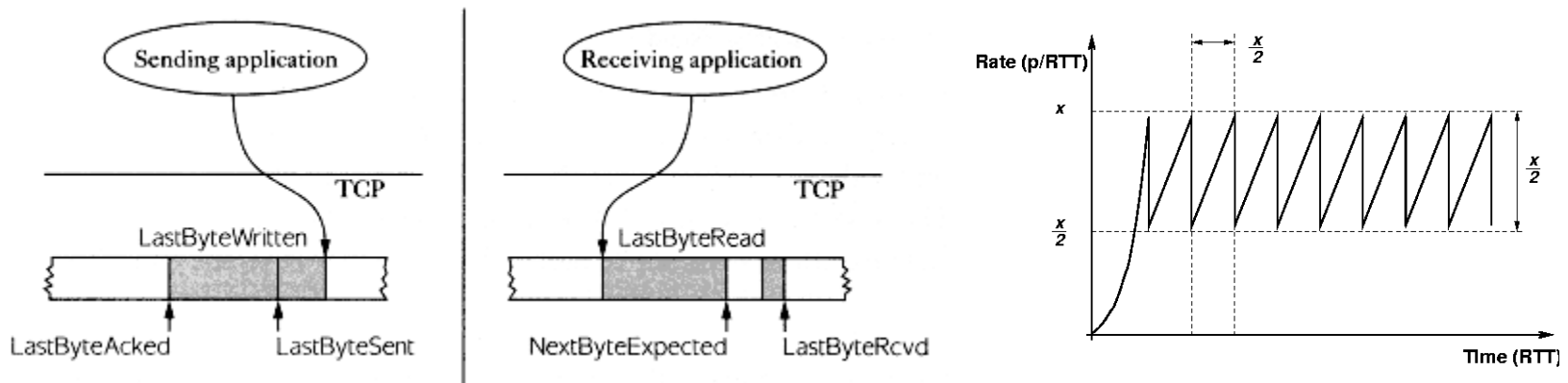
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- Role of TCPR is to
  - ▣ Detect an attempt to reconnect to the same peer
  - ▣ Connect the new TCP endpoint on node B to the old TCP session that was active between London and node A!
  - ▣ Can this be done? Can BGP operate over the resulting half-old,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

# TCP protocol in action

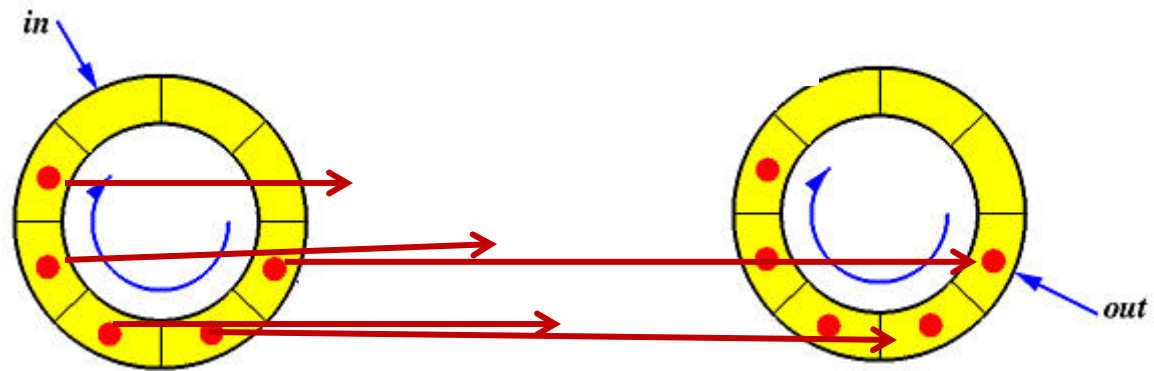
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- TCP has a pair of “windows” within which it sends data “segments” numbered by byte offsets
- Varies window size to match data rate network and receiver can handle



# TCP windows are like a pair of bounded buffers

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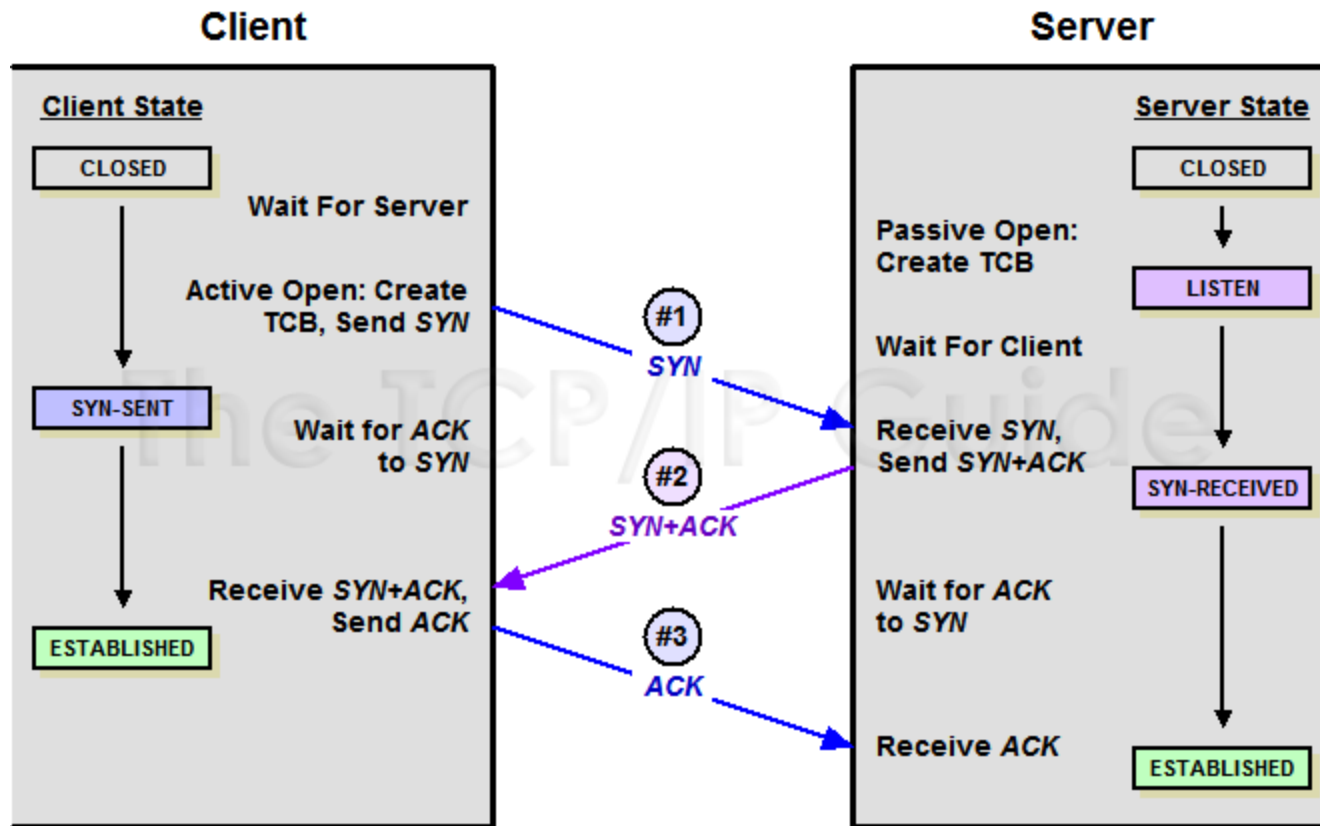
# Sequence numbers established in initial handshake

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- Connection creator (say, A) says to B:
  - ▣ I want to make a connection to you using initial sequence number  $A \rightarrow B$  1234 (a random number)
  - ▣ B replies I will accept your connection using initial sequence number from  $B \rightarrow A$  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

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# Basic TCP-R idea

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- 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

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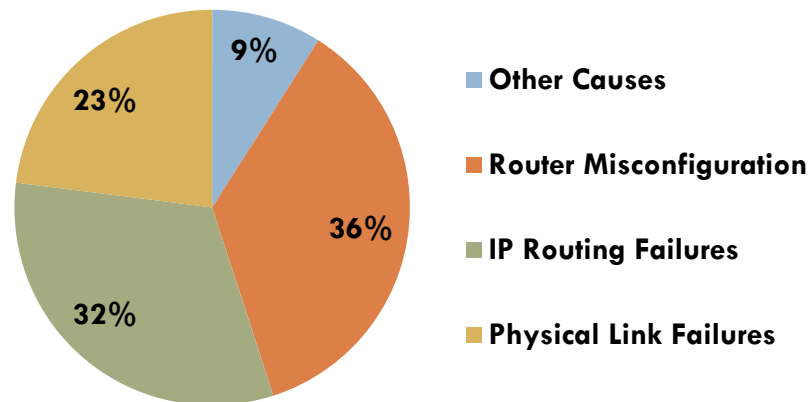
- FT-BGP has a bit more work to do
  - ▣ Old BGP just accepted updates and processed them
  - ▣ FT-BGP must log any updates it sends or receives before TCP acknowledges the incoming update, or sends the outgoing one
  - ▣ FT-BGP must also complete any receive or send that was disrupted by the failover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



# Thus we've made our router more available

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- Goal was to improve on the 2004 situation:



Source: University of Michigan and Sprint, October 2004

- ... 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?

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- 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?

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- 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...

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- Ideas include:
  - ▣ Better control over routing within entire regions
  - ▣ Some way to support end-to-end “circuits” with pre-authentication between sender and receiver
  - ▣ 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



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- 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



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- 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?

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- 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

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- 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



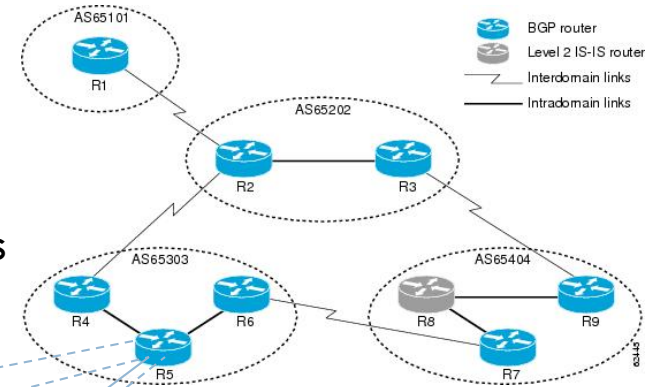
# A secured network

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

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

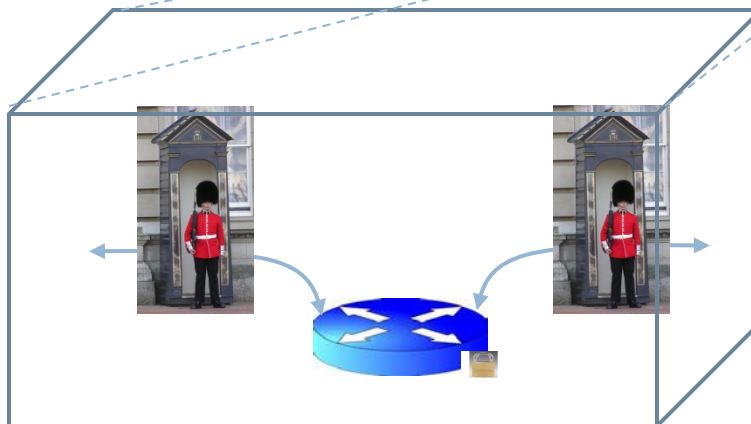
A securely replicated command



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

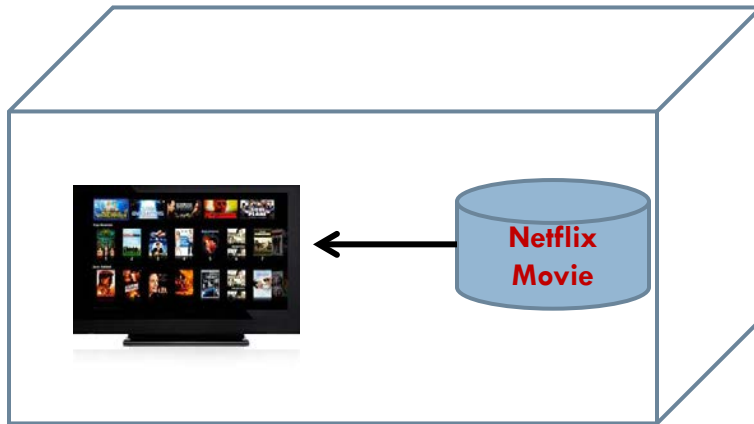
A monitored router can only behave in ways the policy permits

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



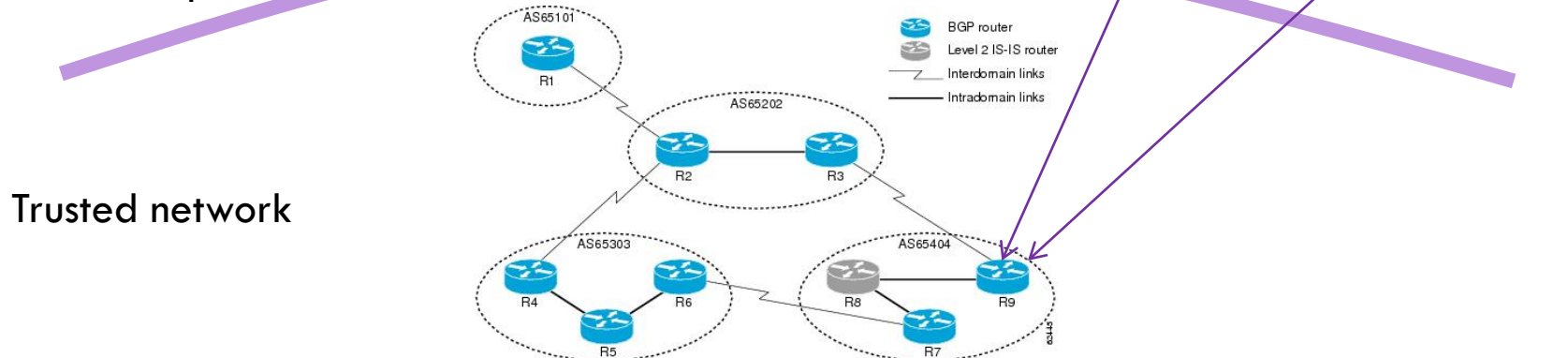
# Hosting a SuperNet on a SecureNet

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

- 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)



# Software Defined Networking: SDN

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- As of today, SDN is the closest thing we have to this vision of a secured and managed network
- SDN uses a controller (like our admiral) to make the decisions. Then the individual components are controlled by commands to update routing tables
- But it hasn't had an easy adoption curve and in fact we've already seen two generations of standards (first OpenFlow, and now P4). Nate Foster's "stuff"

# Conclusions?

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- 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.