Routing in the Future Internet

Marcelo Yannuzzi

Graduate Course (Slideset 1)

Institute of Computer Science

University of the Republic (UdelaR)

August 20th 2012, Montevideo, Uruguay

Department of Computer Architecture
Technical University of Catalonia (UPC), Spain

Institute of Computer Science
University of the Republic (UdelaR), Uruguay

Outline

1. Preamble (Administrative issues)
2. The Internet's architectural organization in domains or Autonomous Systems (ASs)

Outline

1. **Preamble (Administrative issues)**
2. The Internet's architectural organization in domains or Autonomous Systems (ASs)

The basics

Administrative Issues

Professors:

- Marcelo Yannuzzi (CRAAX, Spain, **yannuzzi@ac.upc.edu**)
- Carlos Martínez (LACNIC, UdelaR, **carlosm@fing.edu.uy**)

Local Responsible:

- Eduardo Grampín (UdelaR, **grampin@fing.edu.uy**)

Administrative Issues (cont.)

Course Duration:

- 27 hs in 9 sessions during 3 weeks
- 3 regular sessions per week, each lasting 3 hs (Mon., Wed., and Fri.)

Course Credits and Evaluation

- 4 credits (i.e., 60 hs of dedication)
  - 27 hs (Theory)
  - 6 hs (Professor's office hours)
  - 12 hs (Studing and homework)
  - 15 hs (Final work)

Contents

Contents: 3 blocks

1) Understanding the Internet's Routing Architecture

- Session 1
- Session 2

2) Advanced Routing Aspects

- Session 3
- Session 4
- Session 5
- Session 6

3) Future Internet Routing

- Session 7
- Session 8
- Session 9

Session details: Block 1

Session 1 (Monday, August 20th):
1) Understanding the Internet's Routing Architecture

Session details: Block 1

Session 1 (Monday, August 20th):
1) Understanding the Internet's Routing Architecture

1. Data Plane: a look inside a carrier-grade network, multi-layer aspects, OTN, carrier-grade Ethernet, IP/MPLS,...

Session details: Block 1

Session 1 (Monday, August 20th):
1) Understanding the Internet's Routing Architecture

1. Data Plane: a look inside a carrier-grade network, multi-layer aspects, OTN, carrier-grade Ethernet, IP/MPLS,...
2. Control Plane (mainly routing): including an outline of distance vector, link-state, path vectors, interactions and dependencies, ...

Session details: Block 1

Session 2 (Wednesday, August 22nd):
1) Understanding the Internet's Routing Architecture

Session details: Block 1

Session 2 (Wednesday, August 22nd): 1) Understanding the Internet's Routing Architecture

1. Management Plane: current trends in terms of IP/OTN network operations and coordinated management, etc.

Session details: Block 1

Session 2 (Wednesday, August 22nd): 1) Understanding the Internet's Routing Architecture

1. Management Plane: current trends in terms of IP/OTN network operations and coordinated management, etc.
2. The myths: scale free graphs, power laws, interconnection of ASs, tiered structure, valley-free policies, invariant metrics, ...

Session details: Block 1

Session 2 (Wednesday, August 22nd): 1) Understanding the Internet's Routing Architecture

1. Management Plane: current trends in terms of IP/OTN network operations and coordinated management, etc.
2. The myths: scale free graphs, power laws, interconnection of ASs, tiered structure, valley-free policies, invariant metrics, ...
3. **"Demystify me!"**: What do Internet eXchange Points (IXPs) reveal? The tiered "illusion", valley routes and policies, the topology zoo, etc.

Session details: Block 1

Session 2 (Wednesday, August 22nd): 1) Understanding the Internet's Routing Architecture

1. Management Plane: current trends in terms of IP/OTN network operations and coordinated management, etc.
2. The myths: scale free graphs, power laws, interconnection of ASs, tiered structure, valley-free policies, invariant metrics, ...
3. **"Demystify me!"**: What do Internet eXchange Points (IXPs) reveal? The tiered "illusion", valley routes and policies, the topology zoo, etc.
4. Homework assignment (readings that need to be analyzed and turned in by Monday, August 27th).

Session details: Block 2

Session 3 (Friday, August 24th):
2) Advanced Routing Aspects

Session details: Block 2

Session 3 (Friday, August 24th): 2) Advanced Routing Aspects

1. Insights on internal BGP (iBGP), external BGP (eBGP), route reflectors, their interactions, etc.

Session details: Block 2

Session 3 (Friday, August 24th): 2) Advanced Routing Aspects

1. Insights on internal BGP (iBGP), external BGP (eBGP), route reflectors, their interactions, etc.
2. Analysis of the Japanese Earthquake and Tsunami on March 2011.

Session details: Block 2

Session 3 (Friday, August 24th): 2) Advanced Routing Aspects

1. Insights on internal BGP (iBGP), external BGP (eBGP), route reflectors, their interactions, etc.
2. Analysis of the Japanese Earthquake and Tsunami on March 2011.
3. Research Challenges in interdomain routing.

Session details: Block 2

Session 3 (Friday, August 24th): 2) Advanced Routing Aspects

1. Insights on internal BGP (iBGP), external BGP (eBGP), route reflectors, their interactions, etc.
2. Analysis of the Japanese Earthquake and Tsunami on March 2011.
3. Research Challenges in interdomain routing.
   - Outline of the scalability issues.

Session details: Block 2

Session 3 (Friday, August 24th): 2) Advanced Routing Aspects

1. Insights on internal BGP (iBGP), external BGP (eBGP), route reflectors, their interactions, etc.
2. Analysis of the Japanese Earthquake and Tsunami on March 2011.
3. Research Challenges in interdomain routing.
   - Outline of the scalability issues.
   - Traffic Engineering: solutions and research challenges.

Session details: Block 2

Session 3 (Friday, August 24th): 2) Advanced Routing Aspects

1. Insights on internal BGP (iBGP), external BGP (eBGP), route reflectors, their interactions, etc.
2. Analysis of the Japanese Earthquake and Tsunami on March 2011.
3. Research Challenges in interdomain routing.
   - Outline of the scalability issues.
   - Traffic Engineering: solutions and research challenges.
   - Churn and its impact on the DFZ.

Session details: Block 2

Session 3 (Friday, August 24th): 2) Advanced Routing Aspects

1. Insights on internal BGP (iBGP), external BGP (eBGP), route reflectors, their interactions, etc.
2. Analysis of the Japanese Earthquake and Tsunami on March 2011.
3. Research Challenges in interdomain routing.
   - Outline of the scalability issues.
   - Traffic Engineering: solutions and research challenges.
   - Churn and its impact on the DFZ.
   - Routing convergence.

Session details: Block 2

Session 3 (Friday, August 24th): 2) Advanced Routing Aspects

1. Insights on internal BGP (iBGP), external BGP (eBGP), route reflectors, their interactions, etc.
2. Analysis of the Japanese Earthquake and Tsunami on March 2011.
3. Research Challenges in interdomain routing.
   - Outline of the scalability issues.
   - Traffic Engineering: solutions and research challenges.
   - Churn and its impact on the DFZ.
   - Routing convergence.
   - Routing Policies: the stable path problem, policy disputes, etc.

Session details: Block 2

Session 3 (Friday, August 24th): 2) Advanced Routing Aspects

1. Insights on internal BGP (iBGP), external BGP (eBGP), route reflectors, their interactions, etc.
2. Analysis of the Japanese Earthquake and Tsunami on March 2011.
3. Research Challenges in interdomain routing.
   - Outline of the scalability issues.
   - Traffic Engineering: solutions and research challenges.
   - Churn and its impact on the DFZ.
   - Routing convergence.
   - Routing Policies: the stable path problem, policy disputes, etc.
   - Routing Security.

Session details: Block 2

Session 4 (Monday, August 27th):
2) Advanced Routing Aspects

Session details: Block 2

Session 4 (Monday, August 27th): 2) Advanced Routing Aspects

1. Review, analysis, and active discussion of the readings (homework).

Session details: Block 2

Session 4 (Monday, August 27th): 2) Advanced Routing Aspects

1. Review, analysis, and active discussion of the readings (homework).
2. Routing scalability issues: research and industrial perspectives.

Session details: Block 2

Session 4 (Monday, August 27th): 2) Advanced Routing Aspects

1. Review, analysis, and active discussion of the readings (homework).
2. Routing scalability issues: research and industrial perspectives.
3. LISP, its initial goals vs. its current goals and its expected evolution.

Session details: Block 2

Session 4 (Monday, August 27th): 2) Advanced Routing Aspects

1. Review, analysis, and active discussion of the readings (homework).
2. Routing scalability issues: research and industrial perspectives.
3. LISP, its initial goals vs. its current goals and its expected evolution.
4. Routing security: main problems and research challenges.

Session details: Block 2

Session 5 (Wednesday, August 29th):
2) Advanced Routing Aspects

Session details: Block 2

Session 5 (Wednesday, August 29th): 2) Advanced Routing Aspects

1. Routing Security: advances in standardization bodies (IETF).

Session details: Block 2

Session 5 (Wednesday, August 29th):
2) Advanced Routing Aspects

1. Routing Security: advances in standardization bodies (IETF).
2. RPKI.

Session details: Block 2

Session 5 (Wednesday, August 29th):
2) Advanced Routing Aspects

1. Routing Security: advances in standardization bodies (IETF).
2. RPKI.
3. ROA.

Session details: Block 2

Session 5 (Wednesday, August 29th): 2) Advanced Routing Aspects

1. Routing Security: advances in standardization bodies (IETF).
2. RPKI.
3. ROA.
4. Live demo showing origin validation.

Session details: Block 2

Session 5 (Wednesday, August 29th): 2) Advanced Routing Aspects

1. Routing Security: advances in standardization bodies (IETF).
2. RPKI.
3. ROA.
4. Live demo showing origin validation.
5. Homework assignment (readings that need to be analyzed and turned in by Monday, September 3rd).

Session details: Block 2

Session 6 (Friday, August 31st):
2) Advanced Routing Aspects

Session details: Block 2

Session 6 (Friday, August 31st): 2) Advanced Routing Aspects

1. Routing Security: BGPSEC, its paradigm, new challenges and unsolved problems, research lines of work, etc.

Session details: Block 2

Session 6 (Friday, August 31st): 2) Advanced Routing Aspects

1. Routing Security: BGPSEC, its paradigm, new challenges and unsolved problems, research lines of work, etc.
2. LISP Security: LISP-SEC.

Session details: Block 2

Session 6 (Friday, August 31st): 2) Advanced Routing Aspects

1. Routing Security: BGPSEC, its paradigm, new challenges and unsolved problems, research lines of work, etc.
2. LISP Security: LISP-SEC.
3. The gap between BGPSEC and LISP-SEC

Session details: Block 3

Session 7 (Monday, September 3rd):
3) Future Internet Routing

Session details: Block 3

Session 7 (Monday, September 3rd): 3) Future Internet Routing

1. Review, analysis, and active discussion of the readings (homework).

Session details: Block 3

Session 7 (Monday, September 3rd): 3) Future Internet Routing

1. Review, analysis, and active discussion of the readings (homework).
2. Path-State Vectors (PSVs).

Session details: Block 3

Session 8 (Wednesday, September 5th):
3) Future Internet Routing

Session details: Block 3

Session 8 (Wednesday, September 5th): 3) Future Internet Routing

1. Path-State Vectors (PSVs) and overlays.

Session details: Block 3

Session 8 (Wednesday, September 5th): 3) Future Internet Routing

1. Path-State Vectors (PSVs) and overlays.
2. Large scale (event-driven) simulations.

Session details: Block 3

Session 9 (Friday, September 7th):
3) Future Internet Routing

Session details: Block 3

Session 9 (Friday, September 7th): 3) Future Internet Routing

1. The spectrum of possibilities brought by Software Defined Networks (SDNs).

Session details: Block 3

Session 9 (Friday, September 7th): 3) Future Internet Routing

1. The spectrum of possibilities brought by Software Defined Networks (SDNs).
2. Open APIs, OpenFlow, JUNOS SDK, Cisco ONE, the Path-State Protocol (PSP), OPENER, etc.

Session details: Block 3

Session 9 (Friday, September 7th): 3) Future Internet Routing

1. The spectrum of possibilities brought by Software Defined Networks (SDNs).
2. Open APIs, OpenFlow, JUNOS SDK, Cisco ONE, the Path-State Protocol (PSP), OPENER, etc.
3. Outsourcing to the Cloud and its impact on routing, etc.

Session details: Block 3

Session 9 (Friday, September 7th): 3) Future Internet Routing

1. The spectrum of possibilities brought by Software Defined Networks (SDNs).
2. Open APIs, OpenFlow, JUNOS SDK, Cisco ONE, the Path-State Protocol (PSP), OPENER, etc.
3. Outsourcing to the Cloud and its impact on routing, etc.
4. Assignment of final works for course approval.

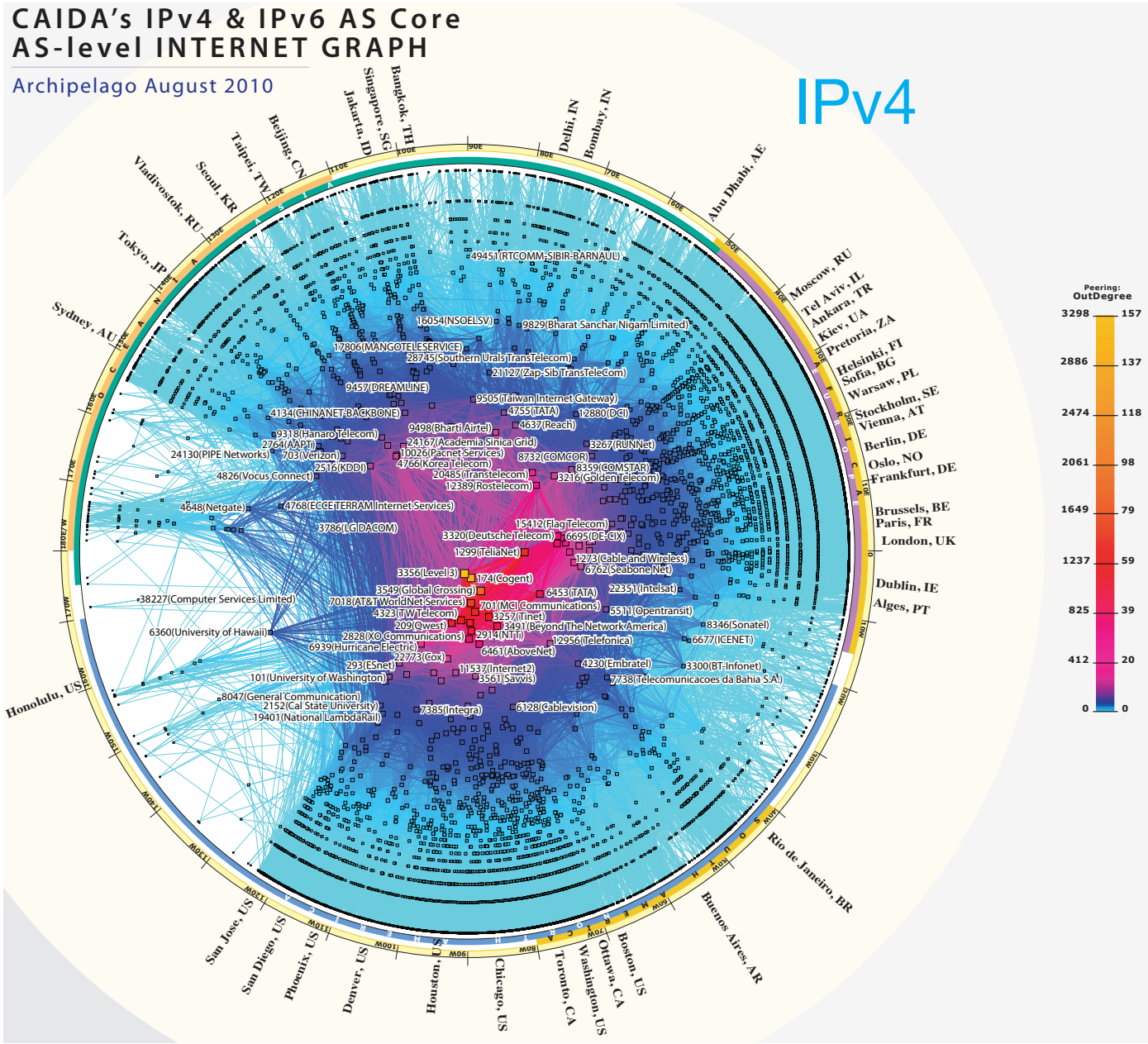
Bibliography

- Internet Routing Architectures, Second Edition, Sam Halabi Danny McPherson, Publisher: Cisco Press Second Edition August 23, 2000 ISBN: 1-57870-233-X, 528 pages.
- BGP Design and Implementation, Randy Zhang, Micah Bartell, Published by: Cisco Press ISBN: 1-58705-109-5
- Plus a list of specific references that shall be provided during the course.

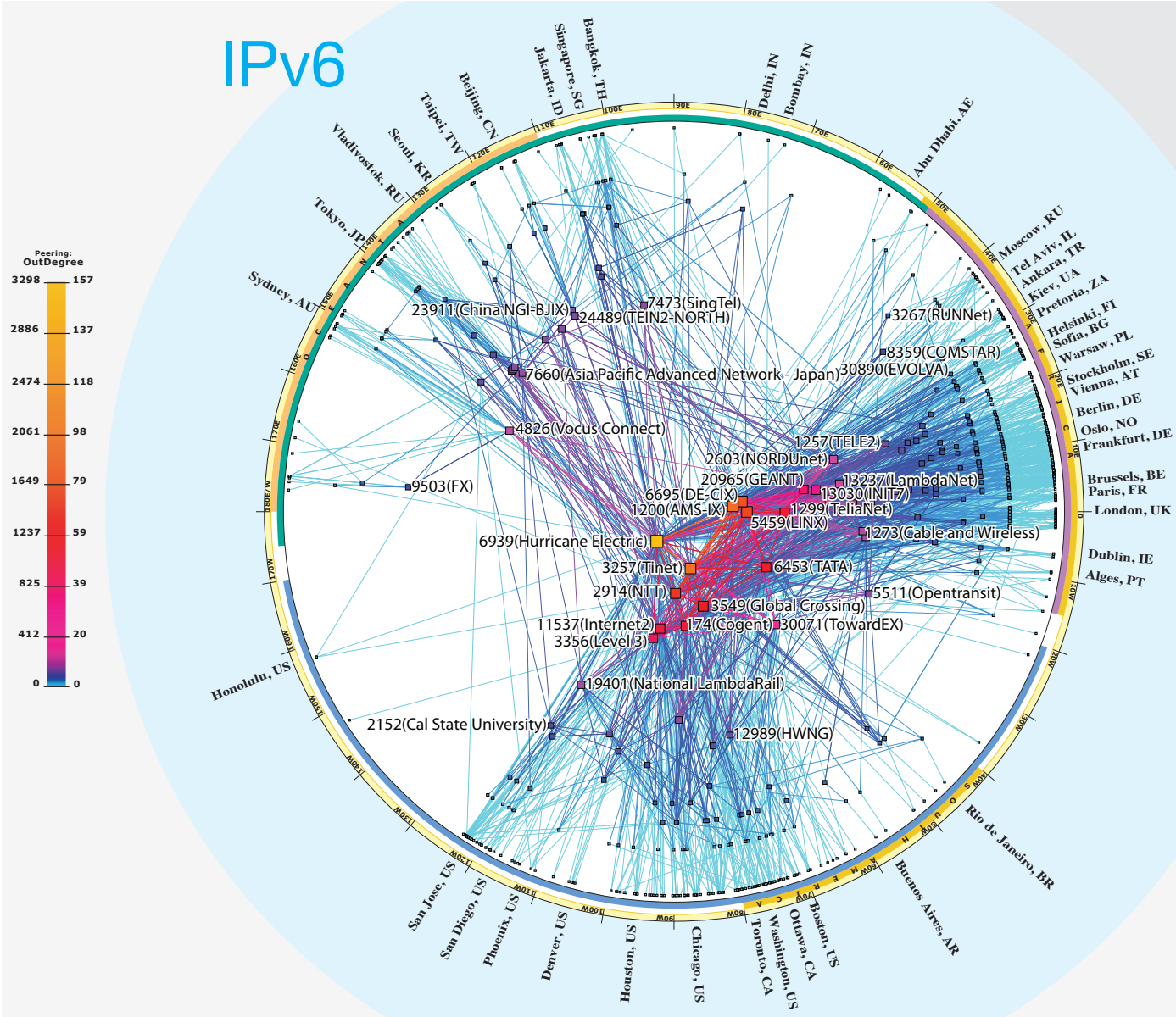
Outline

1. Preamble (Administrative issues)
2. **The Internet's architectural organization in domains or Autonomous Systems (ASs)**

The Internet's map (source: CAIDA)



The Internet's map (source: CAIDA)



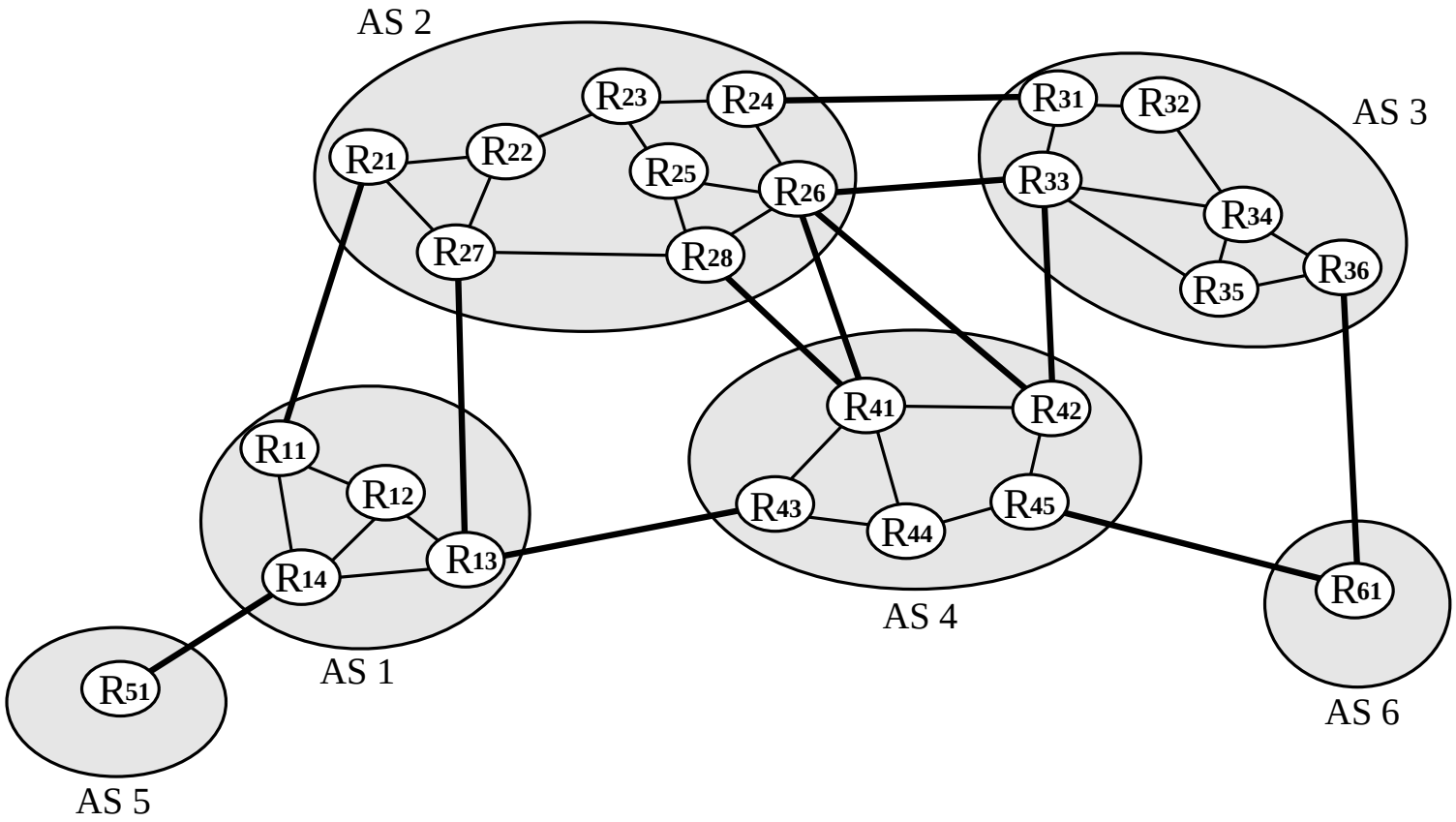
Basic Background: Autonomous Systems (ASs)

- The Internet is a decentralized collection of networks, grouped and interconnected in the form of domains or Autonomous Systems (ASs).

Strength: distributed & independent management of the routing

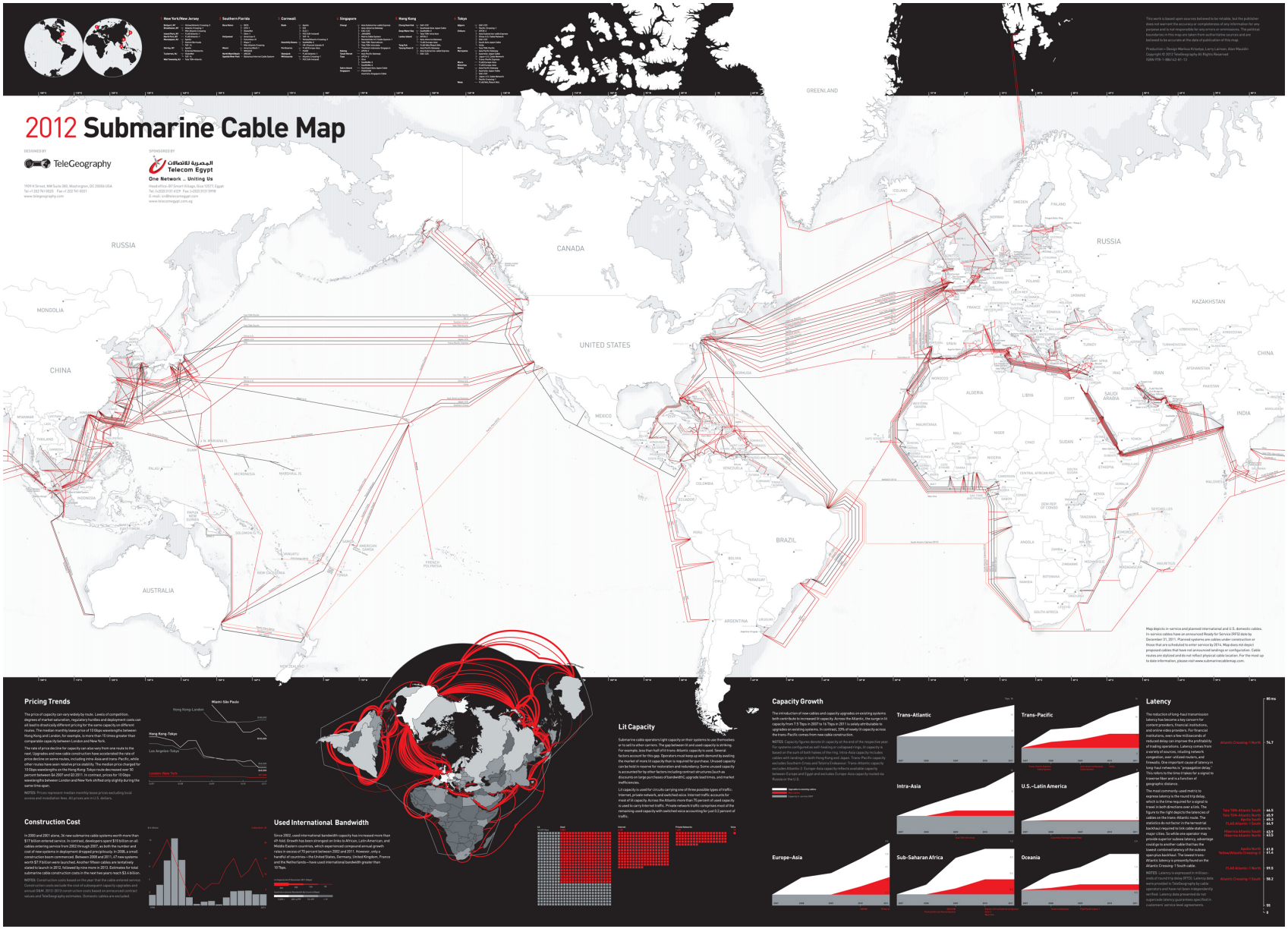
- An AS typically represents a pool of networks (routers, links, hosts, ...) managed by a single authority, and under a common routing policy.
- The Internet is composed of around 40.000 ASs as August of 2012.
- Each AS uses one or more Interior Gateway Protocols (IGPs) for routing within the AS.
- IGP information must not leak outside the AS $\rightarrow$ in terms of routing an AS is seen as a black box

Interconnection of Autonomous Systems



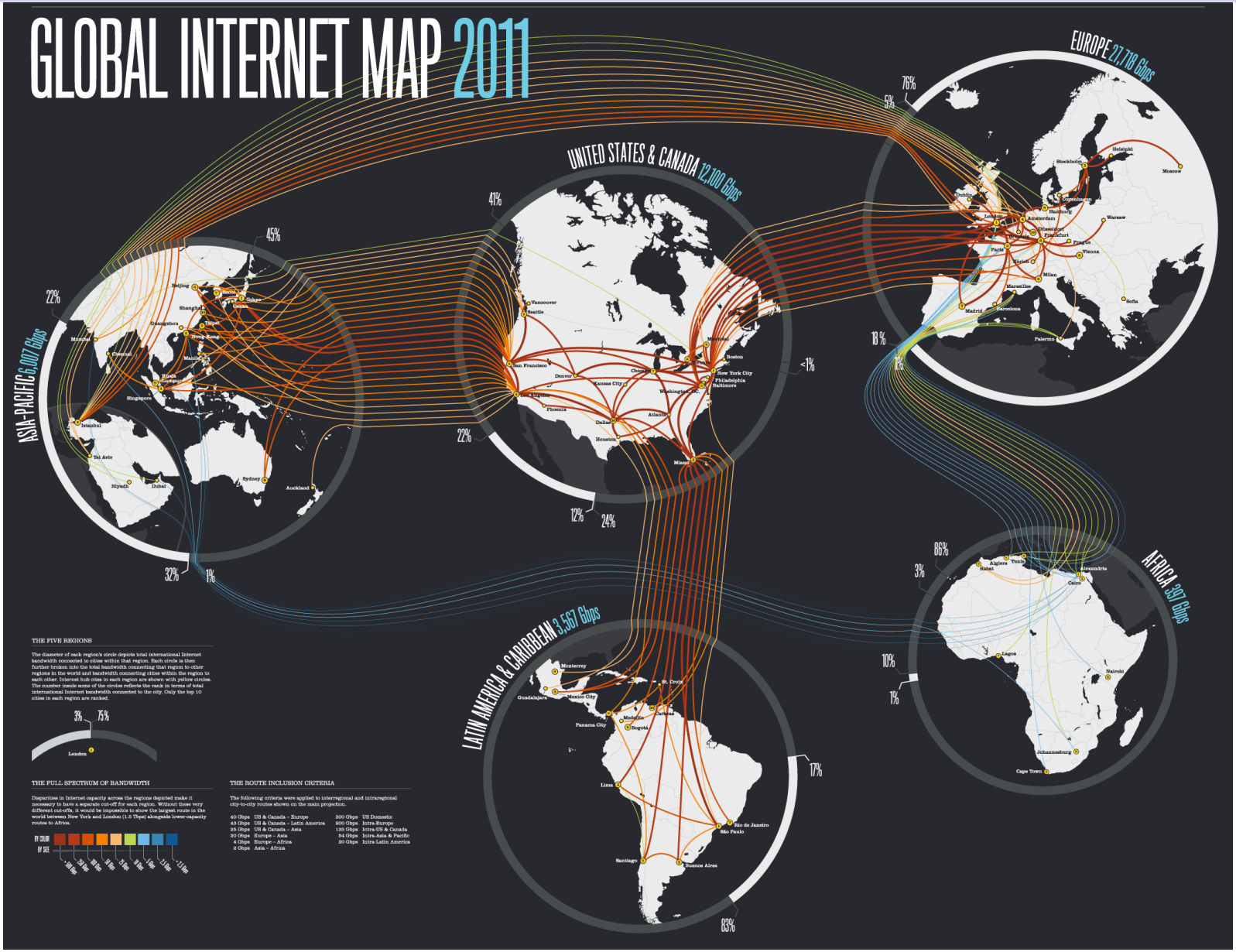
- Source: B. Quoitin, S. Uhlig, C. Pelsser, L. Swinnen, and O. Bonaventure, “Interdomain Traffic Engineering with BGP,” IEEE Communications Magazine, Vol. 41, Issue 5, May 2003.

Submarine cable map 2012



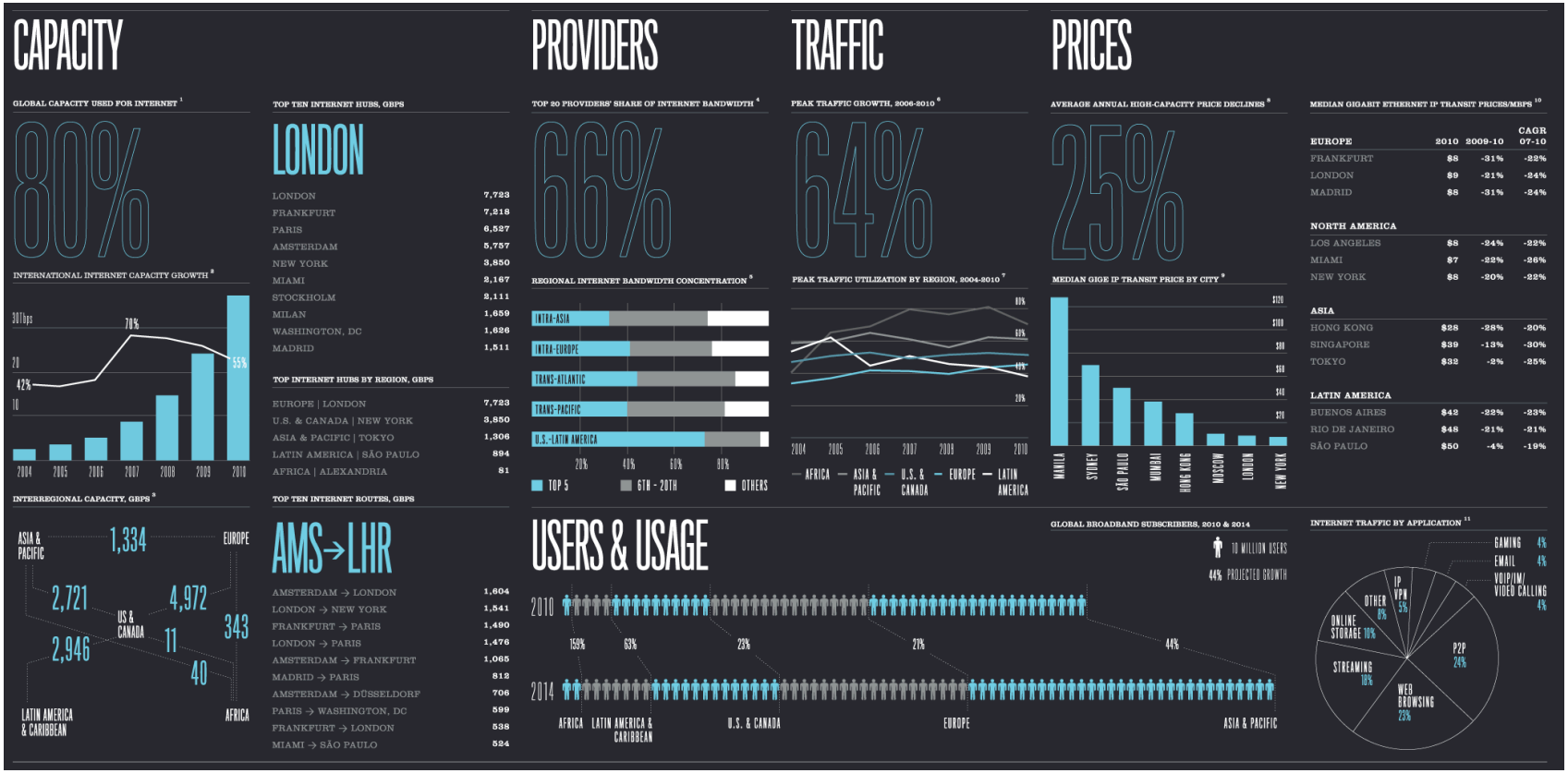
Source: TeleGeography

Virtual interconnection map 2011



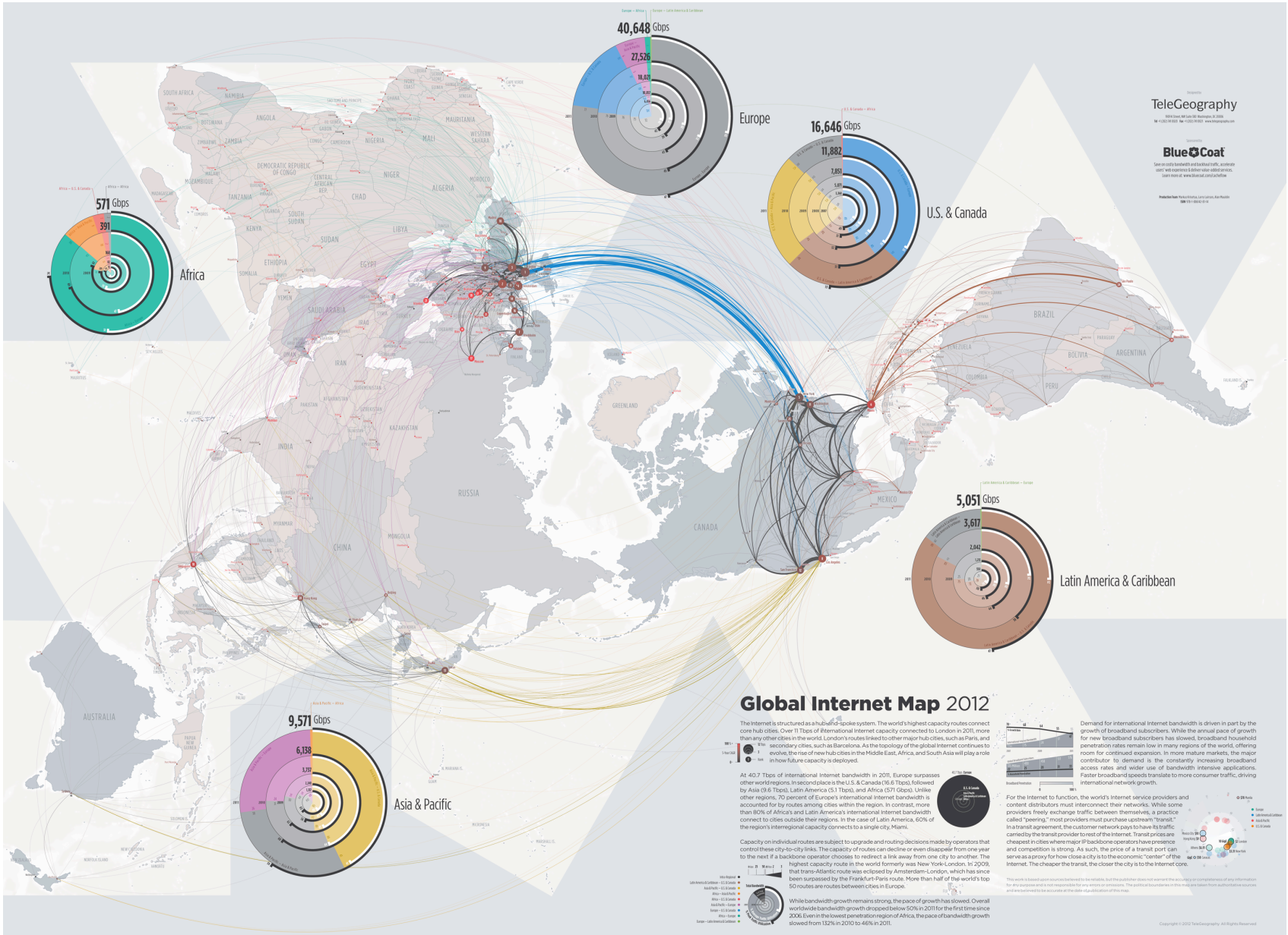
- Source: TeleGeography

Virtual interconnection map 2011



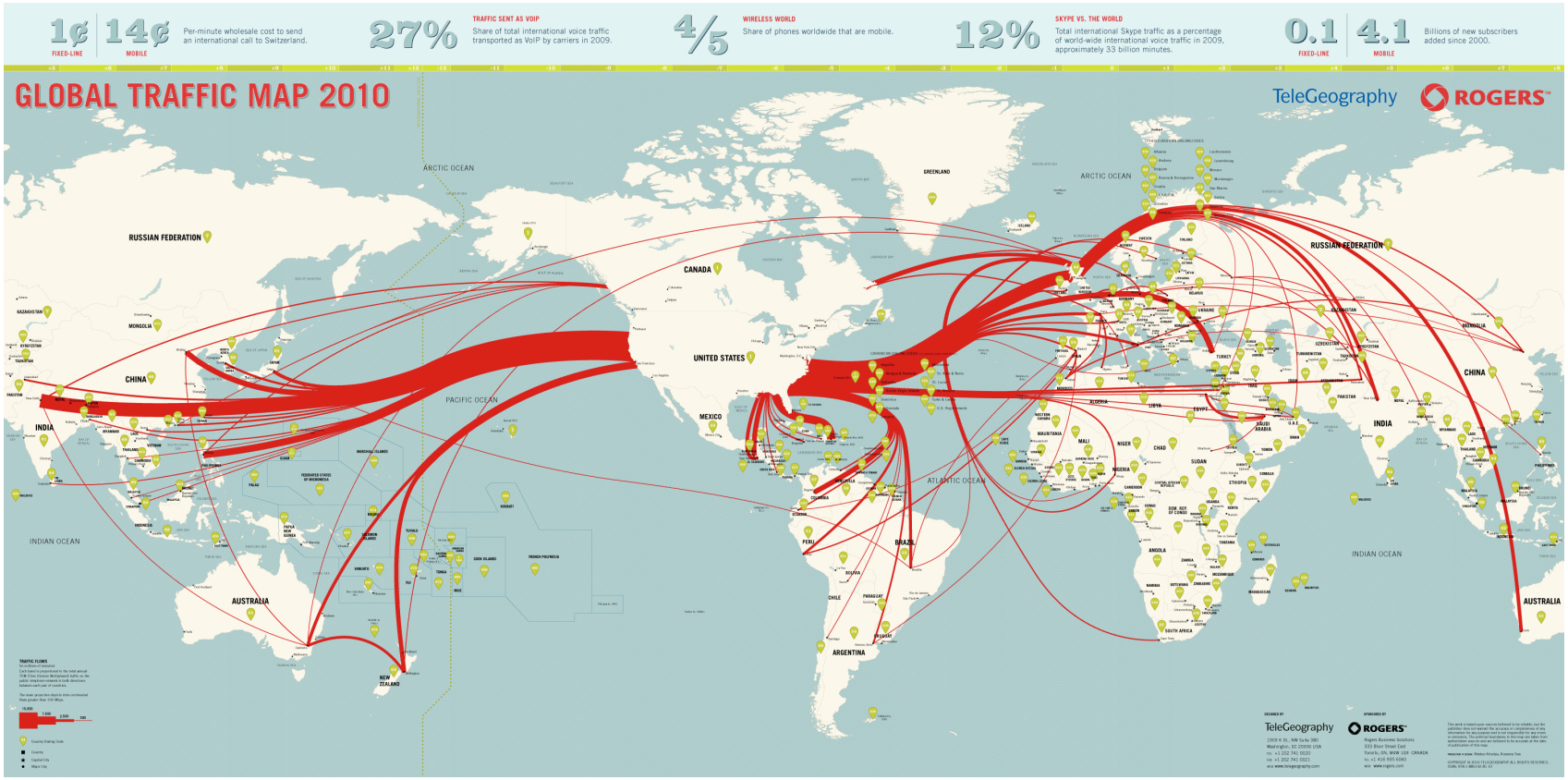
- Source: TeleGeography

Virtual interconnection map 2012



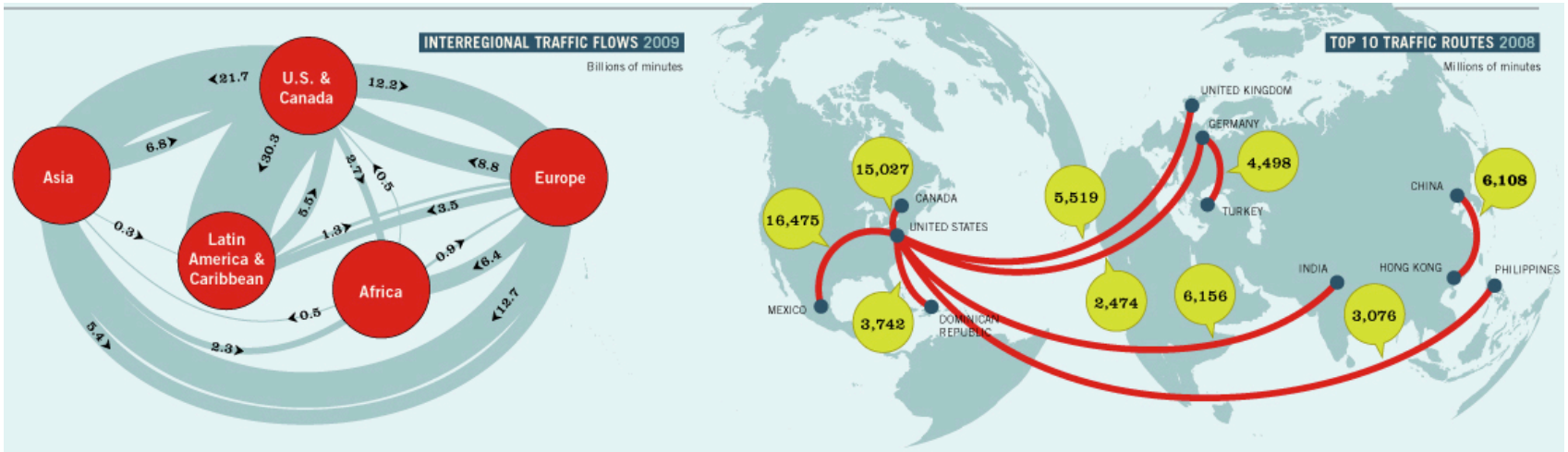
- Source: TeleGeography

Global VoIP traffic map 2010



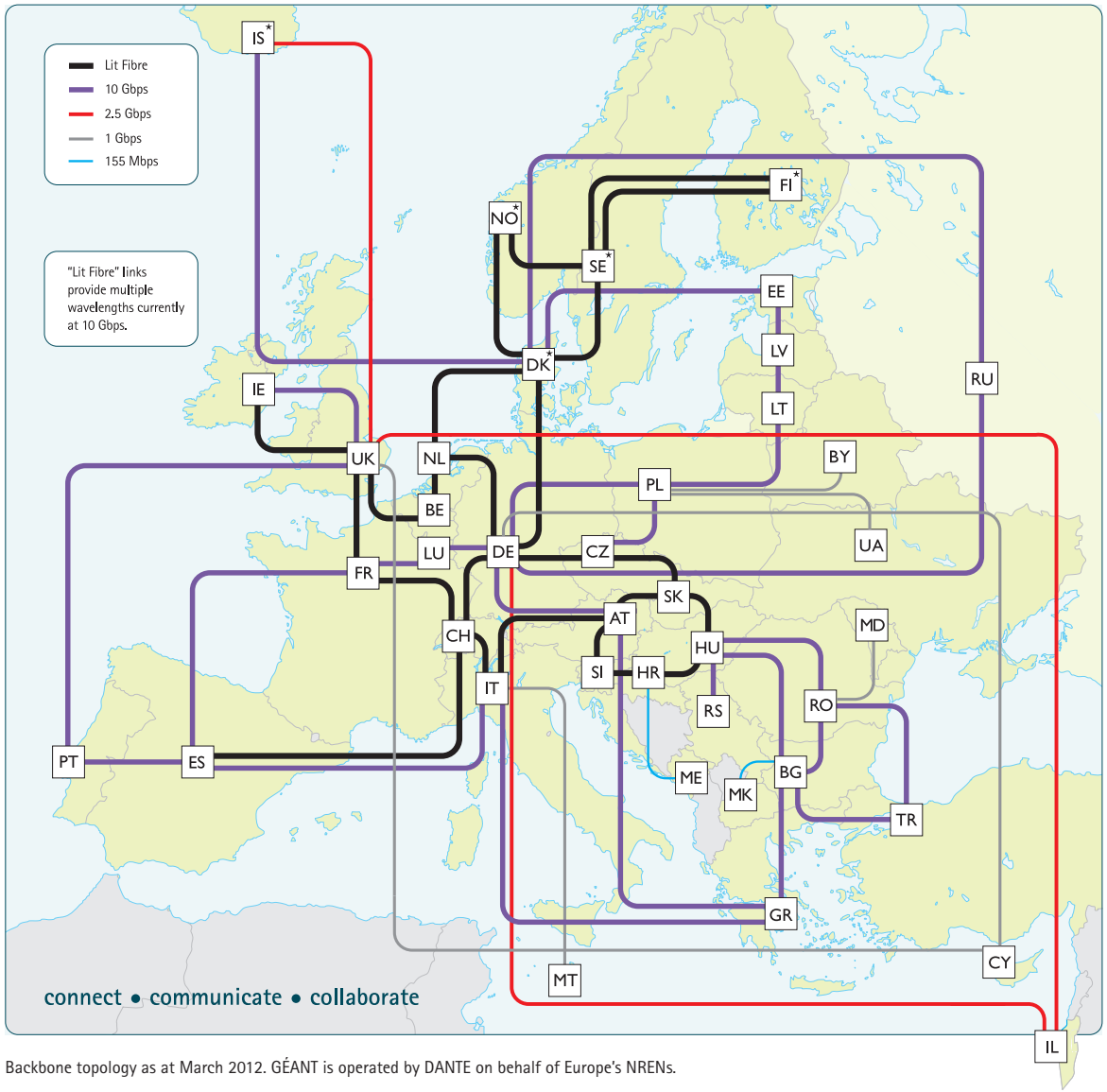
- Source: TeleGeography

Main VoIP traffic routes 2008/2009



- Source: TeleGeography

European Research Network Topology



Backbone topology as at March 2012. GÉANT is operated by DANTE on behalf of Europe's NRENs.