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Research Executive Agency  
Marie Curie Actions – Networks for Initial Training

**Project No:** 607584

**Project Acronym:** CleanSky

**Project Full Name:** Network for Cloud Computing Eco-System

## **Marie Curie Actions**

# **Final Report**

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**Project coordinator name:**  
Prof. Xiaoming Fu

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**Project coordinator organisation name:**  
GEORG-AUGUST-UNIVERSITAET GOETTINGEN  
STIFTUNG OEFFENTLICHEN RECHTS

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# Final Report

## PROJECT FINAL REPORT

<b>Grant Agreement number:</b>	607584
<b>Project acronym:</b>	CleanSky
<b>Project title:</b>	Network for Cloud Computing Eco-System
<b>Funding Scheme:</b>	FP7-MC-ITN
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<b>Project co-ordinator:</b>	
<b>Organisation PIC:</b>	999845640
<b>Organisation legal name:</b>	GEORG-AUGUST-UNIVERSITAET GOETTINGEN STIFTUNG OEFFENTLICHEN RECHTS
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# 1. FINAL PUBLISHABLE SUMMARY REPORT

## Comments:

As a paradigm for information technology (IT), cloud computing is “a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.” Cloud computing is evolving and supported not only in small data centers but also over largescale, energy-efficient new computing in frastructures. Example scenarios of large-scale cloud computing include scientific computing and telecommunication services, where big data and traffic are generated and need to be processed in a cost-efficient manner.

CleanSky ITN (<http://www.cleansky-itn.org/>) aims to develop innovative ideas in the emerging areas within the “eco-system” of cloud computing: data center evolution, consolidation and service migration, and beyond, via structural training of young researchers. To achieve this goal, a unique combination of academic institutions and industrial organizations will collaborate together and create a multidisciplinary (computer science, telecommunications, scientific computing and optimization theory), international (four European countries plus USA and China) and intersectoral (public and private; education and industry) environment to embed a pool of young researchers for innovative research in cloud computing.

The specific objectives of CleanSky are to develop innovative methodologies and approaches to satisfy application requirements and ensure efficiency within the emerging cloud computing paradigm and to optimize the energy and provisioning costs of individual data centers. In particular, Cleansky aims at improving the network infrastructure that supports the cloud eco-system, wherein Software Defined Networking (SDN) and Network Function Virtualization (NFV), two new paradigms have a big impact on efficiency and resource provisioning, especially in data centers and cloud environments.

In the first half of the project, Cleansky fellows have been working and collaborating on a variety of challenges, including the characterization and measurement of cloud network usage, technical methods to improve efficiency and resource provisioning and the theoretical foundations for doing so. For each of these challenges concrete problems have been investigated, including the modeling of user requests and the allocation of these requests to caches (characterization), measuring failures in cloud services (characterization), scaling clouds to computation- or storage intensive applications (technical methods), service function chaining for mobile and software defined networks (technical methods), or developing theoretical models for virtual network function placement and energy efficiency of these functions (theoretical foundation).

In the second half of the project, Cleansky fellows have been working and collaborating on new networking cloud relevant technologies such as edge and optical cloud networks, network function virtualization and microservices. Specifically, they have proposed solutions for data management in edge cloud; balancing Multiple Objectives for NFV Resource Allocation; resource Management Framework for NFV-based service function chaining, renewable energy based deployment of Virtual Network Functions, dynamic Backpressure and scheduling for NFV service chains; energy-aware provisioning in optical cloud networks, optimizing resource utilization of complex services; long-term energy efficient storage of gene sequencing, energy efficient network path usage of edge resources; a joint traffic anomaly detection and root cause analysis based approach for deploying network functions as microservices; and the development of a mathematical model that jointly considers dynamic network service composition strategies, scalable network function placement and carrier grade redundancy.

As an initial training network, CleanSky also aims at providing excellent training to the twelve fellows that contributed to the research described above. In this regard, CleanSky has organized 3 summer schools and co-located training workshops for fellows and external participants. We also organized a total of three conferences. These conferences were also open to external members and also had talks from external speakers. CleanSky has also actively disseminated the results via publications, talks at conferences/workshops as well as poster sessions on the sidelines of the conferences and summer schools organized by CleanSky.

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<http://www.cleansky-itn.org/>

## 2. USE AND DISSEMINATION OF FOREGROUND

### Section A (public) – DISSEMINATION MEASURES

#### Dissemination activities

##### Comments:

NOTE: D5.6 provides a detailed summary of the dissemination activities throughout the project. Here, we provide a quick summary of the dissemination activities.

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Media and Channels  
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Press releases: 8 press releases (includes public press release, news article, article in news letter)

Cleansky website: The project website, which is available at <http://www.cleansky-itn.org/>, acted as a hub for the project, both internally and externally. The project website includes:

- project information including its vision, goals, and partners,
- personal web pages of all CleanSky fellows,
- resources like publications,
- information about conferences and training events, and
- sections with news and updates from social media channels.

Social Media: The project made extensive use of social media, in particular Facebook (<https://www.facebook.com/cleanskyitn>). The Facebook posts addressed both researchers as well as the general public who was interested in, e.g. hashtags relevant to CleanSky research. CleanSky fellows and their work, CleanSky events, and results from the project were highlighted through this channel. The project's Twitter account can be found at <https://twitter.com/CleanSkyITN>. It was mainly used to re-publish information that is also published via Facebook. As this did not seem to attract a significant amount of interest, the CleanSky project decided to provide access to the account also to the fellows. This allowed the fellows to report their own work via Twitter directly and it generated more contributions in this channel thus making it more attractive.

Usage of partner-specific Channels: CleanSky combined not only the expertise of its international consortium, but also the opportunity to use partner-specific DOE channels as multipliers. Obviously, partners used press releases or other material from the media package to disseminate information about CleanSky within their networks. Furthermore, partner networks were also valuable targets for outreach activities and for the exploitation of algorithms or software.

Dissemination to the general public: Regarding the dissemination to the general public, all partners exploited their channels (like those mentioned earlier) for disseminating the work done in CleanSky to a broad audience. According to the description of work, CleanSky made its project results publicly visible through the following dissemination activities:

- The CleanSky website as introduced above.
- Publication of the project results in leading international conferences and journals.
- Regular presentations of research results at national, European, and international workshops.
- Project deliverables.

- Participation in international organization activities, e.g., in project-related IEEE and ACM committees.

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## Scientific Publications and Presentations

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One core objective of the CleanSky Initial Training Network was to enable excellent research. The core dissemination instrumented to inform about the results of such excellent research are publications. CleanSky ESRs and ERs therefore published their work in peer reviewed leading international conferences or journals. According to the Description of Work, it was planned to have at least three publications per ESR over a period of three years and at least two publications per ER over a period of two years. We had 45 (published or accepted) until the end of the project. Complementing training activities, e.g. during CleanSky summer schools or training events, helped the ESRs and ERs to improve their scientific writing skills and to increase the probability of successful submissions at leading conferences and journals. The CleanSky fellows also presented their scientific results to various audiences. This happened in the context of accepted scientific papers at conferences, at workshops, or at partner-internal events.

Within the reporting period, CleanSky fellows and researchers produced 48 scientific publications in total and CleanSky fellows and partners gave 66 presentations related to CleanSky. The publications from CleanSky fellows can be further subdivided as follows:

- Published (this includes publications that have been accepted for publication at a journal or conference, but cannot be cited yet): 48
- Submitted (papers that are submitted and currently under review): 1
- In preparation (papers that are currently prepared by fellows to be submitted timely): 2-3

The complete list of publications including five publications by CleanSky partners can be found in the website as well as Annex B of D5.6.

As particularly the ESR fellows progress to the later stages of their fellowships, the research output has improved in both quality (including publications at signature venues such as ACM SIGCOMM 2017, ACM CONEXT 2018) and quantity.

## Publications

LIST OF SCIENTIFIC PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES

No.	Title / DOI	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Date of publication	Relevant pages	Is open access provided to this publication ?	Type
1	RConf(PD): Automated resource configuration of complex services in the cloud ht <a href="https://doi.org/10.1016/j.future.2018.02.027">tps://doi.org/10.1016/j.future.2018.02.027</a>	Abhinandan S. Prasad , David Koll , Jesus Omana Iglesias , Jordi Arjona Aroca , Volker Hilt , Xiaoming Fu	Future Generation Computer Systems	Vol. 87	Elsevier	Netherlands	01/10/2018	639-650		Peer reviewed
2	Policy Management Engine (PME): A policy-based schema to classify and manage sensitive data in cloud storages <a href="https://doi.org/10.1016/j.jisa.2017.07.003">https://doi.org/10.1016/j.jisa.2017.07.003</a>	Faraz Fatemi Moghaddam , Philipp Wieder , Ram in Yahyapour	Journal of Information Security and Applications	Vol. 36	Elsevier Limited	Netherlands	01/10/2017	11-19		Peer reviewed
3	Reliable Virtual Machine Placement and Routing in Clouds 10.1109/TPDS.2017.2693273	Song Yang , Philipp Wieder , Ram in Yahyapour , Stojan Trajanovski , Xiaoming Fu	IEEE Transactions on Parallel and Distributed Systems	Vol. 28/Issue 10	IEEE Computer Society	United States	01/10/2017	2965-2978		Peer reviewed
4	Energy-Aware Provisioning in Optical Cloud Networks ht <a href="https://doi.org/10.1016/j.comnet.2017.03.008">tps://doi.org/10.1016/j.comnet.2017.03.008</a>	Song Yang , Philipp Wieder , Ram in Yahyapour , Xiaoming Fu	Computer Networks	Vol. 118	Elsevier	Netherlands	01/05/2017	78-95		Peer reviewed
5	CATENAE: A scalable service function chaining system for legacy mobile networks <a href="https://doi.org/10.1002/nem.1965">https://doi.org/10.1002/nem.1965</a>	Roberto Bifulco , Anton Matusiuk , Alessio Silvestro	International Journal of Network Management	Vol. 27/Issue 2	John Wiley and Sons Ltd	United Kingdom	01/03/2017	e1965		Peer reviewed
6	Inter-Burst Segregation Protocol Guarant	Sachin	IEEE Communications Letters	Vol.	Institute of Electrical	United States	01/10/2016	1959-1962		Peer re

	teeing Loss-Free Packet-Switched Networks 10.1109/LCOMM.2016.2594291	Sharma , Dider Colle , Wouter Tavernier , Mario Pickavet , Piet Demeester		20/Issue 10	and Electronics Engineers Inc.					viewed
7	Measures for Network Structural Dependency Analysis 10.1109/LCOMM.2018.2864109	Yordanos T. Woldeyohannes , Yuming Jiang	IEEE Communications Letters	-	Institute of Electrical and Electronics Engineers Inc.	United States	07/08/2018	1-1		Peer reviewed
	A scalable resource allocation scheme for NFV: Balancing utilization and path stretch 10.1109/ICIN.2018.8401631	Y. T. Woldeyohannes , Ali Mohammadkhan , K. K. Ramakrishnan , Yuming Jiang	2018 21st Conference on Innovation in Clouds, Internet and Networks and Workshops (ICIN)		IEEE		19/02/2018	1-8		Conference
	MISE 10.1145/3155921.3155923	Alessio Silvestro , Roberto Bifulco , Fabian Schneider , Xiaoming Fu , Jussi Kangasharju	Proceedings of the 2nd Workshop on Cloud-Assisted Networking - CAN '17		ACM Press	New York, New York, USA	11/12/2017	37-42		Conference
	Token-based policy management (TBPM): A reliable data classification and access management schema in clouds 10.1109/CCST.2017.8167836	Faraz Fatemi Moghaddam , Philipp Wieder , Ram in Yahyapour	2017 International Carnahan Conference on Security Technology (ICCST)		IEEE		23/10/2017	1-6		Conference
	Failure process characteristics of cloud-enabled services 10.1109/RNDM.2017.8093033	Besmir Tola , Yuming Jiang , Bjarne E. Helvik	2017 9th International Workshop on Resilient Networks Design and Modeling (RNDM)		IEEE		04/09/2017	1-7		Conference
	NFVnice 10.1145/3098822.3098828	Sameer G. Kulkarni , Wei Zhang , Jinho Hwang , Shriram Rajagopalan , K. K. Ramakrishnan , Timothy Wood , May utan Arumai	Proceedings of the Conference of the ACM Special Interest Group on Data Communication - SIGCOMM '17		ACM Press	New York, New York, USA	21/08/2017	71-84		Conference



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	RAERA 10.1145/3098208.3098217	Abhinandan S. Prasad , Mayutan Aru maithurai , David Koll , Xiaoming Fu	Proceedings of the Workshop on Mobile Edge Communications - MECOMM '17		ACM Press	New York, New York, USA	21/08/2017	49-54		Conference
	Managing Data in Computational Edge Clouds 10.1145/3098208.3098212	Nitinder Mo han , Pengy uan Zhou , Keerthana Govindaraj , Jussi Kan gasharju	Proceedings of the Workshop on Mobile Edge Communications - MECOMM '17		ACM Press	New York, New York, USA	21/08/2017	19-24		Conference
	REARM: Renewable energy based resilient deployment of Virtual Network Functions 10.1109/EuCNC.2017.7980676	Sameer G Kulkarni , Mayutan Aru maithurai , K.K. Ra makrishnan , Xiaoming Fu	2017 European Conference on Networks and Communications (EuCNC)		IEEE		12/06/2017	1-6		Conference
	DRENCH: A semi-distributed resource management framework for NFV based service function chaining 10.23919/IFIPNetworking.2017.8264858	Argyrios G. Tasiopoulos , Sameer G. Kulkarni , Mayutan Aru maithurai , Ioannis Psaras , K. K. Ra makrishnan , Xiaorning Fu , George Pavlou	2017 IFIP Networking Conference (IFIP Networking) and Workshops		IEEE		12/06/2017	1-9		Conference
	Federated policy management engine for reliable cloud computing 10.1109/ICUFN.2017.7993931	Faraz Fatemi Moghaddam , Philipp Wieder , Ram in Yahyapour	2017 Ninth International Conference on Ubiquitous and Future Networks (ICUFN)		IEEE		04/07/2017	910-915		Conference
	POBRES: Policy-based re-encryption schema for secure resource management in clouds 10.1109/EUROCON.2017.8011070	Faraz Fatemi Moghaddam , Philipp Wieder , Ram in Yahyapour	IEEE EUROCON 2017 -17th International Conference on Smart Technologies		IEEE		01/07/2017	15-21		Conference

Optimal Resource Configuration of Complex Services in the Cloud 10.1109/CCGRID.2017.67	Abhinandan S. Prasad , David Koll , Jesus Omana Iglesias , Jordi Arjona Aroca , Volker Hilt , Xiaoming Fu	2017 17th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing (CCGRID)	IEEE		14/05/2017	42-53		Conference
Is today's DNS the right solution for middleboxes selection? 10.1145/3069383.3069389	A. Silvestro , R. Bifulco , F. Schneider , X. Fu , J. Kangasharju	Proceedings of the 4th Workshop on CrossCloud Infrastructures & Platforms - Crosscloud'17	ACM Press	New York, New York, USA	23/04/2017	1-2		Conference
Grouping Computational Data in Resource Caches of Edge-Fog Cloud 10.1145/3069383.3069391	Nitinder Mohan , Pengyuan Zhou , Keerthana Govindaraj , Jussi Kangasharju	Proceedings of the 4th Workshop on CrossCloud Infrastructures & Platforms - Crosscloud'17	ACM Press	New York, New York, USA	23/04/2017	1-2		Conference
Latency-Sensitive Data Allocation for cloud storage 10.23919/INM.2017.7987258	Song Yang , Philipp Wieder , Muzzamil Aziz , Ramin Yahyapour , Xiaoming Fu	2017 IFIP/IEEE Symposium on Integrated Network and Service Management (IM)	IEEE		08/05/2017	1-9		Conference
CityFlow, enabling quality of service in the Internet: Opportunities, challenges, and experimentation 10.23919/INM.2017.7987289	Sachin Sharma , David Palma , Joao Goncalves , Dimitri Staesens , Nick Johnson , Charaka Palansuriya , Ricardo Figueiredo , Luis Cordeiro , Donal Morris , Adam Carter , Rob Baxter , Didier Colle ,	2017 IFIP/IEEE Symposium on Integrated Network and Service Management (IM)	IEEE		08/05/2017	272-280		Conference

		Mario Pickavet								
NFV service dynamicity with a DevOps approach: Insights from a use-case realization 10.23919/INM.2017.7987357	Steven Van Rossem , Xue jun Cai , Ivano Cerrato , Per Danielsson , Felician Nemeth , Bertrand Pechenot , Istvan Pelle , Fulvio Risso , Sachin Sharma , Pontus Skoldstrom , Wolfgang John	2017 IFIP/IEEE Symposium on Integrated Network and Service Management (IM)		IEEE		08/05/2017	674-679			Conference
Neo-NSH: Towards scalable and efficient dynamic service function chaining of elastic network functions 10.1109/ICIN.2017.7899429	Sameer Kulkarni , Mayutan Arumathurai , K. K. Ramakrishnan , Xiaoming Fu	2017 20th Conference on Innovations in Clouds, Internet and Networks (ICIN)		IEEE		07/03/2017	308-312			Conference
Profiling and Grouping Users to Edge Resources According to User Interest Similarity 10.1145/3010079.3010081	Pengyuan Zhou , Jussi Kangasharju	Proceedings of the 2016 ACM Workshop on Cloud-Assisted Networking - CAN '16		ACM Press	New York, New York, USA	12/12/2016	43-48			Conference
Edge-Fog cloud: A distributed cloud for Internet of Things computations 10.1109/CIOT.2016.7872914	Nitinder Mohan , Jussi Kangasharju	2016 Cloudification of the Internet of Things (CIoT)		IEEE		23/11/2016	1-6			Conference
Reliable Virtual Machine placement in distributed clouds 10.1109/RNDM.2016.7608297	Song Yang , Philipp Wieder , Ram in Yahyapour	2016 8th International Workshop on Resilient Networks Design and Modeling (RNDM)		IEEE		13/09/2016	267-273			Conference
Policy Engine as a Service (PEaaS): An Approach to a Reliable Policy Management Framework in Cloud Computing Environments 10.1109/FiCloud.2016.27	Faraz Fatemi Moghaddam , Philipp Wieder , Ram in Yahyapour	2016 IEEE 4th International Conference on Future Internet of Things and Cloud (FiCloud)		IEEE		22/08/2016	137-144			Conference

Ready-to-deploy service function chaining for mobile networks 10.1109/NETSOFT.2016.7502411	Roberto Bifulco , Anton Matsiuk , Alessio Silvestro	2016 IEEE NetSoft Conference and Workshops (NetSoft)		IEEE		06/06/2016	175-183		Conference
DVMP: Incremental traffic-aware VM placement on heterogeneous servers in data centers 10.1109/IWQoS.2016.7590390	Dan Li , Syed Shah-e-Mardan Ali Rizvi , Fangxin Wang , Wu He	2016 IEEE/ACM 24th International Symposium on Quality of Service (IWQoS)		IEEE		23/06/2016	1-10		Conference
Name enhanced SDN framework for service function chaining of elastic Network functions 10.1109/INFOCOMW.2016.7562043	Sameer G Kulkarni , Mayutan Arumathurai , Argyriou Tsipopoulos , Yiaonis Psaras , K.K. Ramakrishnan , Xiaoming Fu , George Pavlou	2016 IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS)		IEEE		10/04/2016	45-46		Conference
ARVE 10.1145/3229556.3229564	Pengyuan Zhou , Wenxiao Zhang , Tristan Braud , Pan Hui , Jussi Kangasharju	Proceedings of the 2018 Workshop on Mobile Edge Communications - ME COMM'18		ACM Press	New York, New York, USA	20/08/2018	25-30		Conference
Anveshak 10.1145/3229556.3229560	Nitinder Mohan , Aleksandr Zavadovski , Pengyuan Zhou , Jussi Kangasharju	Proceedings of the 2018 Workshop on Mobile Edge Communications - ME COMM'18		ACM Press	New York, New York, USA	20/08/2018	7-12		Conference
An effective user revocation for policy-based access control schema in clouds 10.1109/CloudNet.2017.8071549	Faraz Fatemi Moghaddam , Philipp Wieder , Ramtin Yahyapour	2017 IEEE 6th International Conference on Cloud Networking (CloudNet)		IEEE		25/09/2017	1-6		Conference
A Reliable Ring Analysis Engine for Estab	Faraz Fatemi	2018 41st International Conference on		IEEE		04/07/2018	1-5		Conference

lishment of Multi-Level Security Management in Clouds 10.1109/TSP.2018.8441183	Moghaddam , Philipp Wieder , Ram in Yahyapour , Touraj Khodadadi	Telecommunications and Signal Processing (TSP)							
REINFORCE: Achieving Efficient Failure Resiliency for Network Function Virtualization based Services	Sameer G Kulkarni (ESR5), Guy ue Liu, K.K. Ramakrishnan, Mayutan Arumathurai, Timothy Wood, Xiaoming Fu	ACM CONEXT 2018 (ACM CoNEXT'18)		ACM		04/12/2018		Yes	Conference
Issues in Supporting Third-Party's In-Network Services in the Internet	Alessio Silvestro, Roberto Bifulco, Sachin Sharma, Fabian Schneider, Jussi Kangasharju, Xiaoming Fu	Ph.D Forum Netsys 2017	-	IEEE Computer Society		13/03/2017			Monogram
REARM: Renewable Energy based Resilient Deployment of Virtual Network Functions	Sameer G Kulkarni, Mayutan Arumathurai, K.K. Ramakrishnan, Xiaoming Fu	Ph.D Forum Netsys 2017	-	IEEE Computer Society		13/03/2017			Monogram
Resource Management for Efficient, Scalable and Resilient Network Function Chains	Sameer Kulkarni			University of Goettingen, Institute of Computer Science	Germany	04/07/2018			Thesis
Architectural Support for Implementing Service Function Chains in the Internet	Alessio Silvestro			University of Goettingen, Institute of Computer Science		25/06/2018			Thesis
Automated Provisioning of Fairly Priced Resources	Abhinandan Sridhara Rao Prasad			University of Goettingen, Institute of Computer Science		21/06/2018			Thesis
Multi-Layered Policy Generation and Managements in Clouds	Faraz Fatemi Moghaddam			University of Goettingen, Institute of Com		12/12/2017			Thesis

