ARC Project 13/18-054 : Software Defined Networks
Final report

O. Bonaventure, Y. Deville, R. Jungers
P. Schaus and R. Sadre

1 Introduction

This report compiles the main results obtained by the ARC project entitled *Modeling, Design and Optimization of Software Defined Networks* (grant 13/18-054). This project involves the following primary investigators[1] at UCL:

- Prof. Olivier Bonaventure, ICTEAM/INGI
- Prof. Y. Deville, ICTEAM/INGI
- Prof. R. Jungers, ICTEAM/INMA

In addition, three professors who were recently recruited at UCL have collaborated to the project :

- Prof. P. Schaus, ICTEAM/INGI
- Prof. R. Sadre, ICTEAM/INGI
- Prof. E. Rivire, ICTEAM/INGI

This document is organised as follows. Section 2 provides the administrative information. Section 5 summarizes recent travels and presentations from project members. The earlier travels and presentations have been reported in the yearly reports. Section 3 compiles the main scientific results obtained during the covered period. These results are described in more details in the submitted and published articles that are listed in section 4.

2 Administrative Information

[1] Prof. P. Heymans from UNamur was also involved at the beginning of the project, but due to administrative reasons, the UCLouvain and UNamur were split.

UCL Université catholique de Louvain

ANNEXE IV.a :
TABLEAU DU PERSONNEL A CHARGE DE L'ACTION DE RECHERCHE CONCERTEE

!!! A envoyer à anouk.distelmans@uclouvain.be en début de convention (prévisions) ainsi qu'annuellement le 1er février pour l'année civile écoulée et en fin de convention pour la période complète de la recherche ARC !!!

CONVENTION ARC N° : 13/18-054 COMPTE.S N C1.31403.001 DATE DE DEBUT : 01/09/2013 DATE DE FIN : 31/08/2018.

PROMOTEURS UCL (TOUS) : O. Bonaventure – Y. Deville – R. Jungers

PERIODE CONCERNEE* 2018 DATE DE LA MISE A JOUR : 16/11/2018

NOM, Prénom	Statut**	% d'occupation sur l'ARC	Période d'occupation sur l'ARC
LEBRUN DAVID	DOCTORANT BOURSIER	100 %	01/09/2013-31/08/2017
HARTERT RENAUD	DOCTORANT BOURSIER	100%	01/09/2013-30/09/2013 (FSR ensuite –ADRE ok)
MATTHEW Philippe	DOCTORANT BOURSIER	100%	03/09/2013-30/09/2013 (au final, n'aura pas été à charge de l'ARC entre le 01/10/2013 et le 31/12/2013 car est passé sous FRIA, avec remboursement de sa rémunération à l'ARC pour cette période)
GONZE FRANCOIS	DOCTORANT BOURSIER	100%	01/02/2014-15/09/2014 (est passé ensuite sous CDD ASSISTANT UCL - non à charge - ADRE Ok)
LAURENT NICOLAS	DOCTORANT BOURSIER	100%	21/02/2014-30/09/2014 (est passé ASP FNRS ensuite)
GAY STEVEN	DOCTORANT BOURSIER	100%	01/12/15-30/11/2016
TILMANS OLIVIER	DOCTORANT BOURSIER	100%	01/07/15-30/09/2015 (car est passé sous FRIA au 01/10/2015)
GUSEV VLADIMIR	DOCTORANT BOURSIER	100%	05/04/2015-31/08/2018
SANAND ATHALYE	DOCTORANT BOURSIER	100%	10/10/2015-09/10/2017
JADIN MATHIEU	DOCTORANT BOURSIER	100%	01/09/2016-30/09/2017 (accepté au FRIA au 01/10/17)
GORBY KABASELE NDONDA	DOCTORANT BOURSIER	100%	15/10/2016-31/08/2018
BERGER GUILLAUME	DOCTORANT BOURSIER	100%	15/09/2017-30/09/17 (accepté au FRIA au 01/10/17)
VIET HOANG TRAN	ASSISTANT DE RECHERCHE	100%	01/03/2018-31/08/2018
ZHEMING WANG	ASSISTANT DE RECHERCHE	100%	03/01/2018-31/08/2018

* Selon que la subvention est en cours OU arrivée à terme, mettre respectivement l'année écoulée OU la période complète de la subvention.

** A PRECISER : **Scientifique** (spécifier si doctorant boursier, doctorant contractuel, post-doctorant boursier, post-doctorant contractuel, senior, autres), **technique** ou **administratif.**

NOM et prénom du promoteur porte-parole : le professeur Mr. Bonaventure Olivier Signature : ……

VU PAR ADRE : …… ***ACCORD SPER :*** ……

(NOM, Prénom, signature, cachet, date) ***(NOM, Prénom, signature/visa, date)***

ANNEXE IV.b :
TABLEAU DU PERSONNEL NON A CHARGE DE L'ACTION DE RECHERCHE CONCERTEE

!!! A envoyer à anouk.distelmans@uclouvain.be en début de convention (prévisions) ainsi qu'annuellement le 1er février pour l'année civile écoulée et en fin de convention pour la période complète de la recherche ARC !!!

CONVENTION ARC N° : 13/18-054 COMPTE.S N° : C1.31403.001 **DATE DE DEBUT : 01/09/2013 DATE DE FIN :** 31/08/2018

PROMOTEURS UCL (TOUS) : O. Bonaventure (porte-parole) – Y. Deville – R. Jungers

PERIODE CONCERNEE* : 2018 DATE DE LA MISE A JOUR : 16/11/2018

NOM, Prénom	Statut**	Source de financement	% occupation sur l'ARC	Période d'occupation sur l'ARC
BONAVENTURE OLIVER	Professeur		10%	01/09/2013- 31/08/2018
VISSICCHIO STEFANO	Post doc. contractuel	FNRS	10%	01/09/2013- 30/09/2016
PAASCH CHRISTOPH	Post doc. contractuel	UE	5%	01/09/2013- 30/09/2014
DUCHENE FABIEN	Assistant	UCL	5%	01/09/2013- 31/08/2018
HESMANS BENJAMIN	Doctorant contractuel	UCL	10%	01/09/2013- 30/09/2016
HESMANS BENJAMIN	Assistant	FRIA	5%	01/10/2016-31/12/2017
CANINI MARCO	Professeur	UCL	10%	01/09/2013- 30/09/2016
DEVILLE YVES	Professeur	UCL	10%	01/09/2013- 31/08/2018
SCHAUS PIERRE	Professeur	UCL	10%	01/09/2013- 31/08/2018
DEJEMEPPE CYRILLE	Doctorant contractuel	RW	5%	01/09/2013- 31/09/2016
MAIRY JEAN-BAPTISTE	Doctorant boursier	FNRS	5%	01/09/2013- 31/08/2015
BUI QUOC TRUNG	Doctorant boursier	UCL + coopération Vietnam	5%	01/09/2013- 31/12/2014
SAINT-GUILLAIN MICHEL	Assistant	UCL	5%	01/09/2013- 31/08/2018
AUBRY FRANCOIS	Assistant	UCL	5%	01/09/2013- 31/08/2018
RATHEIL HOUNDJI VINASETAN	Doctorant boursier	UCL + coopération Bénin	5%	01/09/2013- 31/12/2016
VAN CAUWELAERT SASCHA	Assistant	UCL	5%	01/09/2013- 31/09/2016
VAN CAUWELAERT SASCHA	Doctorant contractuel	UCL	5%	01/10/2016-31/08/2018
PONCIN CHANTAL	Administratif	UCL	2%	01/09/2013- 31/08/2018
JUNGERS RAPHAEL	Professeur	UCL	10%	01/09/2013- 31/08/2018
HOLLANDERS ROMAIN	Assistant	UCL	5%	01/09/2013- 31/12/2016
HARTERT RENAUD	Doctorant Boursier	FSR	5%	01/10/2013- 31/12/2015

GAY STEVEN	Post doc contractuel	UCL	5%	01/01/2014- 30/11/2016
MASSEN FLORENCE	Post doc. contractuel	UCL	5%	01/09/2013- 31/12/2013
PHILIPPE MATTHEW	Doctorant Boursier	FRIA	5%	01/10/2013- 28/02/2018
LAURENT NICOLAS	Doctorant Boursier ASP	FNRS	5%	01/10/2014- 31/12/2016
GONZE FRANCOIS	Assistant CDD	UCL	5%	16/09/2014- 31/12/2017
SADRE RAMIN	Professeur	UCL	10%	01/09/2014- 31/08/2018
TILMANS OLIVIER	Doctorant	UCL	5%	15/08/2014- 30/06/2015
TILMANS OLIVIER	Doctorant Boursier	FRIA	5%	01/10/2015- 31/08/2018
AOGA JOHN	Doctorant Boursier	UCL	5%	16/09/2015- 11/03/2017
AOGA JOHN	Doctorant Boursier	FRIA	5%	11/03/2017 – 31/08/2018
DECONINCK QUENTIN	Assistant	UCL	5%	16/09/2015- 30/09/2016
DECONINCK Quentin	Doctorant Boursier	FNRS	5%	01/10/2016-31/08/2018
VERHAEGHE HELENE	Assistante	UCL	5%	16/09/2015- 31/08/2018
KHONG MINH THANH	Doctorant Boursier	UCL	5%	06/01/2015- 31/12/2016
DERVAL GUILLAUME	Doctorant contractuel	UCL (FSR)	5%	01/01/2017-15/09/2017
DERVAL GUILLAUME	Assistant	UCL	5%	16/09/2017-31/08/2018
BERGER GUILLAUME	Doctorant Boursier	FRIA	5%	01/10/2017-31/08/2018
LEGAT BENOIT	Doctorant Boursier ASP	FNRS	5%	01/10/2016-31/08/2018
JADIN MATHIEU	Doctorant Boursier	FRIA	5%	01/10/2017-31/08/2018
RIVIERE ETIENNE	Professeur	UCL	2%	01/09/2017-31/08/2018
CARVAJALGOMEZ RAZIEL	Assistant	UCL	5%	15/09/2017-31/08/2018
CHARLES THOMAS	Assistant	UCL	5%	01/01/2018-31/08/2018
XAVIER GILLARD	Assistant	UCL	5%	01/01/2018-31/08/2018
GAEL ALGIN	Doctorant Boursier	UCL+ coopération Bénin	5%	01/01/2018-31/08/2018

***** Selon que la subvention est en cours OU arrivée à terme, mettre respectivement l'année écoulée OU la période complète de la subvention.

****** A PRECISER : **Scientifique** (spécifier si doctorant boursier, doctorant contractuel, post-doctorant boursier, post-doctorant contractuel, senior, autres), **technique** ou **administratif.**

NOM et prénom du promoteur porte-parole : …… **Signature :** ……

VU PAR ADRE/RFON : …… ***ACCORD SPER :*** ……

(NOM, Prénom, signature, cachet, date) ***(NOM, Prénom, signature/visa, date)***

3 Scientific Results

The yearly reports have described the results that have been obtained on the different tasks of the project since its beginning. We refer the reader to these previous reports for these yearly informations. In this section, we highlight the most important results obtained by the project.

The project started shortly after the creating of Segment Routing [1] and the first discussions within the Internet Engineering Task Force (IETF). Segment Routing was initially presented as a drastic simplification of the networking architecture. Instead of requiring the utilisation of specific signalling protocols, it relies on the existing link state routing protocols such as OSPF and IS-IS to distribute the MPLS labels. Beyond the expected impact on networking protocols, Segment Routing brought a fundamental change to the way paths are computed in a network. A unique feature of Segment Routing compared to all the other networking technologies is that with Segment Routing a path between a source and a destination node is composed as a succession of shortest paths between intermediate nodes. With the MPLS variant of Segment Routing, these paths are identified by their MPLS label that is placed inside each packet. With the IPv6 variant of Segment Routing [2], these paths are encoded as a source route inside the IPv6 Segment Routing Header. This contrasts with popular networking architectures such as plain IP that uses a single shortest path between the source and the destination while MPLS with RSVP-TE can be configured to use any path. These different types of paths have lead to very different traffic engineering techniques [3, 4, 5]. In pure IP networks, a popular technique is to tune the weights of the link-state routing protocol [4]. With Segment Routing, the traffic engineering problem can be solved by using very different techniques. During the last years of the project, we have proposed several innovative solutions to optimise the traffic flows in large networks. With Vladimir Gusev, we have also shown that the problem connects with classical problems from applied mathematics and combinatorial optimization.

This is illustrated in the figure below. The numbers associated to the links are the IGP weights. With pure IP routing, the path from node a to node f is the shortest one, i.e. the one via node a. With RSVP-TE, any path can be constructed between node a and node f, e.g. a-g-b-c-e-f, but this requires state on all intermediate nodes. With Segment Routing, we trade the state in the routers with labels in the packets. A path is now a succession of shortest paths. For example, the figure below shows the a-c-f paths. To send packets along those paths, node a sends packets that contain two labels: (1) the label to reach node c and (2) the label to reach node f. The packets are first forwarded according to node cs label and there are two shortest paths of equal cost between a and c. When they reach node c, it pops the top label and then packets are forwarded along the shortest path to reach node f.

Our research on Segment Routing has been focussed on two different but very important aspects of this new network architecture. The first one is the design of innovative optimisation techniques that can be applied by network operators to leverage the unique characteristics of Segment Routing. The second one is the IPv6 variant of Segment Routing [2].

Our first important contribution on traffic engineering for Segment Routing is the paper *A Declarative and Expressive Approach to Control Forwarding Paths in Carrier-Grade Networks* presented at SIGCOMM'15 [6]. This was the first

scientific paper to propose and evaluate traffic engineering techniques that support Segment Routing. It is now considered by many researchers and industry as the baseline over which new techniques must be compared. Renaud Hartert, who lead this early work, developed more efficient traffic engineering techniques later. These new techniques are summarised in *Expect the Unexpected: Sub-Second Optimization for Segment Routing* [7] and in Renaud Hartert's Ph.D. thesis [8]. Another interesting scientific result is *REPETITA: Repeatable Experiments for Performance Evaluation of Traffic-Engineering Algorithms* [9], an open-source framework that contains the implementations of the main traffic engineering techniques that are compatible with Segment Routing and allows researchers to compare their new algorithms with existing ones. Finally our latest work [10] revisits the traffic engineering for Segment Routing problem using a mathematical programming and column generation approach providing optimality guarantees.

Another Ph.D. student, Francois Aubry explored other use cases than the classical traffic engineering problem. In *SCMon: Leveraging Segment Routing to Improve Network Monitoring* [11], presented at INFOCOM16, he proposed a new technique to create efficient cycles that a monitoring node can used to verify the performance of a live network. His most recent paper that will be presented at Conext18, *Robustly Disjoint Paths with Segment Routing* [12] demonstrates that it is possible with Segment Routing to provide a service where packet flows remain disjoint even if a failure occurred.

David Lebrun explored the networking aspects of Segment Routing during his Ph.D. He started his Ph.D. at the same time as the first discussions about the IPv6 variant of Segment Routing. During the ARC-SDN project, he has proposed several important contributions that have influenced the design of this IPv6 extension [2]. He was the first to implement IPv6 Segment Routing in the Linux kernel [13]. His implementation has heavily influenced several of the design choices that have shaped the specification of the IPv6 Segment Routing Header. It has been included in the mainline Linux kernel since version 4.14. This implies that any Linux host can now use IPv6 Segment Routing. Another important contribution is a new architecture that leverages IPv6 Segment Routing for enterprise networks [14].

Besides this kernel implementation, David also contributed to support Service Function Chaining. The IPv6 variant of Segment Routing enables a very nice feature that is called network programming [15]. With network programming, a router can expose network functions as IPv6 addresses and the packets that are sent towards those addresses are processed by a specific function on the router before being forwarded. We demonstrated in *SRv6Pipes: enabling in-network bytestream functions* the possibility of realising such service chains with TCP [16]. We then went one step further by enabling the inclusion of network functions directly inside the Linux kernel by leveraging the eBPF virtual machine that is supported by recent Linux kernel. Within his Master thesis, Mathieu Xhonneux proposed to use eBPF to implement such network functions on Linux. His architecture is described in more details in *Leveraging eBPF for programmable network functions with IPv6 Segment Routing* [17] with several use cases. This extension has also been accepted in the mainline Linux kernel.

Matthew Philippe's PhD thesis was initially motivated by decentralized optimization of stability guarantees in networked environments. In 2017 we submitted and published the conference papers [18], [19], followed by the journal

version [20] (accepted in 2018). The journal version has been accepted for publication in IEEE Transactions on Automatic Control. In 2018, we submitted novel results on the subject (acceptance pending), putting us one step closer to a complete understanding of these stability criteria.

The work of Sanand Dilip was devoted to the analysis of the impact of network imperfections, like dropouts and switching delays, in the performances of a controller. We have proposed control algorithms to palliate these imperfections and minimize the cost of control in a networked environment.

Ph.D. student Gorby Kabasele Ndonda studied how software-defined networking can be employed to protect Industrial Control Systems (ICS). The latter have been the target of an increasing number of cyber-attacks over the past years. In 2015, researchers proposed to employ SDN techniques to avoid eavesdropping attacks in ICS networks. To avoid that all packets are forwarded along the same path in such networks, their multipath routing strategy alternated between several paths from a source host to the destination host. Gorby showed that this strategy can result in delay peaks which are highly undesired in real-time ICS. He proposed a priority multipath routing strategy which makes use of rule priorities in OpenFlow to ensure that there is always a matching forwarding rule in a switch. Experiments showed that the approach effectively eliminates delay peaks and that selected paths compromise well between their disjointness and their cost [21].

In a second work, Gorby showed that SDN can be used to efficiently implement intrusion detection and prevention mechanisms in ICS. Many ICS network protocols, e.g. Modbus/TCP, have no security mechanism. The constraints that they must satisfy, such as high availability or real time communication, make it challenging to apply traditional intrusive security measures. In the paper published in [22], he proposed a two-level intrusion detection system for ICS networks. The first level consists of flow and Modbus whitelists, leveraging P4 for efficient real-time monitoring directly on the network switches. Packets without matching whitelist entries are forwarded to the second level, where they are analyzed by a security engine using deep packet inspection. The engine communicates with the SDN controller and can instruct it to adapt the filters on the switches. We showed by experiments that our design has only a small impact on communication latencies in the ICS and is effective against Modbus/TCP oriented attacks.

3.1 Valorisation

Most of the software artefacts (e.g. prototype, protocol implementation or optimisation technique) developed within the project have been released under an open-source license to encourage other researchers to improve and extend the project results.

Some of the project results could lead to a commercial usage. The Linux implementation of IPv6 Segment Routing [13] and its eBPF extension [17] have already been included in the official Linux kernel. They were released under the open-source GPLv2 license which is the standard software license for the Linux kernel. It is likely that companies will reuse these two implementations in commercial products in the coming years.

Another candidate for commercial utilisation is the prototype that was developed for the *Software Resolved Networks: Rethinking Enterprise Networks*

with IPv6 Segment Routing paper [14]. This prototype contains a controller and support tools that could be used to deploy new enterprise networks.

The optimisation algorithms that were developed to solve the different traffic engineering problems that were tackled within this project could also be exploited by enterprises or network operators. For this, they would need to be included in a traffic engineering or network management tool that collects information from the network and can reconfigure the routers on-the-fly.

3.2 Perspectives

The project has reached its objectives. From a scientific viewpoint, the project results have been presented in the most selective conferences and several of the project results have already influenced industry through standardisation and inclusion in the mainline Linux kernel. The cooperation between the different project members has been very fruitful and has enabled us to obtain results that would have been impossible to achieve in isolated research groups.

4 Project publications

We list in this section the scientific articles that have been published by the team members during the last 5 years.

4.1 Project publications in 2014

- Abbasi E. K., Acher M., Heymans P., and Cleve A. Reverse Engineering Web Configurators. *IEEE Conference on Software Maintenance, Reengineering and Reverse Engineering (CSMR-WCRE)* (2014) pp 264-273.

- Bui, Q. T., Pham, Q.-D., and Deville, Y. Solving the agricultural land allocation problem by constraint-based local search. In *19th International Conference on Principles and Practice of Constraint Programming (CP 2014)* (2013), pp. 749–757.

- Bui, Q. T., Pham, Q.-D., and Deville, Y. Solving the quorum-cast routing problem as a mixed integer program. In *11th International Conference on Integration of Artificial Intelligence (AI) and Operations Research (OR) techniques in Constraint Programming (CPAIOR 2014)* (2014), pp. 45–54.

- Canini, M., Cicco, D. D., Kuznetsov, P., Levin, D., Schmid, S., and Vissicchio, S. STN: A Robust and Distributed SDN Control Plane. Open Networking Summit (ONS) Research track, 2014.

- Canini, M., and Jungers, R. M. The software-defined network revolution. *ERCIM News 2014*, 97 (2014).

- Clad, F., Vissicchio, S., Merindol, P., Francois, P., and Pansiot, J.-J. Computing minimal update sequences for graceful router-wide reconfigurations. *Networking, IEEE/ACM Transactions on PP*, 99 (2014), 1–1.

- Classen A., Cordy M., Heymans P., Legay A., and Schobbens P-Y. Formal semantics, modular specification, and symbolic verification of product-line behaviour. *Science of Computer Programming*, 80(PART B):416–439, 2014.

- Cordy M., Heymans P., Legay A., Schobbens P-Y., Dawagne B., and Leucker M. Counterexample guided abstraction refinement of product-line behavioural models. *The 22nd ACM SIGSOFT International Symposium on the Foundations of Software Engineering*, (FSE 2014), pp 190–201.

- Cordy M., Willemart M., Dawagne B., Heymans P., and Schobbens P-Y. An extensible platform for product-line behavioural analysis, *Proceedings of the 18th International Software Product Line Conference: Companion Volume for Workshops, Demonstrations and Tools - Volume 2*, pp 102–109, ACM Press, 2014.

- Deville, Y., Hentenryck, P. V., and Mairy, J.-B. Domain consistency with forbidden values. *Constraints* (2013), 377–403.

- Devroey X., Perrouin G., Cordy M., Legay A., Schobbens P-Y., and Heymans P. State machine flattening: Mapping study and assessment. ArXiv, March 2014, 13 pages.

- Devroey X., Perrouin G., Cordy M., Schobbens P-Y, Legay A., and Heymans P. Towards Statistical Prioritization for Software Product Lines Testing, *In Proceedings of the Eighth International Workshop on Variability Modelling of Software-Intensive Systems*, (VaMoS '14), Article 10, 7 pages, ACM Press, 2014.

- Devroey, X., Perrouin, G., Cordy, M., Papadakis, M., Legay, A., and Schobbens, P. A variability perspective of mutation analysis. *The 22nd ACM SIGSOFT International Symposium on the Foundations of Software Engineering, Visions and Challenge Track*, (FSE 2014), pp. 841–844.

- Devroey X., Perrouin G., Legay A., Cordy M., Schobbens P-Y., and Heymans P. Coverage criteria for behavioural testing of software product lines, *In proceedings of Leveraging Applications of Formal Methods, Verification and Validation. Technologies for Mastering Change* (ISoLA 2014), Lecture Notes in Computer Science vol. 8802, pages 336–350, Springer.

- Devroey, X., Perrouin, G., and Schobbens, P.-Y. Abstract test case generation for behavioural testing of software product lines. In *Proceedings of the 18th International Software Product Line Conference: Companion Volume for Workshops, Demonstrations and Tools - Volume 2* (New York, NY, USA, 2014), SPLC '14, ACM, pp. 86–93.

- Gonze, F., and Jungers, R. M. On the synchronizing probability function and the triple rendezvous time: New approaches to Černý's conjecture. *Lecture Notes in Computer Science 8977* (2015), 212–223.

- Gonze, F., Jungers, R. M., and Trahtman, A. N. A note on a recent attempt to improve the pin-frankl bound. *ArXiv preprint, submitted to DMTCS* (2014).
- Henard C., Papadakis M., Perrouin G., Klein J., Heymans P, and Le Traon Y. L. Bypassing the combinatorial explosion: Using similarity to generate and prioritize t-wise test configurations for software product lines. *IEEE Transactions on Software Engineering*, 40(7):650–670, 2014.
- Ho, T.-V., Deville, Y., and Bonaventure, O. Multi-objective traffic engineering for data center networks. *Computer Networks* (2014), 167–182.
- Jean-Baptiste, Deville, Y., and Lecoutre, C. Domain k-wise consistency made as simple as generalized arc consistency. In *11th International Conference on Integration of Artificial Intelligence (AI) and Operations Research (OR) techniques in Constraint Programming (CPAIOR 2014)* (2014), pp. 235–250.
- Jungers, R. M., D'Innocenzo, A., and Di Benedetto, M. D. Feedback stabilization of dynamical systems with switched delays. *Proceedings of the IEEE CDC2012* (2012).
- Jungers, R. M., D'Innocenzo, A., and Di Benedetto, M. D. Further results on controllability of linear systems with switching delays. *Proceedings of the IFAC World congress* (2014).
- Jungers, R. M., D'Innocenzo, A., and Di Benedetto, M. D. How to control linear systems with switching delays? *Proceedings of the ECC* (2014).
- Jungers, R. M., D'Innocenzo, A., and Di Benedetto, M. D. Modeling, analysis and design of linear systems with switching delays. *Arxiv:1401.1673* (2014).
- Laurent, N., Vissicchio, S., and Canini, M. Sdload: An extensible framework for sdn workload generation. In *Proceedings of the Third Workshop on Hot Topics in Software Defined Networking* (New York, NY, USA, 2014), HotSDN '14, ACM, pp. 215–216.
- Lebrun, D. Supporting IPv6 Segment Routing in the Linux kernel. Tech. rep., UCL, 2014. Available from `http://www.segment-routing.org`.
- Lebrun, D., Vissicchio, S., and Bonaventure, O. Towards test-driven software defined networking. In *Network Operations and Management Symposium (NOMS), 2014 IEEE* (May 2014), pp. 1–9.
- Lombardi, M., and Schaus, P. Cost impact guided lns. *Proceedings of International Conference on Integration of AI and OR Techniques in Constraint Programming* (2014).
- Mairy, J.-B., Hentenryck, P. V., and Deville, Y. Optimal and efficient filtering algorithms for table constraints. *Constraints* (2014), 77–120.

- Mouthuy, S., Massen, F., Hentenryck, P. V., and Deville, Y. A multi-stage very large-scale neighborhood search for the vehicle routing problem with soft time-windows. *Journal of Transportation Science* (2015).

- Sauvage-Thomase C., Biri N., Perrouin G., and Heymans P. Towards a systematic approach for cognitively efficient configuration visualizations. *Journée Lignes de Produits*, 2014.

- Pierre Schaus, R. H. Multi-objective large neighborhood search. *International Conference on Principles and Practice of Constraint Programming* (2013).

- Renaud Hartert, P. S. A support-based algorithm for the bi-objective pareto constraint in twenty-eighth. *In Twenty-Eighth AAAI Conference on Artificial Intelligence* (2014).

- Schaus, P. Variable objective large neighborhood search: A practical approach to solve over-constrained problems. *International Conference on Tools with Artificial Intelligence (ICTAI)* (2013).

- Tilmans, O., and Vissicchio, S. Igp-as-a-backup for robust sdn networks. In *Network and Service Management (CNSM), 2014 10th International Conference on* (Nov 2014), pp. 127–135.

- Van Cauwelaert, S., Lombardi, M., and Schaus, P. Supervised learning to control energetic reasoning: Feasibility study. In *Doctoral Program CP2014* (2014).

- Vanbever, L., and Vissicchio, S. Enabling SDN in old school networks with Software-Controlled Routing Protocols. Open Networking Summit (ONS) research track, 2014.

- Vianney le Clément de Saint-Marcq, Pierre Schaus, C. S., and Lecoutre, C. Sparse-sets for domain implementation. *TRICS Workshop - Techniques foR Implementing Constraint programming Systems* (2013).

- Vissicchio, S., Vanbever, L., and Bonaventure, O. Opportunities and research challenges of hybrid software defined networks. *SIGCOMM Comput. Commun. Rev. 44*, 2 (Apr. 2014), 70–75.

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5 Recent travels and presentations

- February 2018, O. Bonaventure keynote presentation at DRCN18 paris
- April 2018, M. Jadin, presentation of an article [14] at SOSR'2018
- July 2018, R. Jungers, participation at CPS Porto
- May 2018, O. Bonaventure, participation at SIGCOMM'2018 TPC meeting (Boston)
- May 2018, F. Duchene, presentation of an article [14] at IFIP Networking 2018
- June 2018, R. Jungers, participation at ECMI 2018, Budapest. Presentation of an invited talk 'Path-complete positivity as a generalization of consensus'
- June 2018, H.Verhaeghe and P. Schaus, participation and presentation of article at CPAIOR 2018

- June 2018, Viet Hoang, presentation of an article [24] and the TMA conference, Vienna
- July 2018, H. Verhaeghe, P. Schaus, participation and presentation of article at IJCAI 2018, Stockholm
- August 2018, H. Verhaeghe, participation at CP'2018,Lille
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