INTRIG
INFORMATION & NETWORKING TECHNOLOGIES RESEARCH & INNOVATION GROUP

FEEC
Faculdade de Engenharia Elétrica e de Computação
UNICAMP

SwitchON Workshop
Miami, Jan. 8-9, 2015

SWITCH ON
RESEARCH · COLLABORATION · EDUCATION

Prof. Christian Esteve Rothenberg

Department of Computer Engineering and Industrial Automation (DCA)
Faculty of Electrical and Computer Engineering (FEEC)
University of Campinas (UNICAMP)

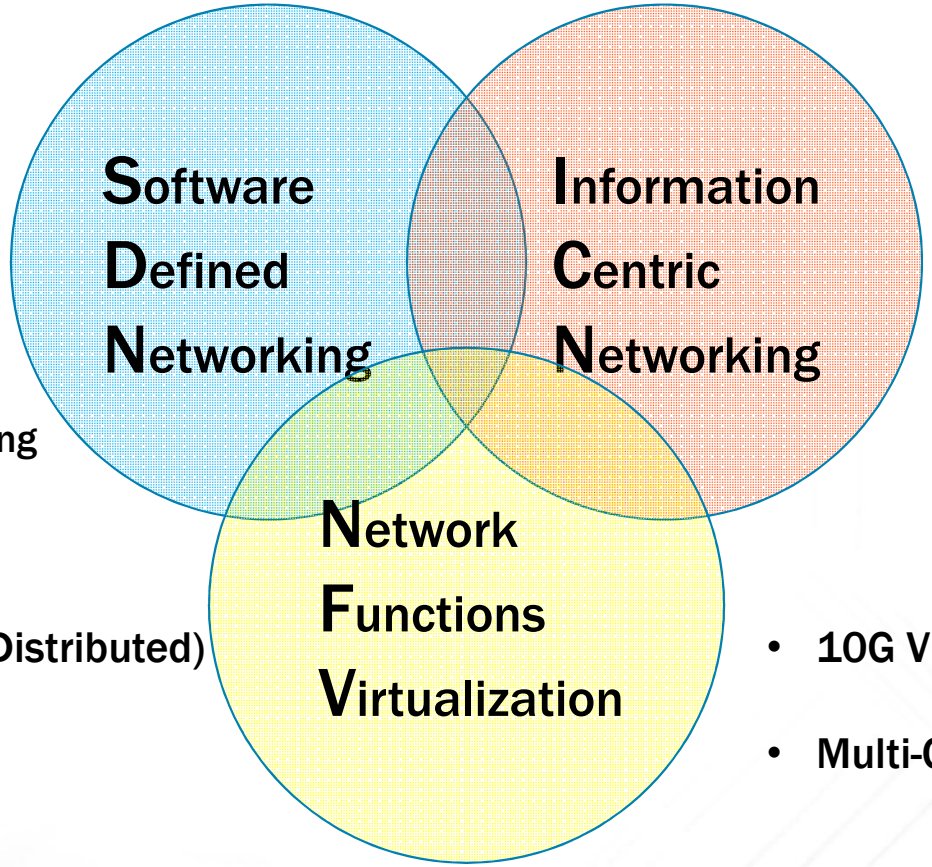
About: Christian Esteve Rothenberg

INTRIG INFORMATION & NETWORKING TECHNOLOGIES RESEARCH & INNOVATION GROUP

- Assistant Professor (tenure track) at FEEC/UNICAMP (since 2013)
  - Leading the INTRIG lab at DCA/FEEC/UNICAMP
    INTRIG: Information & Networking Technologies Research & Innovation Group
  - Currently, supervising 6 PhD, 5 MSc candidates, and 4 undergrad students
- PhD in Electrical and Computer Engineering (FEEC/UNICAMP, 2010),
  MSc in Electrical Eng and Information Technlogy (Darmstadt University, 2006),
  Telecommunication Eng (Universidad Politécnica de Madrid, 2004)
  - Visiting researcher at Ericsson Research Nomadic Lab, Jorvas, Finland, 2008, participated in EU Publish/Subscribe Internet Routing Paradigm (PSIRP).
- Research Scientist at CPqD R&D Center in Telecommunication (2010-2013)
  - Technical Lead of SDN activities in the Converged Networking Division
- ONF Research Associate (since Apr/2013)

Research Interests and Main Goals & Results

- RouteFlow (hybrid IP-SDN)
- softswitch13
- libfluid (ONF Driver)
- SDN-2-SDN Peering



- Mini-CCNx -> Mini-NDNx
- Wireless / Mobility
- LIPSIN (in-packet Bloom filters)

- MD2-NFV (Multi-Domain Distributed)
- VNF-a-a-S

- 10G VNF
- Multi-Core Architectures

Research Projects and Open Source Results

Technical lead of successful open source projects:

- libfluid, winner of the ONF Driver Competition (Mar/2014)
  - http://opennetworkingfoundation.github.io/libfluid/
- softswitch13, first OpenFlow 1.2 and 1.3 soft switch, controller, and testing framework [funded and in technical collaboration with Ericsson] (2011 - 2013)
  - https://github.com/CPqD/ofsoftswitch13
- Mini-CCNx, fast prototyping and experimentation of CCN networks (2013 -)
  - https://github.com/carlosmscabral/mn-ccnx
- RouteFlow, first IP routing architecture for SDN (2010 -)
  - https://github.com/routeflow/

(Selected) Publications related to SDN

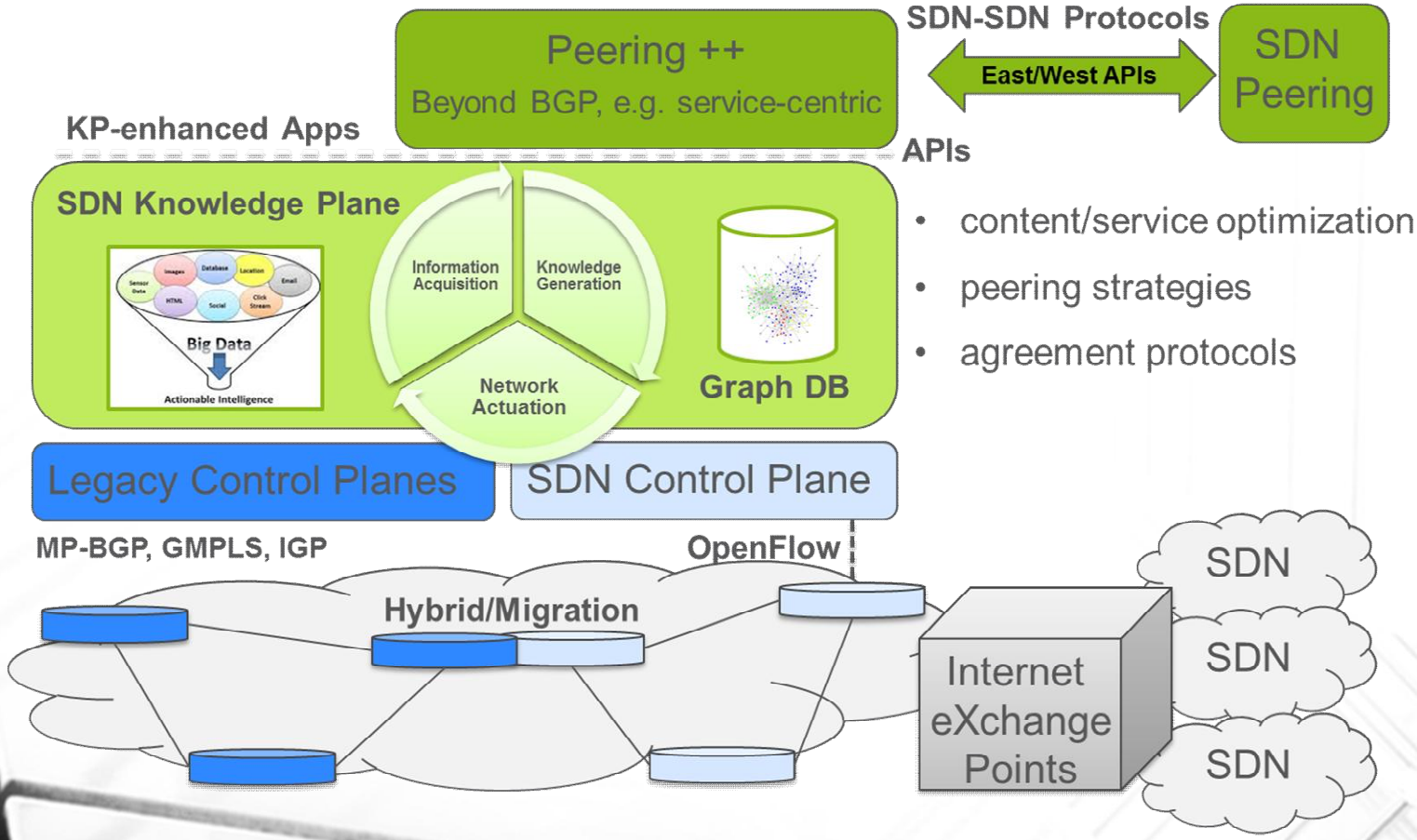
- **Software-Defined Networking: A Comprehensive Survey.**
  Diego Kreutz, Fernando M. V. Ramos, Paulo Verissimo, Christian Esteve Rothenberg, Siamak Azodolmolky, Steve Uhlig. In Proceedings of the IEEE, Jan., 2015.
  - http://arxiv.org/abs/1406.0440 https://github.com/SDN-Survey/latex/wiki
- **When Open Source Meets Network Control Planes.**
  Rothenberg, C.E. Chua, R. ; Bailey, J. ; Winter, M. ; Correa, C.N.A. ; de Lucena, S.C. ; Salvador, M.R. ; Nadeau, T.D.. In IEEE Computer, vol.47, no.11, pp.46,54, Nov. 2014
- **Cardigan: SDN Distributed Routing Fabric Going Live at an Internet Exchange.**
  Jonathan P. Stringer, Carlos Corrêa, Josh Bailey, Dean Pemberton, Qiang Fu, Christopher Lorier, Richard Nelson, Christian Esteve Rothenberg. In IEEE ISCC, June 2014
  - *Cardigan: Deploying a Distributed Routing Fabric.*" In ACM SIGCOMM 2013 - HotSDN'13 (Poster)
- **Revisiting Routing Control Platforms with the Eyes and Muscles of Software-Defined Networking**
  Christian E. Rothenberg, Marcelo R. Nascimento, Marcos R. Salvador, Carlos Corrêa, Sidney Lucena, and Robert Raszuk. In ACM SiGCOMM HotSDN, Aug 2012

US-Brazilian collaborations

- Ericsson Research in San Jose
  - Attila Takacs. “Advanced Peering with a Software-Defined Knowledge Plane”
- UC Santa Cruz (UCSC)
  - Prof. Katia Obraczka. “Software-Defined Internetworking Framework”
- ESnet / Lawrence Berkeley National Laboratory
  - Inder Monga. RouteFlow & Software Defined Exchanges
- NSF Named Data Networking (NDN)
  - Prof. Lan Wang (Memphis Univ.). Mini-NDN. http://redmine.named-data.net/projects/mini-ndn
- Open Networking Foundation (ONF)
  - Research Associates. Open Source Developments (libfluid driver, ofsoftswitch, routeflow)
- Software-Defined Networking: A Comprehensive Survey. In Proc. of the IEEE, Jan., 2015.
  - http://arxiv.org/abs/1406.0440 https://github.com/SDN-Survey/latex/wiki

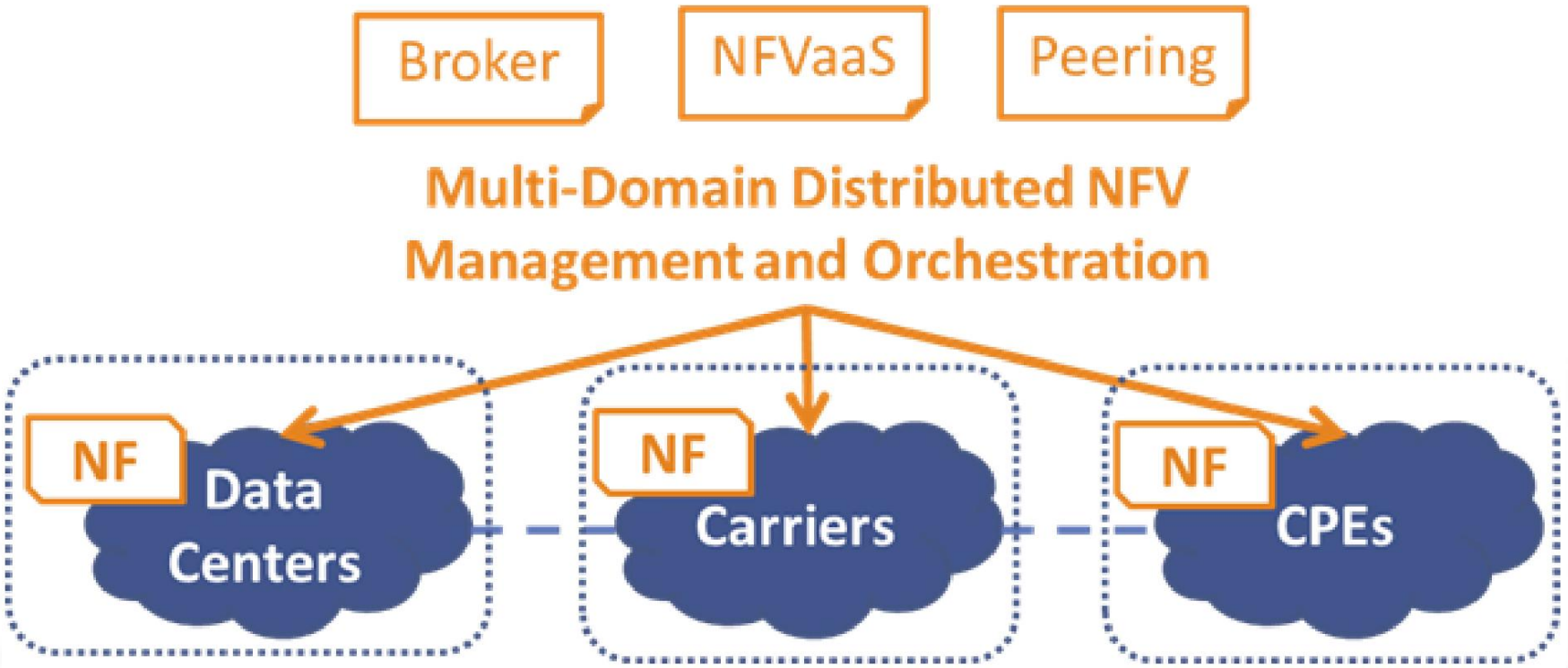
Ongoing research project:
Advanced Peering with a Software-Defined Knowledge Plane

- Duration: 24 months (Started in May/2014) [Funded by Ericsson]

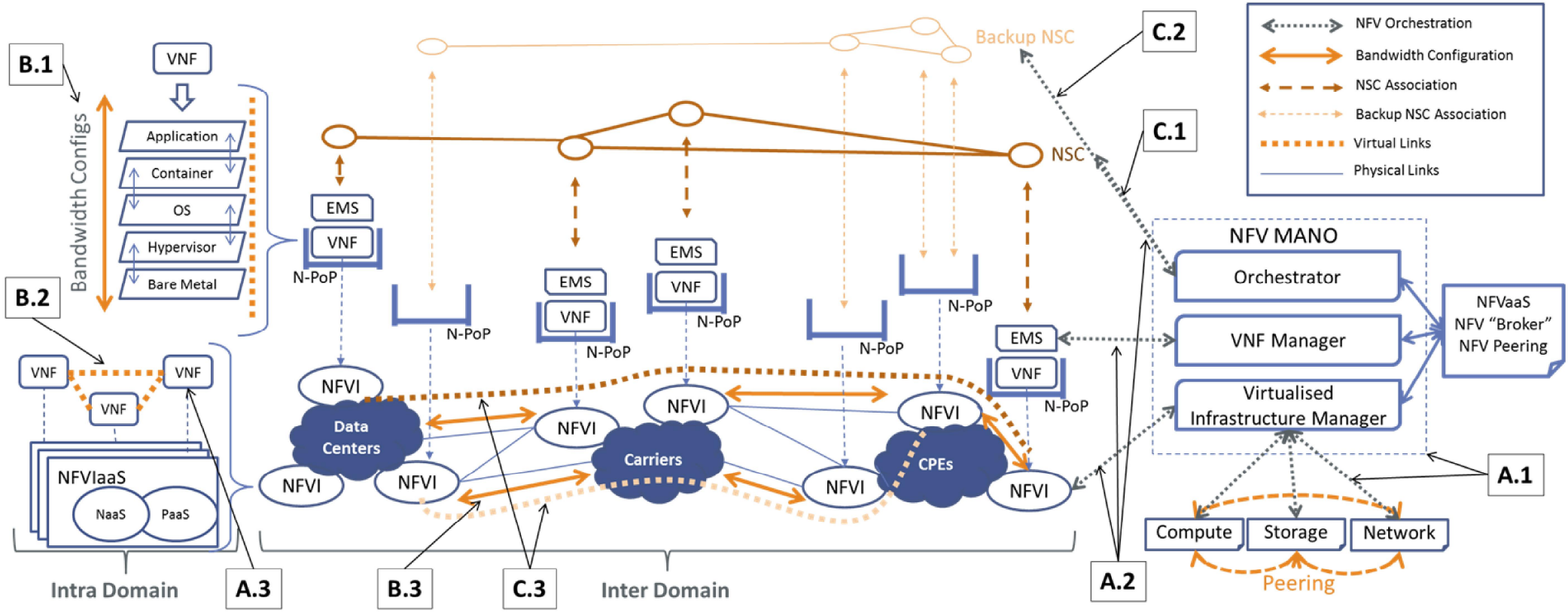


- content/service optimization
- peering strategies
- agreement protocols

Multi-Domain Distributed NFV



Peering Use Cases in Multi-Domain Distributed NFV

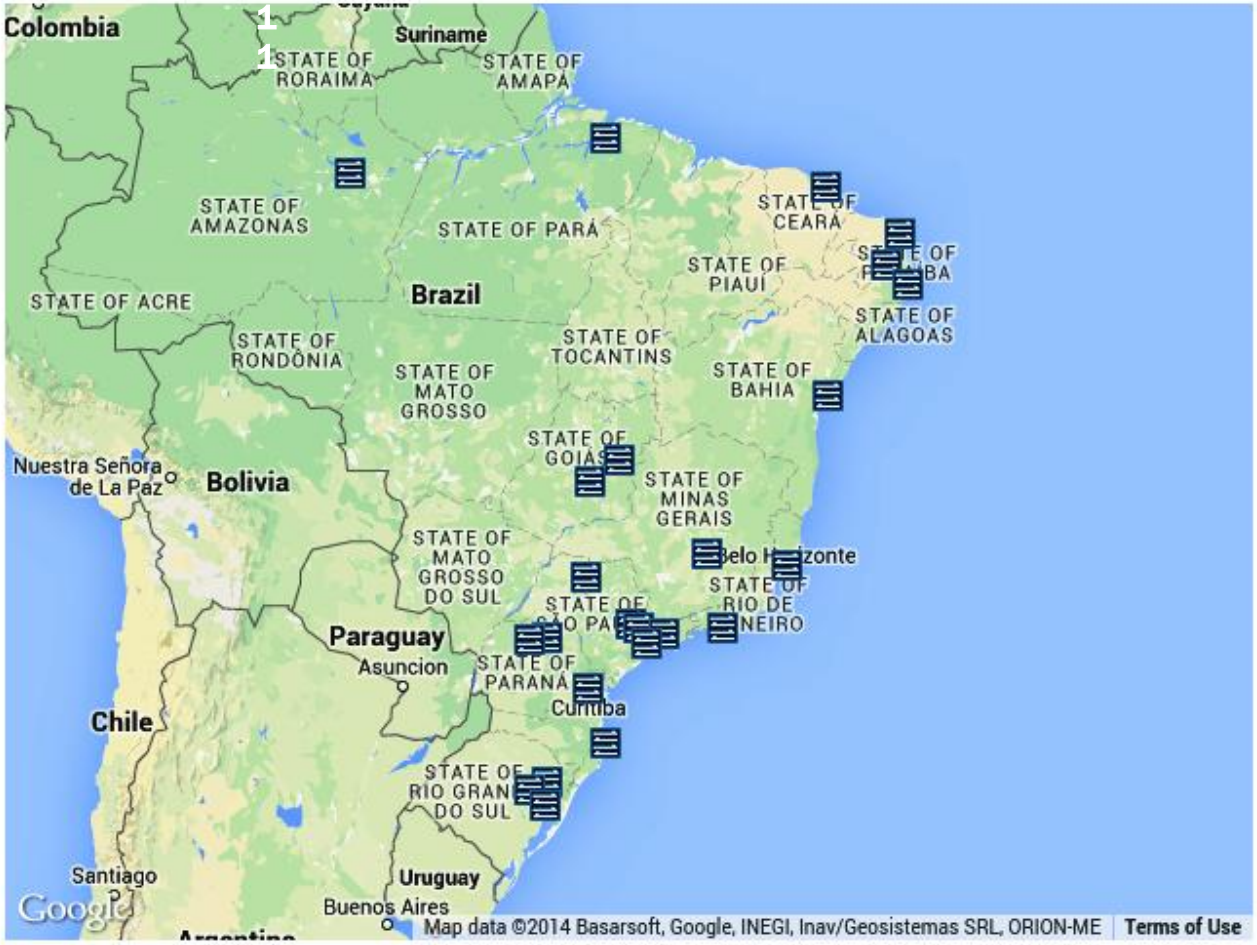


More info: "MD2-NFV: The Case for Multi-Domain Distributed Network Functions Virtualization". To appear in NetSys SDNFlex 2015, Cottbus, Germany, March, 2015.

Related use cases under investigation:
Advanced Peering with a Software-Defined Knowledge Plane

- MD2-NFV
  - Resource trading (computation, storage, network) between different domains to optimize VNF placement across providers (offering NFVI-as-a-Service)
- Flash NFV-Benchmarking Service
  - A fast, distributed benchmarking service to assess candidate locations in terms of computation and network (BW, latency, etc.) from multiple vantage points to support the decision of best location for target VNFs (“try before deploy”).
- NfvQuery
  - Network State & Management primitives for graph databases embodying multi-layer virtualized infrastructures based on semantic graph annotations
- Meta-SDX: Interconnecting SDN-augmented Public IXPs

PTTMetro in Brazil (PTT.br)



- Americana
- Belém
- Belo Horizonte
- Brasília
- Campina Grande
- Campinas
- Cuiabá
- Caxias do Sul
- Curitiba
- Florianópolis
- Fortaleza
- Goiânia
- Lajeado
- Londrina
- Manaus
- Maringa
- Natal
- Porto Alegre
- Recife
- Rio de Janeiro
- Salvador
- Paulista Central (São Carlos)
- São José dos Campos
- São José do Rio Preto
- São Paulo
- Vitória

Location of Each Brazilian IXP (figure extracted from http://www.ptt.br)

Methodology: AS-level Graphs

- Data Sources
  - PTT.br Official Data at www.ptt.br
  - PeeringDB (we found it was unreliable)
  - Telnet Access to IXP's Looking Glasses (most important data source!)
    - BGP Table, Paths Summary, Communities List
- Graph analysis tools based on BGP adjacency matrix of all IXPs:
  - NetworkX https://networkx.github.io
  - Neo4j http://neo4j.com

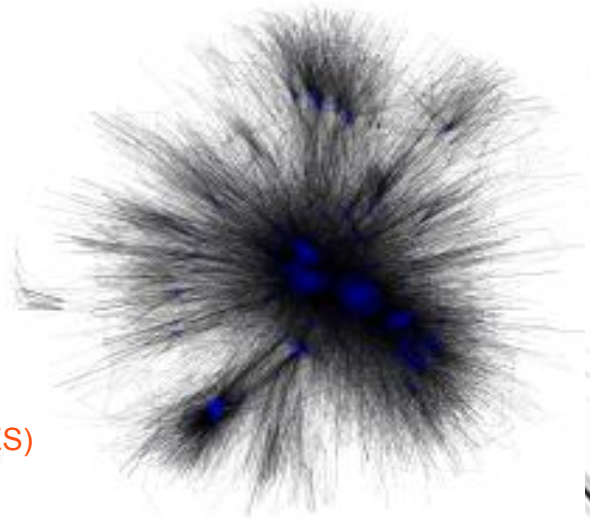


Figure 1b. Example Graph of PTT-VIX (Vitória, ES)

Results

- Profile and Classification of IXP's Members
- AS Vertices's Degree / Depth / Diameter
- Density of Peering
- AS-Prepend for TE
- k-Clique Communities

Results

Analysis of ASes Profile in PTTMetro (PTT.br)								
Category	BRAZIL	+/-	DF	MG	RJ	RS	SP	VIX
1.1 Transit Provider	8.6%	9%	20.8%	14.7%	19.2%	5.0%	5.6%	10.0%
1.2 Access Provider	56.5%	21%	16.7%	41.2%	32.7%	63.0%	67.5%	65.0%
Internet Provider	65.1%	20%	37.5%	55.9%	51.9%	68.0%	73.1%	75.0%
2.1 Content Provider	3.2%	6%	0.0%	2.9%	5.8%	3.0%	4.7%	0.0%
2.2 Hosting Provider	6.8%	5%	8.3%	5.9%	11.5%	2.0%	7.8%	5.0%
Services Provider	10.1%	7%	8.3%	8.8%	17.3%	5.0%	12.5%	5.0%
3.1 Public University	1.8%	19%	0.0%	0.0%	0.0%	2.0%	1.1%	0.0%
3.2 Government	8.8%	13%	33.3%	17.6%	13.5%	8.0%	2.2%	15.0%
3.3 Other	1.8%	3%	4.2%	2.9%	1.9%	1.0%	1.1%	0.0%
Public Organization	12.3%	21%	37.5%	20.6%	15.4%	11.0%	4.4%	15.0%
4.1 Private University	0.7%	3%	0.0%	2.9%	0.0%	4.0%	0.0%	0.0%
4.2 Private Enterprise	10.4%	9%	16.7%	8.8%	15.4%	10.0%	8.9%	5.0%
4.3 Other	1.5%	3%	0.0%	2.9%	0.0%	2.0%	1.1%	0.0%
Private Organization	12.6%	9%	16.7%	14.7%	15.4%	16.0%	10.0%	5.0%

Results

AS-Prepend Analysis in PTTMetro (PTT.br)					
Metric Description	**BRAZIL**	**+/-**	**DF**	**MG**	**VIX**
Number of Routes in BGP Table	898616	-	559159	434264	2663751
Number of Routes in BGP Table with AS-Prepend	251475	-	127184	245129	623965
AS-Prepend X Routes (%)	19.4%	28%	22.7%	56.4%	23.4%
Number of ASes (in PTT Vantage Point)	39413	-	47176	46939	47474
Number of ASes in PTT with AS-Prepend	6746	-	6206	8629	9124
AS-Prepend X AS (%)	15.7%	6%	13.2%	18.4%	19.2%
Number of IXP's Members ASes (Advertisers)	21	-	24	22	18
Number of IXP's Members ASes with AS-Prepend	7	-	7	6	5
AS-Prepend X Members	24.8%	18%	29.2%	27.3%	27.8%

Analysis of Peering Density in PTTMetro (PTT.br)					
Metric Description	**BRAZIL**	**+/-**	**DF**	**MG**	**VIX**
Members Advertising	21	-	24	22	18
Existent Peers	244	-	61	86	86
Combination of Possible Peers [C(m,2)]	381	-	276	231	153
Density (%)	64.1%	31.4%	22.1%	37.2%	56.2%

Results

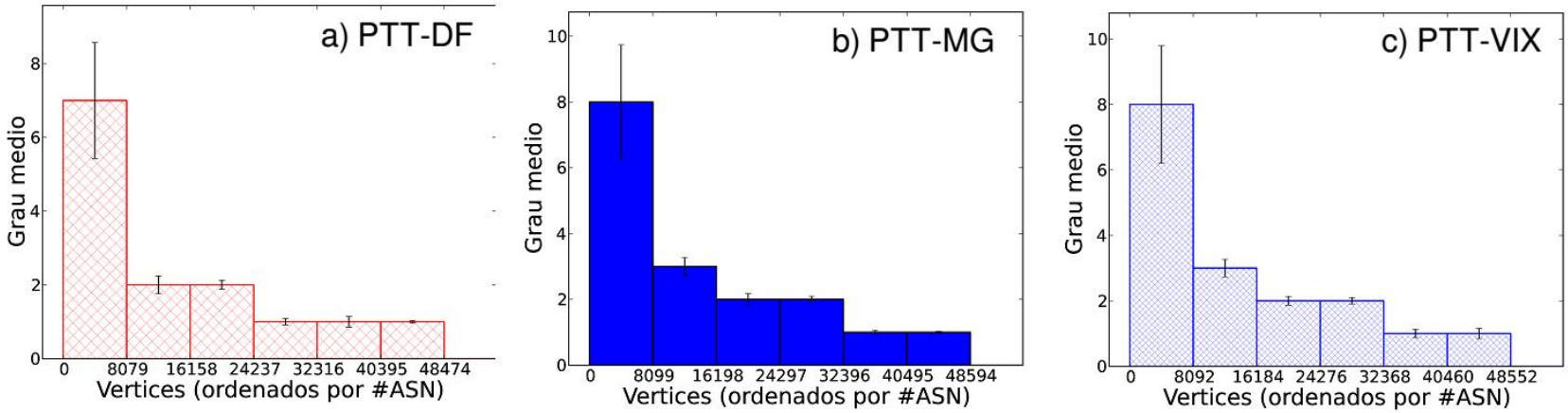


Figure 2. Average Degree of Graphs by ASN

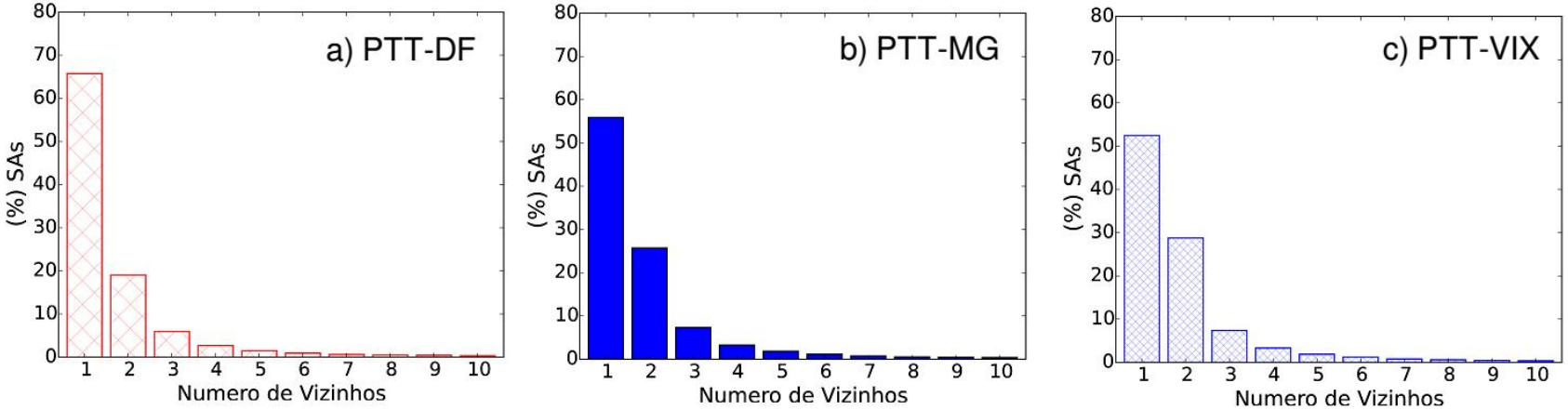


Figure 3. Distribution of Graphs' Degrees

Results

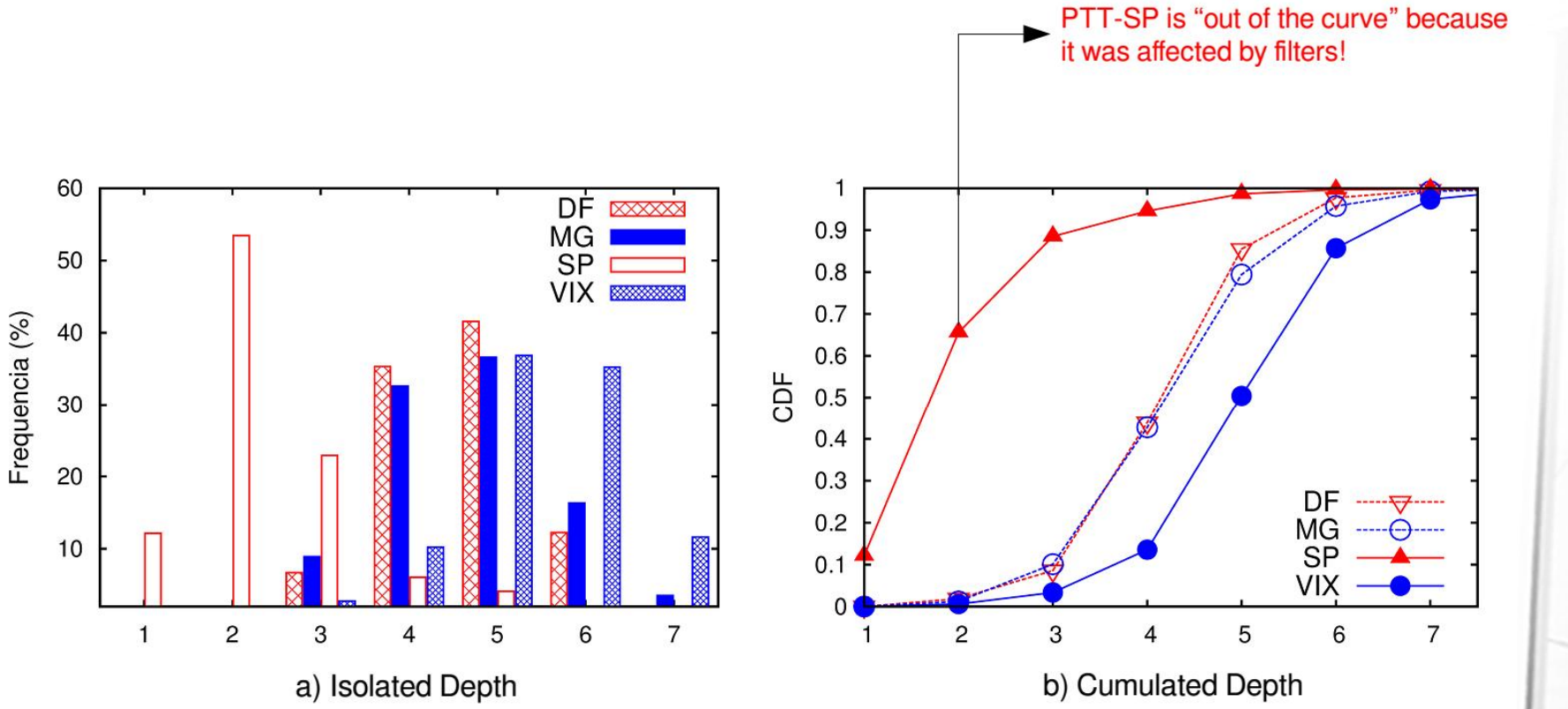


Figure 4. Depth of AS-PATHs

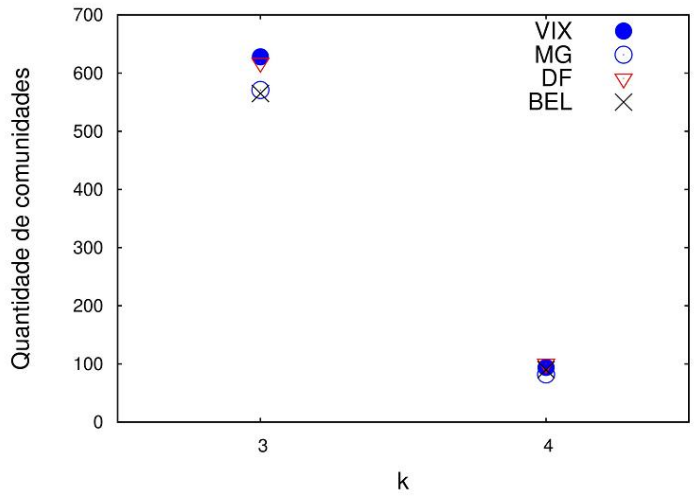


Figure 5a. k3 and k4 Communities

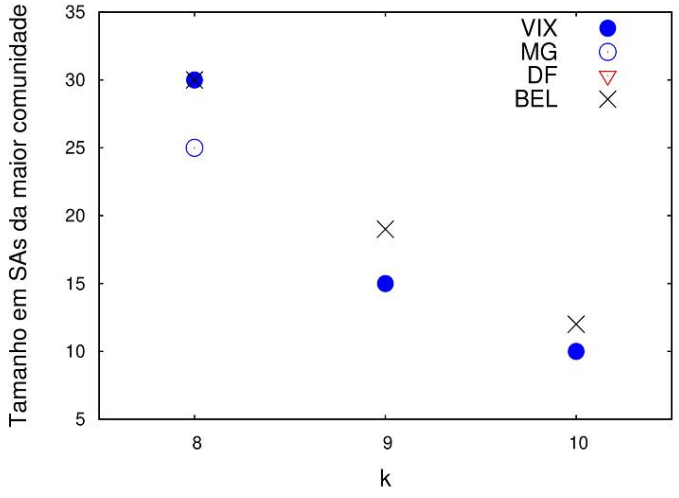


Figure 5c. Larger Communities

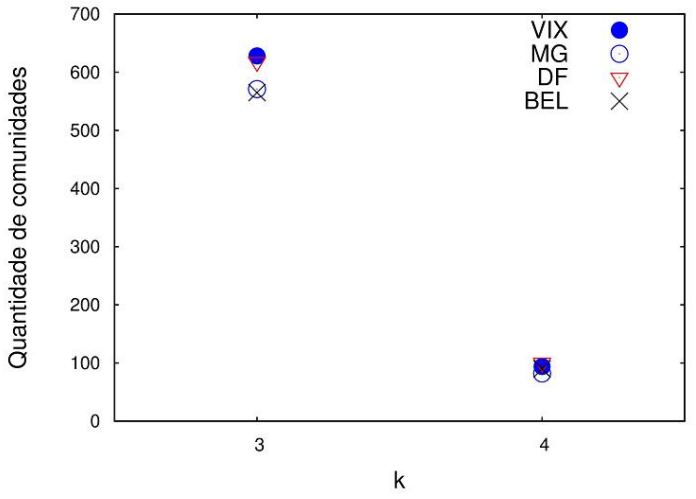


Figure 5a. k3 and k4 Communities

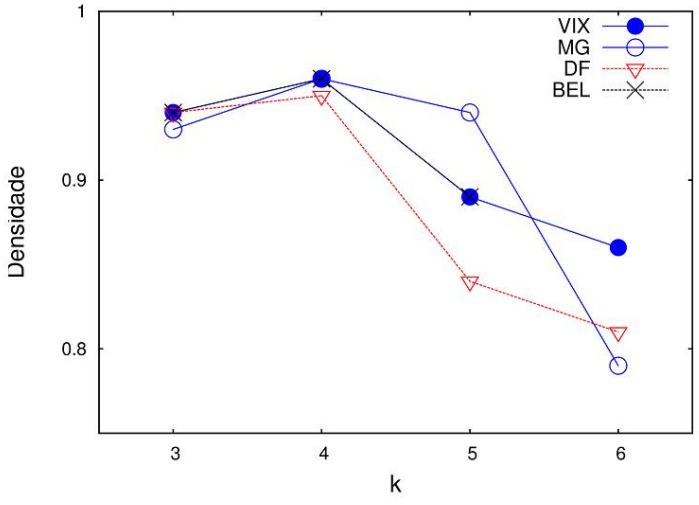


Figure 5b. Density

Thanks! Obrigado! (More) Questions?

chesteve@dca.fee.unicamp.br

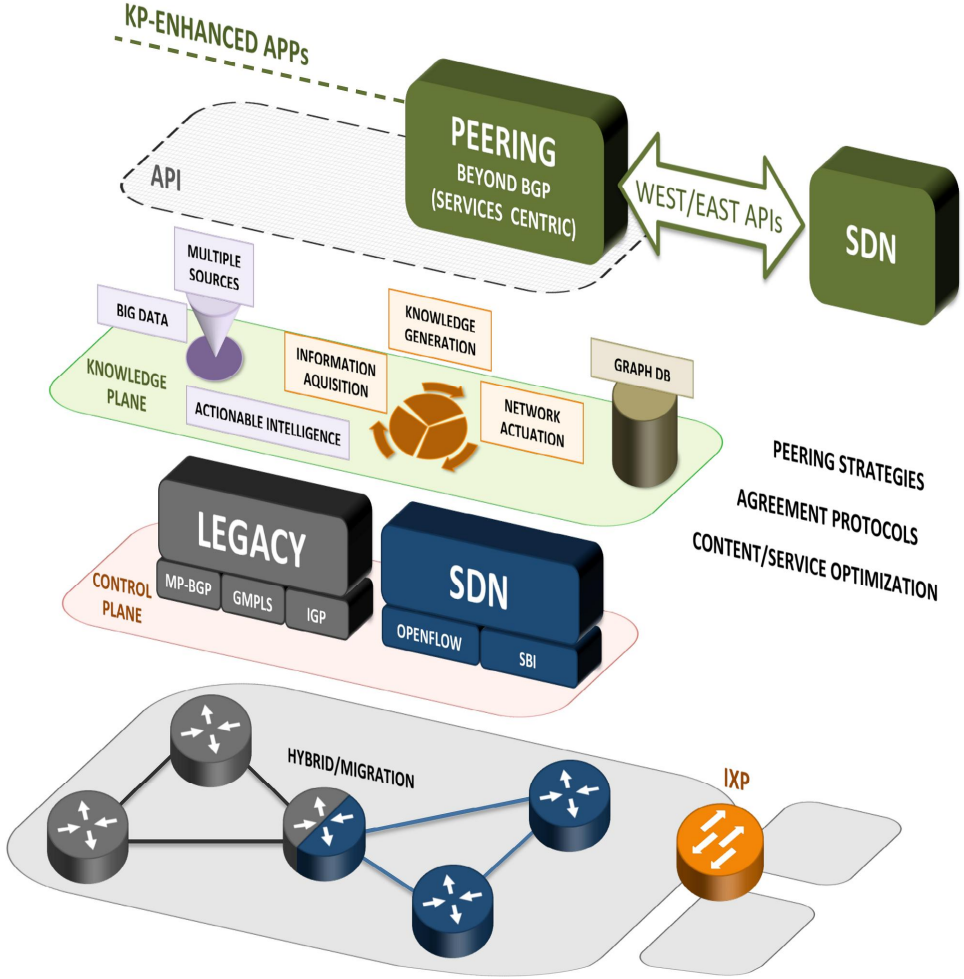
http://www.dca.fee.unicamp.br/~chesteve/

INTRIG INFORMATION & NETWORKING TECHNOLOGIES RESEARCH & INNOVATION GROUP

http://www.intrig.dca.fee.unicamp.br

Ongoing research project:
Advanced Peering with a Software-Defined Knowledge Plane

- Duration: 24 months (Started in May/2014) [Funded by Ericsson]



Research Goals
Advanced Peering with a Software-Defined Knowledge Plane

- Investigate SDN-SDN communication options that allow SDN networks in different administrative domains to achieve advanced peering agreements beyond pure packet routing, for instance by integrating best placement of content and applications.
- Re-examine the concept of Knowledge Plane with the visibility and SDN abstractions (topology map, flow tuples, policy specification) and direct control capabilities (i.e., rich matching and instructions) of OpenFlow/SDN approaches.
- Design Knowledge Plane mechanisms for querying (SDN) network properties of participants at IXPs. Define APIs that allow operators to differentiate and close the gap between applications and networks, with focus on optimizing content/application placement.
- Develop novel SDN control loops (information gathering + knowledge generation + network actuation) leveraging SDN visibility (among other data sources) for data collection and network control via direct OpenFlow/SDN programmability or indirect via existing protocols (non-OF SDN).
- Design suitable data models and available graph-oriented DBs (and/or big data stores for map-reduce like operations) to embody the "Network Information Base" using annotated and semantically meaningful graphs.
- Prototypes of inter-SDN architecture and its building blocks for evaluation and proof of concept purposes. Software prototyping based on OpenDaylight, NoSQL graph-oriented databases (e.g. Neo4j, Titan), and Hadoop-like infrastructures.

Short-bio

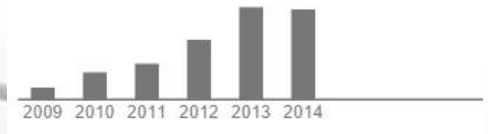
- Christian Esteve Rothenberg is an Assistant Professor in the Faculty of Electrical and Computer Engineering at University of Campinas (UNICAMP), where he received his Ph.D. in Computer Engineering in 2010.
- From 2010 to 2013, he worked as Senior Research Scientist in the areas of IP systems and networking at CPqD Research and Development Center in Telecommunications (Campinas, Brazil), where he was technical lead of R&D acitivities in the field of OpenFlow and SDN such as the RouteFlow project, the OpenFlow 1.3 Ericsson/CPqD softswitch, or the ONF Driver competition.
- Christian holds the Telecommunication Engineering degree from Universidad Politécnica de Madrid (ETSIT - UPM), Spain, and the M.Sc. (Dipl. Ing.) degree in Electrical Engineering and Information Technology from the Darmstadt University of Technology (TUD), Germany, 2006.
- Christian holds two international patents and has over 70 publications including scientific journals and top-tier networking conferences such as SIGCOMM and INFOCOM. Since April 2013, Christian is an Open Networking Foundation (ONF) Research Associate.

Research Interests

- Network Architectures
- Routing & Forwarding
- Data Center Networks
- Cloud Networking
- SDN
- NFV
- ICN

Google Scholar

Citation indices	All	Since 2009
Citations	931	919
h-index	14	14
i10-index	18	18



Change photo

Christian Esteve Rothenberg

Edit | Follow

Assistant Professor at University of Campinas (UNICAMP)
Routing, Internet architectures, Data Center Networks, OpenFlow, Software Defined Networks
Verified email at dca.fee.unicamp.br - Homepage
My profile is public

Title	Cited by	Year
LIPSIN: line speed publish/subscribe inter-networking P Jokela, A Zahemszky, C Esteve Rothenberg, S Arianfar, P Nikander ACM SIGCOMM Computer Communication Review 39 (4), 195-206	344	2009
Theory and practice of bloom filters for distributed systems S Tarkoma, CE Rothenberg, E Lagerspetz Communications Surveys & Tutorials, IEEE 14 (1), 131-155	86	2012
Revisiting routing control platforms with the eyes and muscles of software-defined networking CE Rothenberg, MR Nascimento, MR Salvador, CNA Corrêa, ... Proceedings of the first workshop on Hot topics in software defined networks ...	60	2012
Virtual routers as a service: the routeflow approach leveraging software-defined networks MR Nascimento, CE Rothenberg, MR Salvador, CNA Corrêa, ... Proceedings of the 6th International Conference on Future Internet ...	57	2011
Towards a new generation of information-oriented internetworking architectures C Esteve, F Verdi, M Magalhães First Workshop on Re-Architecting the Internet, Madrid, Spain	45 *	2008
A review of policy-based resource and admission control functions in evolving access and next generation networks CE Rothenberg, A Roos Journal of Network and Systems Management 16 (1), 14-45	39	2008
Forwarding anomalies in Bloom filter-based multicast M Sarela, CE Rothenberg, T Aura, A Zahemszky, P Nikander, J Ott INFOCOM, 2011 Proceedings IEEE, 2399-2407	35	2011
Quagflow: partnering quagga with openflow MR Nascimento, CE Rothenberg, MR Salvador, MF Magalhães ACM SIGCOMM Computer Communication Review 40 (4), 441-442	30	2010
Self-routing denial-of-service resistant capabilities using in-packet Bloom filters CE Rothenberg, P Jokela, P Nikander, M Sarela, J Ylitalo Computer Network Defense (EC2ND), 2009 European Conference on, 46-51	27	2009

(Selected) Publications

- Marcos Siqueira, Fabian Hooft, Juliano Oliveira, Edmundo Madeira, Christian Esteve Rothenberg, Providing Optical Network as a Service with Policy-based Transport SDN. In Journal of Network and Systems Management, June 2014.

- P. Jokela, H. Mahkonen, C. Esteve Rothenberg, and J. Ott. (Deployable) Reduction of Multicast State with In-packet Bloom Filters. In IFIP NETWORKING, 2013.

- S. Tarkoma, C. Esteve Rothenberg and E. Lagerspetz. Theory and Practice of Bloom Filters for Distributed Systems. In IEEE Communications Surveys and Tutorials. Vol. 14, Number 1, 2012

- M. Särelä, C. Esteve Rothenberg, T. Aura, A. Zahemszky, P. Nikander and J. Ott. Forwarding Anomalies in Bloom Filter Based Multicast, In IEEE INFOCOM 2011.

- P. Jokela, A. Zahemszky, C. Esteve, S. Arianfar, and P. Nikander. LIPSIN: Line speed Publish/Subscribe Inter-Networking. In ACM SIGCOMM 2009.