A Comparative Analysis of the IPv6 Inter-Domain Routing in European Countries

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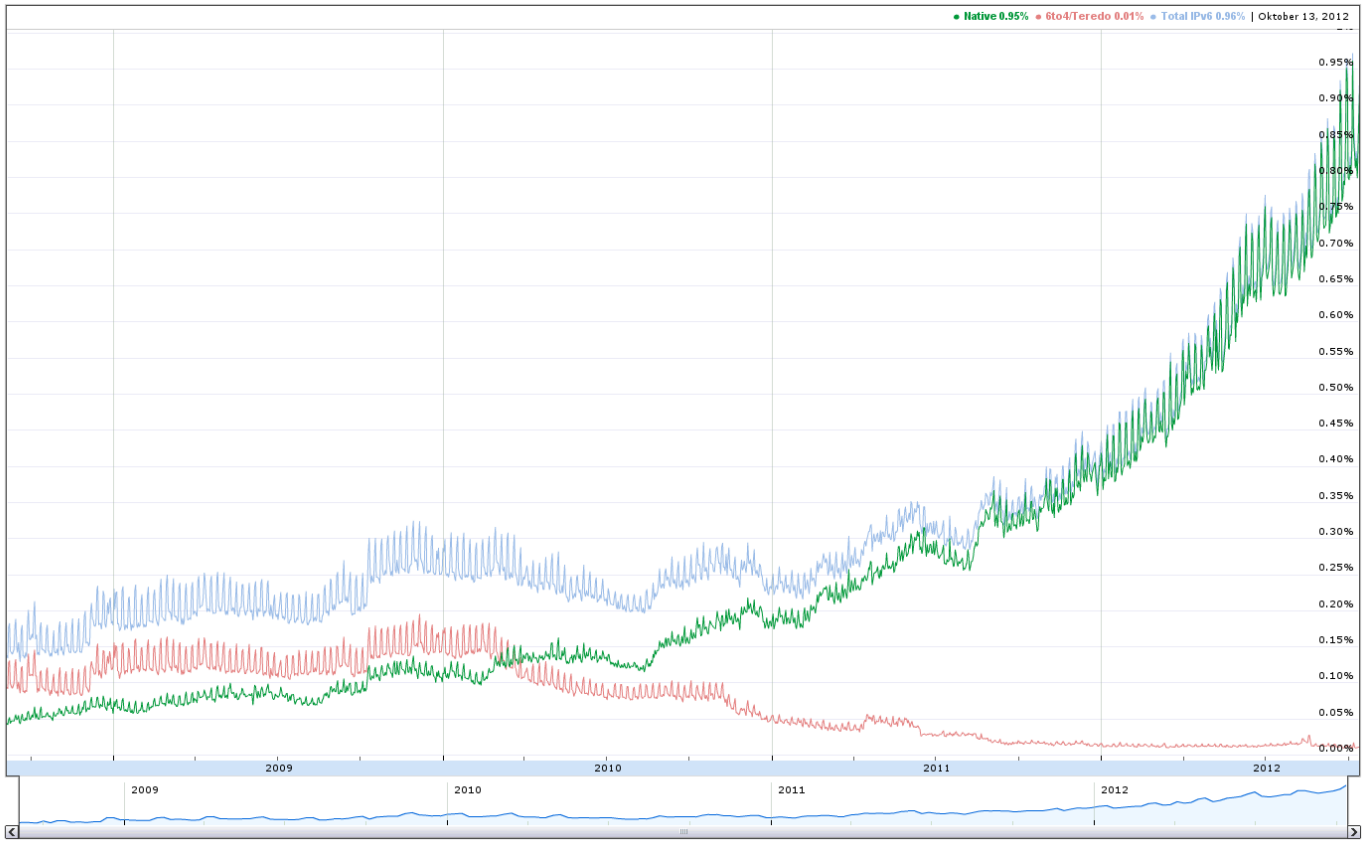
Outline

- Motivation
- Measuring IPv6 deployment
- Methodology
- Results & discussion
- Conclusion & outlook

Motivation

IPv6 is gaining momentum

Users at Google [1]



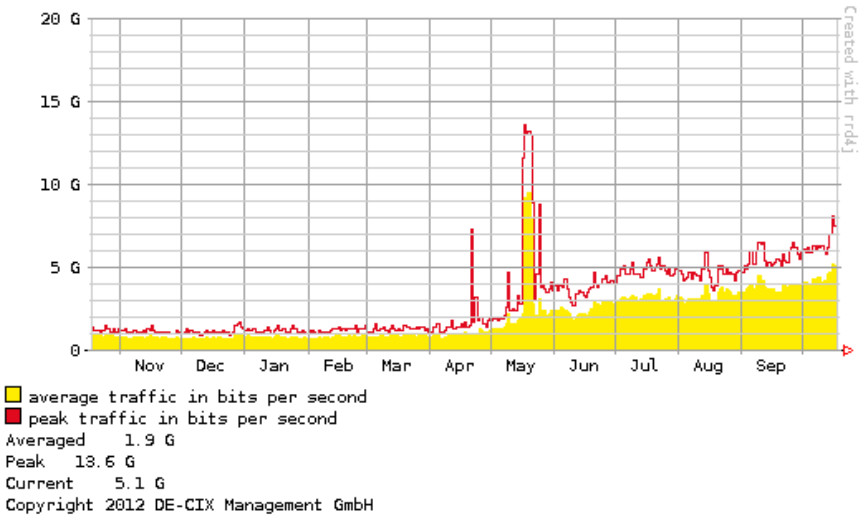
[1] http://www.google.com/ipv6/statistics.html

Motivation

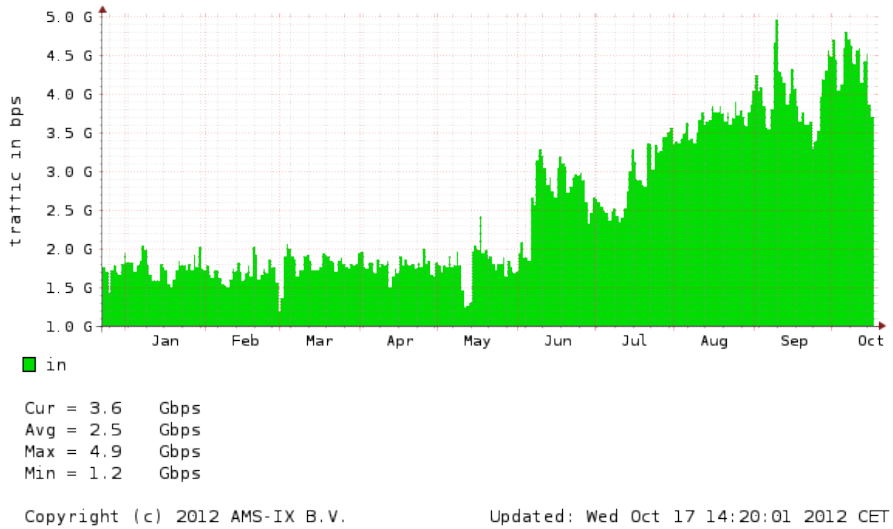
IPv6 is gaining momentum

Traffic at IXPs [2] [3]

DE-CIX



AMS-IX



Why?

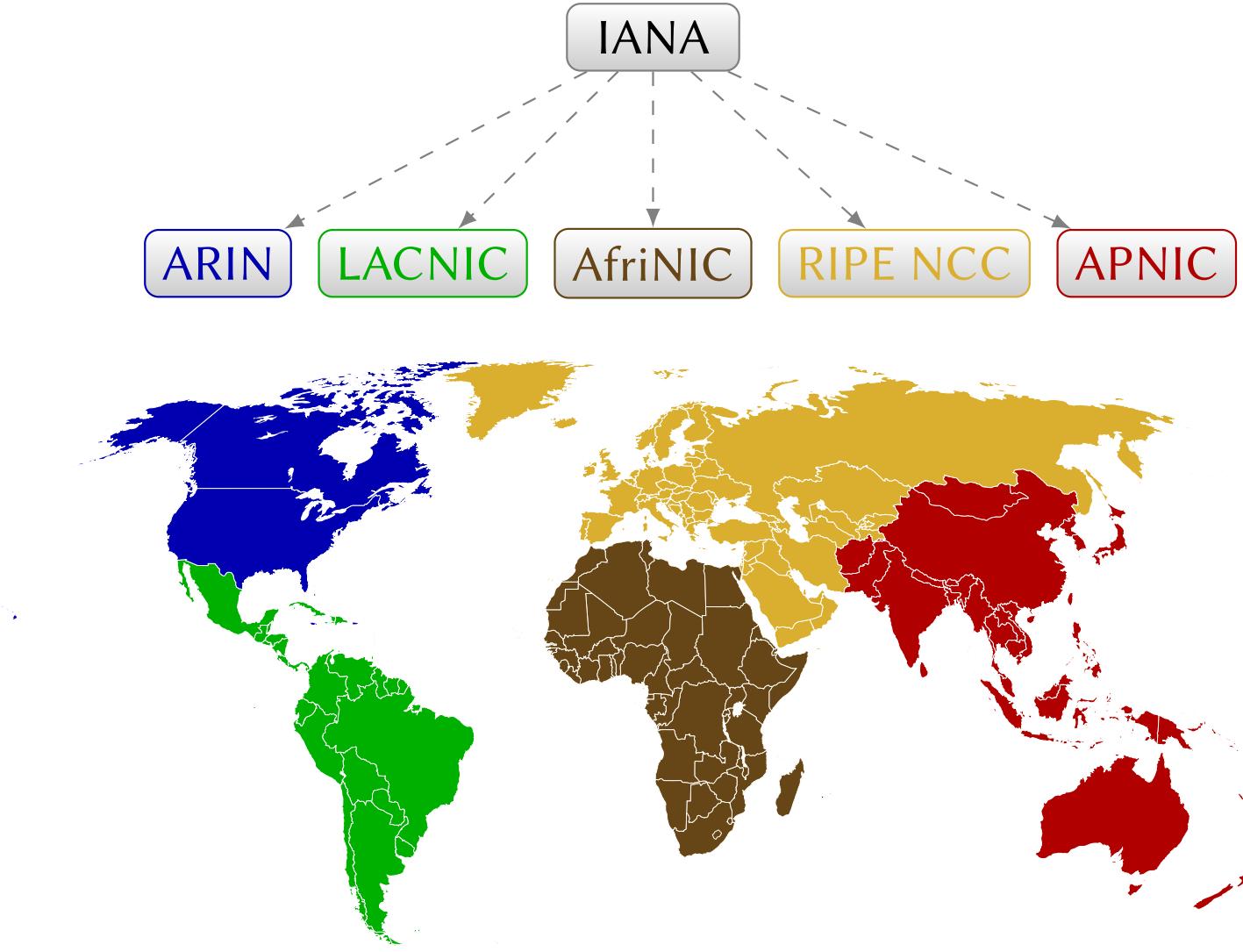
[2] http://www.de-cix.net/about/statistics/

[3] https://www.ams-ix.net/technical/statistics/sflow-stats/ipv6-traffic

Where do
Internet addresses
come from?

Regional Internet registries

Origin of IP adresses



IPv4 address exhaustion

Reaching the last /8 block

/8 block $\approx 16 \times 10^6$ IP addresses

- February 3, 2011 ▷ IANA delegates the last /8 blocks to RIRs
- April 15, 2011 ▷ APNIC reaches the final /8 block
- September 14, 2012 ▷ RIPE reaches the final /8 block

Last block allocation policy: /22 (1024 IP addresses)

The definitive solution:

IPv6

How ready is IPv6?

Global IPv6 deployment

Measurement areas

- Hardware and software support — Market surveys
  - Operating systems, web browsers, end-user applications
  - Network equipment (routers, switches, firewalls, CPEs, ..)
- Traffic
  - IXPs and large ISPs — DE-CIX, AMS-IX, BCIX, ..
  - Content providers — Google, Akamai, Facebook, ..
- Infrastructure
  - Content and services (DNS, email, web, CDNs)
  - Backbone (network links/topology) — Routing

Methodology (1/2)

1. Generate an IPv6 AS-level routing graph [4] — Directed, weighted
2. Using IP-blocks, identify the European ASes [5] — inet6num
3. Generate the routing subgraphs for each European country — Shortest paths
4. For each subgraph compute the distributions of
   - degree
   - distance — Path length in hops
   - clustering

4 Rolf, Winter, *"Modeling the Internet Routing Topology - In Less than 24h"*, 2009

5 Wählisch et al., *"Exposing a Nation-Centric View on the a German Internet -- A Change in Perspective on the AS Level"*, 2012

Methodology (2/2)

5 Rank according to: Ref: EU subgraph

- number of ASes with average degree greater than reference
- the relative number of paths less than $\log(log(\#\text{ASes}))$ Scale-free graph
- global clustering coefficient

The relative maturity index is the sum of the rankings

Results

Heat map of the IPv6 routing maturity

Country	Degree	Rank Distance	Clustering	Maturity Index
HU	3	7	1	11
LU	2	5	11	18
CH	1	10	10	21
RO	4	16	2	22
SK	7	14	9	30

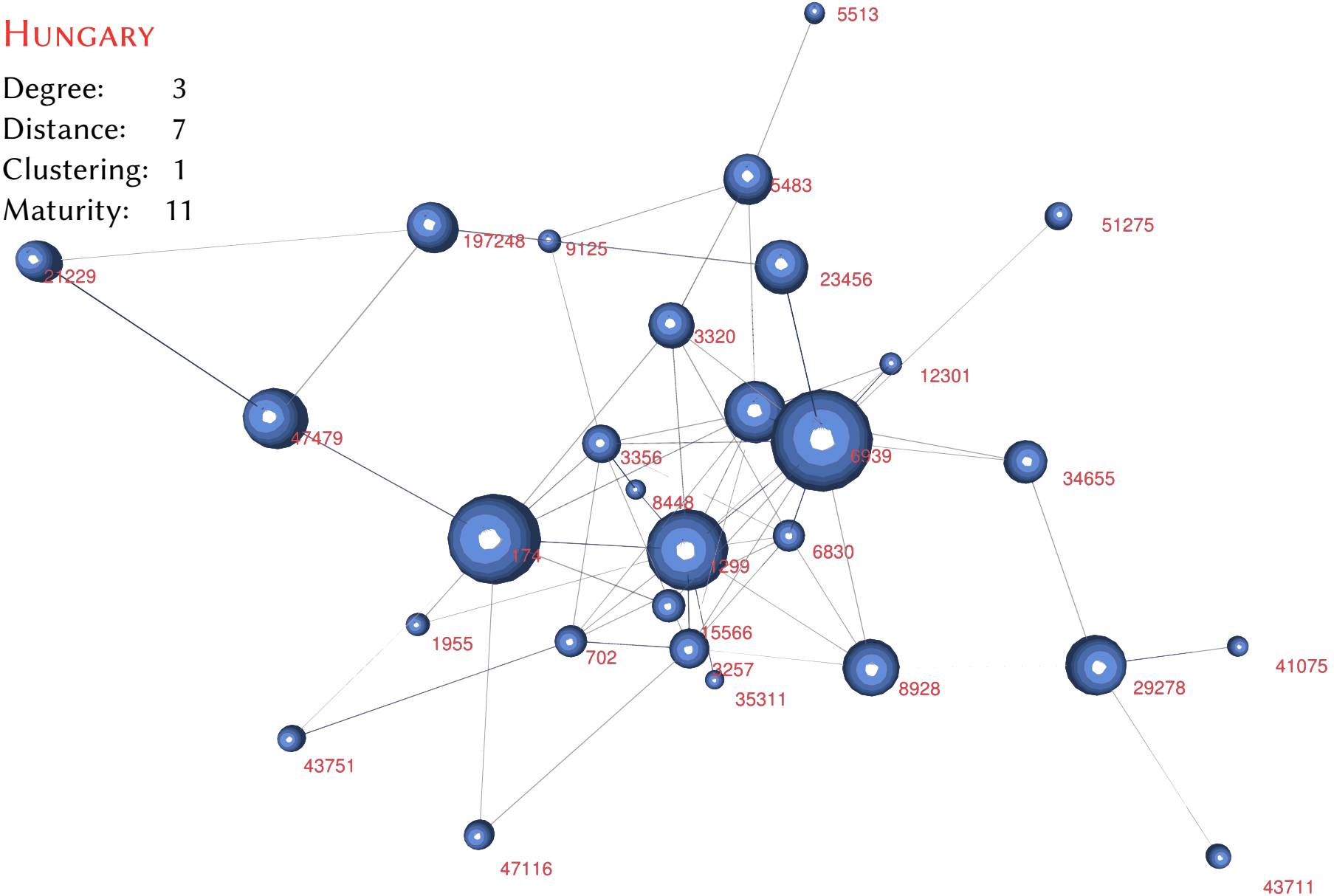
Top-5 ASes sorted by the maturity index

Discussion (1/5)

IPv6 routing graph

Hungary

Degree: 3
Distance: 7
Clustering: 1
Maturity: 11

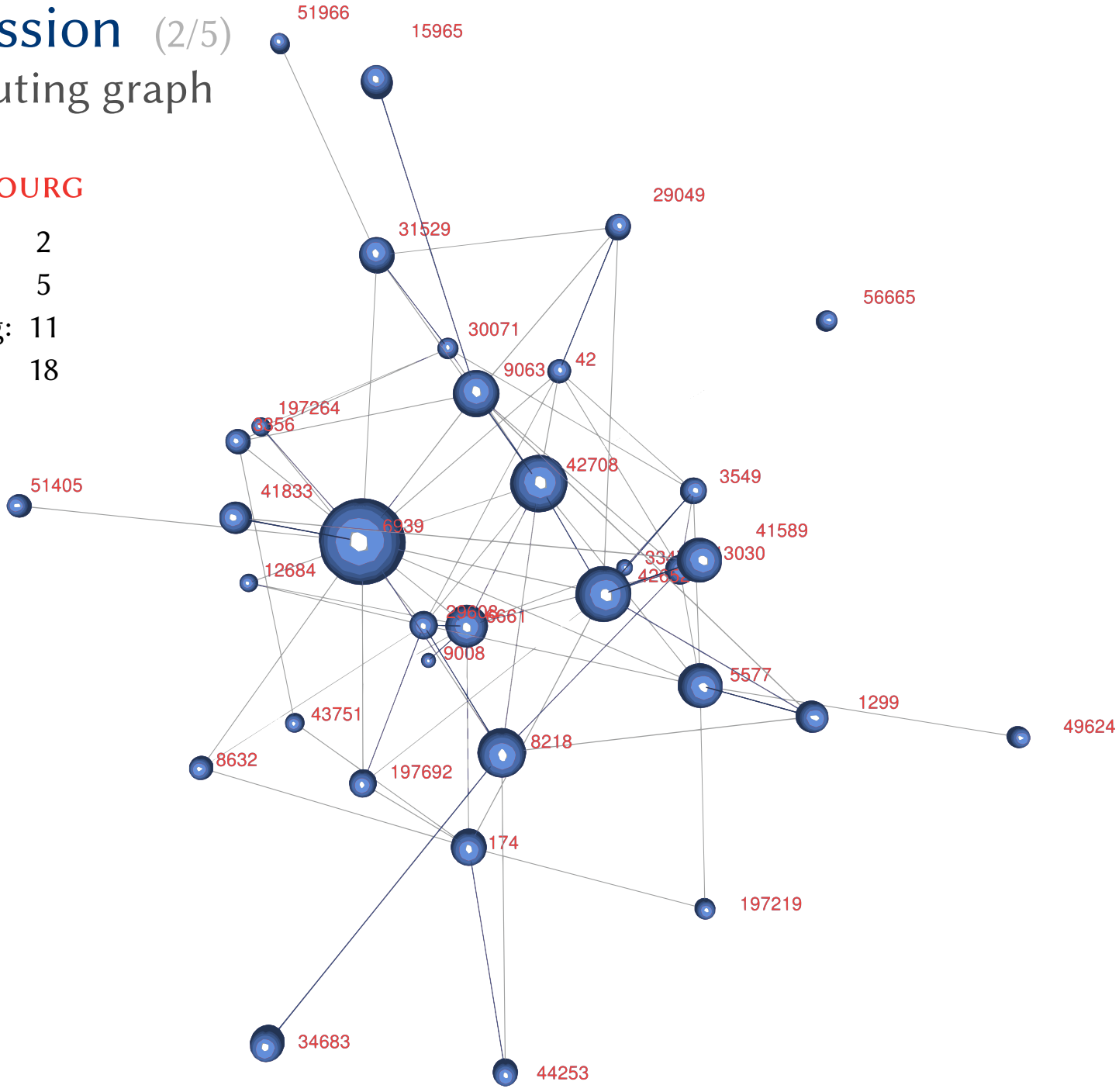


Discussion (2/5)

IPv6 routing graph

Luxembourg

Degree: 2
Distance: 5
Clustering: 11
Maturity: 18

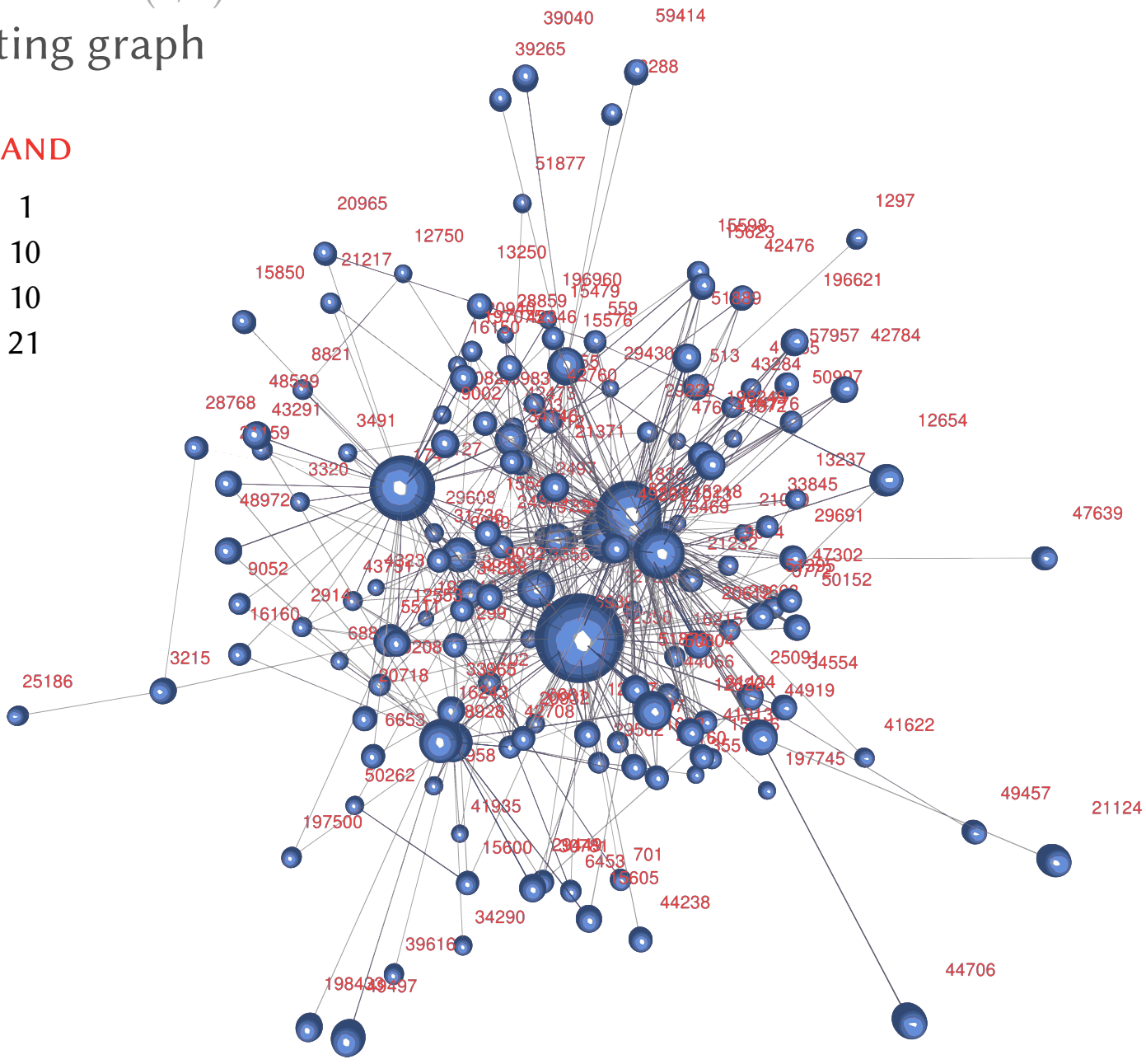


Discussion (3/5)

IPv6 routing graph

Switzerland

Degree: 1
Distance: 10
Clustering: 10
Maturity: 21

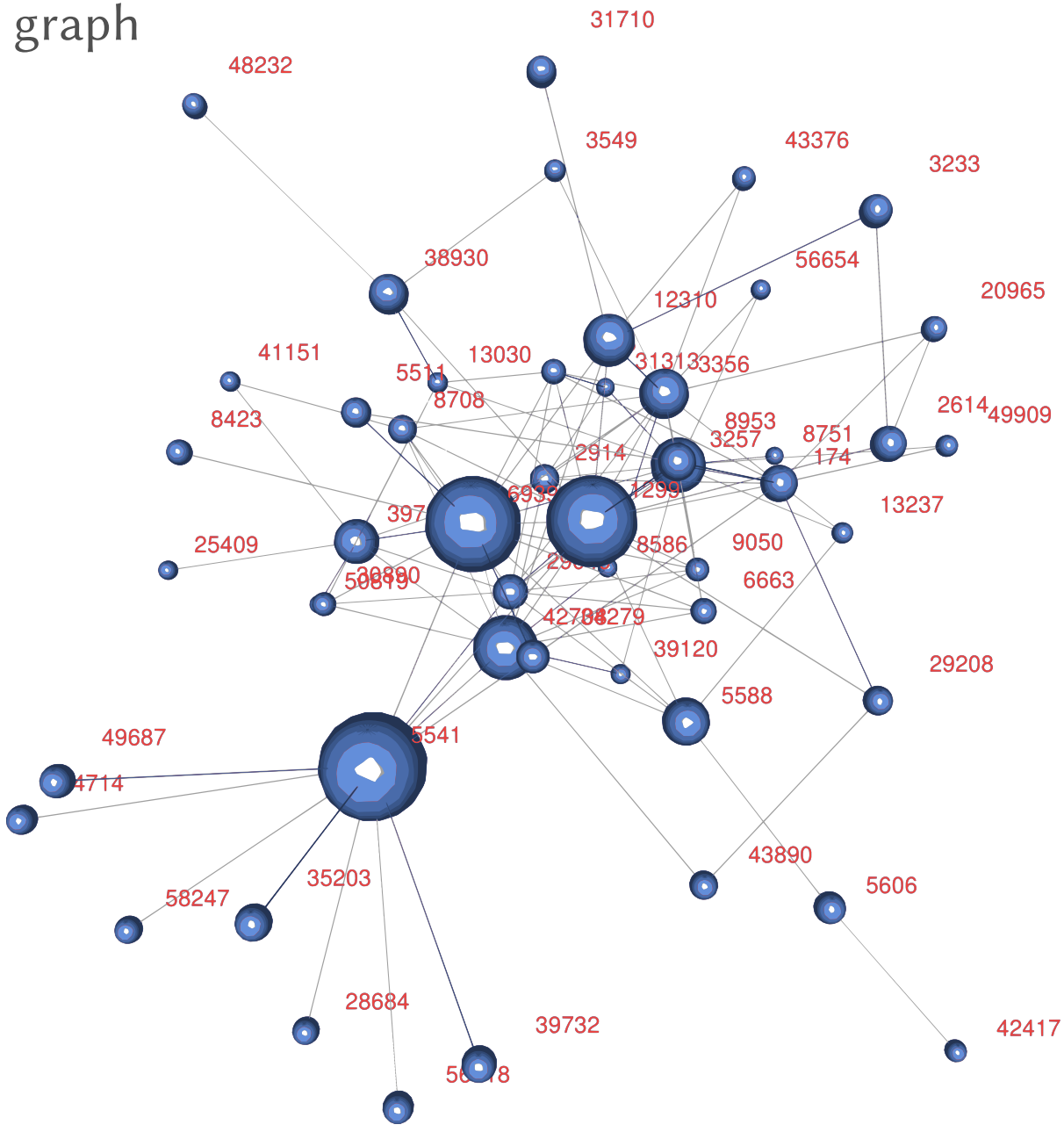


Discussion (4/5)

IPv6 routing graph

Romania

Degree: 4
Distance: 16
Clustering: 2
Maturity: 22

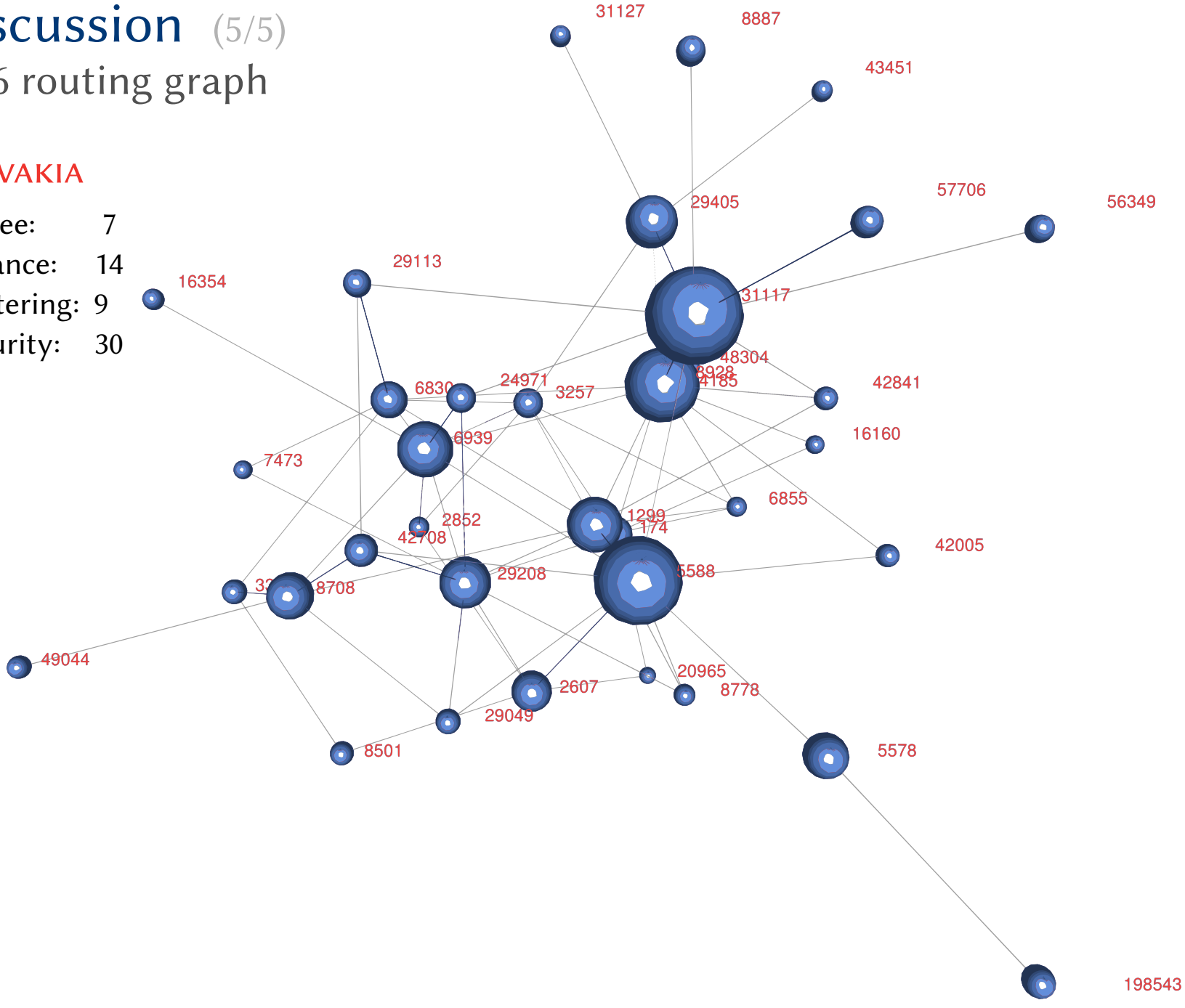


Discussion (5/5)

IPv6 routing graph

Slovakia

Degree: 7
Distance: 14
Clustering: 9
Maturity: 30



Conclusion & outlook

How ready is IPv6 (Inter-domain routing)?

- No final answer, sorry, but ...
- The methodology looks promising, because
  - Catches preparatory activities — Structural analysis
  - Multiple data sources — Public BGP collectors, Whois, third-party

Next steps

- Improve the toolchain
  - Add & aggregate more data sources
  - Broaden the focus — Generic regions
  - Logging & unit testing
- Validity & reliability
  - Operationalization — Construct/model validity
  - Converge & divergence — With other measures
  - Measurement error

- Figure on slide 6 is based on http://en.wikipedia.org/w/index.php?title=File:Regional_Internet_Registries_world_map.svg
- Topology graphs were drawed with igraph[6] and Inkscape[7]

6 http://igraph.sourceforge.net/

7 http://inkscape.org/