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REPORT

Taxonomy for the Network and Service Management Research Field

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Abstract Network and service management has established itself as a research field in the general area of computer networks. However, up to now, no appropriate organization of the field has been carried out in terms of a comprehensive list of terms and topics. In this paper, we introduce a taxonomy for network and service management. With such a taxonomy, it is possible to better understand the landscape of research as well as to reason about possible future challenges and opportunities. As such, in addition to the taxonomy itself, we also present an initial analysis of the field's past, present, and future, based on the records of papers submitted and accepted in major conferences in the area, as well as a site survey

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performed through a questionnaire answered by experts from both industry and academia.

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1 Introduction

Shortly after the second world war, many universities, industries, and governments started research in a brand new area: computing. This research resulted, amongst others, in the publication of papers and books on different topics, such as the design of computer hardware, programming languages, operating systems, and databases. At the end of the sixties, a new topic was added to this list: computer networks. Compared to traditional and nowadays well-organized disciplines, research on how to *manage* computer networks and their associated services started relatively late. The first conference in the field, the IFIP WG6.6 Symposium on Integrated Network Management, was organized in May 1989 in Boston, USA [1, 3]. Since that first conference, many ideas, concepts, and approaches have been proposed [4]. Some of these turned out to be very useful, although others did not make it and have long been forgotten. Although dynamics and reshaping is good for a young and emerging research field, after a while it may become necessary to organize the field a bit, in an attempt to better position and identify experts, research groups, standardization bodies, and events such as conferences.

In the general area of computing, the Association for Computing Machinery (ACM) has created a multi-level classification system that structures key terms like Hardware, Software, and Data at level one, and terms like Computer Communication Networks, Software Engineering, Programming Languages, and Operating Systems at level two [2]. Although the ACM classification does include the keywords Network Management, Network Monitoring, and System Management, it does not provide any further details. The ACM classification therefore does not help to further structure the field of network and service management.

There are many possible goals for a network and service management taxonomy. For example, one goal may to partition standardization efforts and to identify standards bodies in charge of developing standards for the various topics within the taxonomy. As another example, a taxonomy can be used to identify classes of managed objects. In this paper, however, we introduce a network and service management taxonomy whose main goal is to improve the scientific quality of papers that are published in the field. One important way to improve quality is finding the most appropriate reviewers for each submitted paper. Organizers of conferences and (special issues of) journals currently do not have a complete view of who would be the best expert for a certain topic. Instead, Technical Program Committee (TPC) chairs generally create, as part of their Call for Papers (CFP), a list of topics relevant for each specific conference. While submitting a paper, authors can indicate (either as keywords or as part of the submission process) which of these topics are addressed by their papers. In addition, TPC members are asked to fill out a form to indicate their expertises. Conference management systems such as

the Journal and Event Management System (JEMS)[1] and Editor's Assistant (EDAS)[2] have functions to match the expertise of the reviewer to the topic of the paper. For journal management systems (e.g., Manuscript Central), similar functions exist.

Although current approaches of matching reviewers and papers may sometimes work quite well, they have several drawbacks. First, several journals (e.g., IEEE Communications Magazine) rely on the ACM classification system only; this system is too broad to be useful for finding the best match between paper and reviewer. Second, TPC members do not always spend time to indicate their expertises; some recent checks showed, for example, that between 5 and 30 % of TPC members do not respond at all. Third, topics of interest have to be re-entered for every new conference, making this process time consuming and error prone. Fourth, the list of topics is often presented as a flat list, with all topics at the same level of detail. In this scenario, a taxonomy that provides a stable, structured list of topics is essential. So far, however, no such a taxonomy did exist covering current and important topics in the network and service management field. This paper thus introduces an updated taxonomy for that field.

The remainder of this paper is organized as follows. In Sect. 2, we present the methodology employed to identify important topics to then introduce the taxonomy on network and service management itself. By means of a questionnaire answered by experts from both industry and academia, we observe in Sect. 3 the interest in the topics of the taxonomy. In Sect. 4, we classify papers submitted to the major conferences in the field (i.e., NOMS, IM, and CNSM) to understand the landscape of network and service management research, as well as to match the answers of the questionnaire with the landscape of papers from those major conferences. Finally, in Sect. 5, we conclude this paper summarizing our findings and outlining future work.

2 Network and Services Management Taxonomy

In this Section, we introduce the taxonomy for the network and service management field. This taxonomy is the result of a joint collaborative work of the following organizations and initiatives:

- IFIP WG6.6, which is responsible, in the IFIP structure, to lead the efforts on network management;
- The Committee on Network Operations and Management (CNOM) of the IEEE Communications Society;
- The Network Management Research Group (NMRG) of the Internet Research Task Force (IRTF); and
- The Emanics Network of Excellence.

[1] http://jems.sbc.org.br.

[2] http://edas.info.

For a broader dissemination, the original version of the network and service management taxonomy, dated from 2008, is currently available at the SimpleWeb site.[3] Topics are organized in a two-level list of keywords. The first level indicates a broad area, whereas the second level refines that area. Topics from both levels are used by authors to tag their papers and, more generally, by researchers to indicate their expertises and interests. By matching paper keywords to reviewers' expertise, organizers of journals and conferences are able to improve the quality of reviews and, consequently, the quality of papers too.

The network and service management taxonomy was incorporated into JEMS, and has been used by important network management conferences (e.g., NOMS, IM, CNSM) since 2008. Its implementation in JEMS allows conference chairs to share a common set of topics among several conference entries, thus helping to track the interest of authors and reviewers in regards to the several topics of the field. Its usage has the additional benefit of avoiding authors getting confused with conferences in the same area that do not have a consistent list of topics among them.

Originally defined back in 2008, the network and service management community has recently noticed that some important topics were missing from the taxonomy. It was common for TPC chairs, for example, to expand the original taxonomy by defining new topics and linking them to the original terms. As a consequence, an effort to revisit and to improve the original taxonomy, defined in 2008, took place. In the next subsection, we detail the methodology used to identify the important topics that resulted in the second, improved version of our taxonomy. Such a methodology considered the opinion and point-of-view of both industry and academia.

2.1 Methodological Approach for Topics Classification

To identify the most important topics on network and services management, internationally respected people from industry and academia were invited to participate in a survey in September 2013. There exist several conferences and workshops where management aspects are addressed. In this stage of defining the taxonomy we concentrate on selecting respondents that are TPC members of NOMS, IM, and CNSM. These events are recognized as the most important and enduring in the area. In the future, however, members of other conferences can help to improve that taxonomy too. We also prefer to concentrate on NOMS, IM, and CNSM for the moment because important topics that will mature in other events will eventually become important in NOMS, IM, and CNSM as well. We thus believe that NOMS, IM, and CNSM, through their TPC members, reflect topics that are more stable along the time. It does not mean that other topics from other conferences are not important; rather, it means that important topics will show up in the context of NOMS, IM, and CNSM eventually.

Each respondent was requested to answer a questionnaire consisting of:

[3] http://www.simpleweb.org/ifip/taxonomy.html.

- **Challenge Description** a description of an unsolved challenge/problem that needs to be addressed by network and service management systems;
- **Deadline** an estimated date for which the challenge/problem should be solved;
- **Context** the best place(s) to address and to solve the challenge (e.g., industry internal, standardization body, academia).

Each respondent was requested to list approximately 10 challenges. In total, 24 people (13 from industry and 11 from academia) returned the questionnaire. Participants from academia identified, in total, 83 challenges; industry participants identified 84 challenges. We further divided respondents from industry into 5 subgroups, which identified the following number of challenges: network operators (19 challenges); device manufacturers of wired equipment (14 challenges); device manufacturers of wireless equipment (34 challenges); cloud infrastructure and service providers (15 challenges); and network monitoring companies (2 challenges).

In terms of geographical distribution of respondents, Table 1 depicts the percentage of participants from industry and academia from the different continents.

Furthermore, the participants also indicated the time line and whether the identified challenge should be driven by industry, academia, a standardization body, or a joint effort. Based on terms and topics referred to within the questionnaires, 17 new topics were identified and added to the original taxonomy, which results now in a taxonomy composed, in total, of 56 topics.

2.2 Updated Taxonomy

The updated version of the taxonomy was created by extending the original one with topics referred to within the answers of the questionnaire. The updated taxonomy is presented in Table 2, which shows the two-level list of keywords. The 7 first-level keywords identify the seven broad areas from (1) Network Management to (7) Methods. The second-level keywords associated with each first-level keyword are shown as the bulleted keywords below each first-level keyword. New topics are denoted in italic in all Tables of this paper where topics are presented.

First level topics from 1 (Network Management) to 4 (Functional Areas) organize what is being managed (e.g., optical networks, multimedia services, business processes, and security aspects), while first level topics from 5 (Management

Table 1 Geographical distribution of participants from industry and academia

Region	Participant fraction	
	Industry (%)	Academia (%)
Europe	54	64
Middle East		9
South America		9
North America	23	9
Asia	23	9

Table 2 Network and service management taxonomy

1. Network Management	5. Management Approaches
• Ad-Hoc Networks	• Centralized Management
• Wireless and Mobile Networks	• Distributed Management
• IP Networks	• Autonomic and Self Management
• Local Area Networks	• Policy-Based Management
• Optical Networks	• *Federated Network Management*
• Sensor Networks	• *Pro-Active Management*
• Overlay Networks	• *Energy-Aware Network Management*
• *Virtual Networks*	6. Technologies
• *Software Defined and Programmable Networks*	• Protocols
• *Data Center Networks*	• Middleware
• *Smart Grids*	• Mobile Agents
2. Service Management	• P2P
• Multimedia Services (e.g., Voice, Video)	• Grids
• Data Services (e.g., Email, Web)	• Data, Information, and Semantic Modeling
• Hosting (Virtual Machines)	• *Cloud Computing*
• Grids	• *Internet of Things*
• *Cloud Services*	• *Human–Machine Interaction*
• *Resource Provisioning and Management*	• *Operations and Business*
• *QoE-Centric Management*	• *Support Systems (OSS/BSS)*
• *Service Discovery, Migration, and Orchestration*	7. Methods
3. Business Management	• Control Theories
• Legal and Ethical Issues	• Optimization Theories
• Process Management	• Economic Theories
4. Functional Areas	• Machine Learning and Genetic Algorithms
• Fault Management	• Logics
• Configuration Management	• Probabilistic, Stochastic Processes, Queuing Theory
• Accounting Management	• Simulation
• Performance Management	• Experimental Approach
• Security Management	• Design
• SLA Management	• *Monitoring and Measurements*
• Event Management	• *Data Mining and (Big) Data Analytics*

Approaches) to 7 (Methods) report how management targets are managed (e.g., using policy-based approach, employing P2P technologies, and observing results of simulations). An author that is proposing protocols to deploy policies at the controller in an SDN simulated environment, for example, would probably tag his/her paper picking the following first and second level topics: (1) Network Management/Software Defined and Programmable Networks, (2) Management

Approaches/Centralized Management, (3) Management Approaches/Policy-Based Management, and (4) Methods/Simulation.

New topics included in the taxonomy represent increased interest, from both academia and industry, in aspects that were absent in the 2008s version. Because of such increased interest, we draw below some considerations about each new topic included in this new version of the taxonomy.

- **Virtual Networks** This topic includes all aspects related to managing virtualized network environments, e.g., virtual network embedding, network-as-a-service architectures, and Network Function Virtualization (NFV);
- **Software Defined and Programmable Networks** Software Defined Networking (SDN) is most commonly defined as a network consisting of network elements (e.g., routers) whose control and forwarding planes have been separated. This topic is concerned with management issues of such software-driven control planes. It is also related to virtual networks, since SDN can be used as an enabler for implementing network virtualization functionality;
- **Data Center Networks**This topic encompasses aspects related to managing data centers at infrastructure and hardware levels. It is related to Cloud Computing, since cloud Infrastructure-as-a-Service (IaaS) solutions are deployed on top of physical data center infrastructures;
- **Smart Grids** The topic includes all aspects related to managing Smart electrical Grids;
- **Cloud Services** This topic encompasses the management of services and applications deployed upon Cloud Computing middlewares. It does not include management of the cloud middleware itself or the data center it is deployed upon;
- **Resource provisioning and management** This topic encompasses the allocation, provisioning, and management of physical or virtual network, computing, and storage resources for the delivery of services and applications;
- **QoE-Centric Management** Traditionally, services are managed from the operator's point-of-view, focusing on optimizing network-based service parameters and metrics. In contrast, Quality of Experience (QoE)-centric management attempts to manage services based on the end-user's perspective and correlates network parameters with their effect on the end-user's experience;
- **Service Discovery, Migration, and Orchestration** This topic pertains to all algorithmic and protocol aspects of discovering services, setting up complex service delivery chains (e.g., workflows or orchestration), and migrating services (e.g., in cloud environments);
- **Federated Network Management** In the network and service management area, federation refers to the management of a collaboration of multiple (independent) network domains, e.g., the collaborative end-to-end delivery of services;
- **Pro-Active Management** This topic encompasses the management approaches that pro-actively make decisions based on predictions of how the managed environment will evolve. As such, it stands in contrast to reactive management;

- **Energy-Aware Network Management** This topic focuses on the management approaches that attempt to optimize energy consumption of the managed environment;
- **Cloud Computing** This topic is related to managing the cloud middleware itself, such as cloud management algorithms or architectures;
- **Internet of Things** This topic encompasses all aspects related to managing Internet of Things infrastructures and applications;
- **Human–Machine interaction** This topic focuses on the interaction between the management system and its human operator, such as, for example, visualization techniques;
- **Operations and Business Support Systems (OSS/BSS)** This topic encompasses all aspects related to the telecom operator's OSS and BSS.
- **Monitoring and Measurements** This topic is related to approaches for gathering data and information from the underlying managed network.
- **Data Mining and (Big) Data Analytics** This topic consists of techniques for analyzing (potentially huge amounts of) management data (e.g., gathered through monitoring).

3 Analysis of Taxonomy Topics Based on Questionnaire

In this Section, we analyze the relevance of the proposed taxonomy's topics based on the answers of the questionnaire provided by network and service management experts from industry and academia.

Table 3 shows the percentage of questionnaire participants (P) and challenges (C) that refer to each topic, separately for industry and academia. If a participant mentioned a topic in any of his/her reported challenges, then that topic is accounted for that participant only once, regardless the number of challenges of that participant that refers to that topic. As a result, a single topic may look more popular among participants than among challenges.

Topics that were not mentioned by any respondent are omitted. There are different reasons for topics not being mentioned. First, they may have lost their popularity along the years (e.g., Overlay Networks, Data Services, Grids). Second, they may not be as popular in the network and services management community as they are in other related networking communities (e.g., Ad-Hoc Networks, Sensor Networks, Business Management). Third, some terms refer to methodologies, which tend to be forgotten when answering about future research directions (e.g., Simulation, Experimental Approaches, Design).

We consider as very important those topics that are mentioned by at least 20 % of participants from both industry and academia. In total, 11 topics are deemed very important (tagged with a ">" in Table 3): Virtual Networks, Software Defined and Programmable Networks, Fault Management, Security Management, Distributed Management, Autonomic and Self Management, Federated Network Management, Cloud Computing, Internet of Things, Monitoring and Measurements, Data Mining

Table 3 Percentage of questionnaire participants (P) and challenges (C) that referred to the different taxonomy topics

Topic	Industry		Academia	
	P (%)	C (%)	P (%)	C (%)
1. Network Management				
Wireless and Mobile Networks	46.2	10.7	9.1	2.4
LANs	7.7	1.2	0.0	0.0
Optical Networks	0.0	0.0	9.1	1.2
>*Virtual Networks*	53.8	9.5	45.5	12.0
>*Software Defined and Programmable Networks*	38.5	11.9	54.5	9.6
Data Center Networks	7.7	1.2	9.1	1.2
Smart Grids	7.7	1.2	0.0	0.0
2. Service Management				
Cloud Services	23.1	9.5	18.2	2.4
Resource Provisioning and Management	15.4	3.6	45.5	8.4
QoE-Centric Management	30.8	4.8	18.2	2.4
Service Discovery, Migration, and Orchestration	7.7	1.2	36.4	4.8
4. Functional Areas				
>Fault Management	53.8	13.1	36.4	7.2
Configuration Management	15.4	2.4	0.0	0.0
Performance Management	23.1	3.6	0.0	0.0
>Security Management	38.5	7.1	63.6	16.9
SLA Management	7.7	1.2	18.2	2.4
Event Management	0.0	0.0	9.1	1.2
5. Management Approaches				
>Distributed Management	23.1	3.6	36.4	4.8
>Autonomic and Self Management	53.8	8.3	36.4	7.2
Policy-Based Management	15.4	2.4	18.2	4.8
>*Federated Network Management*	23.1	3.6	54.5	13.3
Pro-Active Management	23.1	3.6	0.0	0.0
Energy-Aware Network Management	15.4	2.4	27.3	3.6
6. Technologies				
Data, Information, and Semantic Modeling	30.8	6.0	9.1	1.2
>*Cloud Computing*	30.8	9.5	27.3	14.5
>*Internet of Things*	23.1	4.8	45.5	4.8
Human–Machine Interaction	23.1	3.6	9.1	1.2
Operations and Business Support Systems	30.8	4.8	0.0	0.0
7. Methods				
Control Theories	7.7	1.2	0.0	0.0
Machine Learning and Genetic Algorithms	15.4	2.4	9.1	1.2
Probabilistic Processes, Queuing Theory	7.7	1.2	0.0	0.0
>*Monitoring and Measurements*	23.1	5.0	72.7	14.5
>*Data Mining and (Big) Data Analytics*	46.2	10.7	45.5	8.4

and (Big) Data Analytics. It is important to notice that 7 out of 11 very important topics were not present in the original version of the taxonomy. It is also an indication that even the updated taxonomy presented herein will itself also need to be updated over time as ever new topics are introduced into network and service management, or when some of the topics in today's more focused workshops and smaller conferences migrate into the arena of the prominent three symposia, or when research on the challenges identified by survey respondents begin to result in manuscripts submitted to the major symposia.

For some topics, a highly significant difference in attached importance between academia and industry can be observed. Specifically, for topics deemed highly relevant by academic experts, this is most apparent for (1) Resource Provisioning and Management and (2) Service Discovery, Migration, and Orchestration. Research on these two topics is traditionally very theoretical, focussing on mathematical modelling and algorithm design, which is generally more popular among academics. The topics favoured by industry, but not academia, include (1) Operations and Business Support Systems, (2) Performance Management and (3) Pro-Active Management. These topics generally relate to more applied, operational and engineering problems.

Because we want to stress the importance of key topics previously identified, we summarize in the following subsections the challenges described by experts related to: (1) Security Management, (2) Virtual Networks, and (3) Software Defined and Programmable Networks. These three topics were used to exemplify the results obtained from the questionnaires. For each topic, we list in forthcoming tables the title of challenges mentioned by respondents, the time frame each challenge is expected to be solved, as well as whether the challenge should be tackled by (I)ndustry, (A)cademia, and/or (S)tandardization bodies.

3.1 Security Management

Security is an important topic to both industry and academia, although academia places more emphasis on it. Table 4 presents some of the major challenges that were defined by academic and industry experts, together with the time frame in which they should be solved, and the context in which this should happen. In the first and second columns of the table, the challenges and the time frames are listed, respectively. In the third column, the context in which each challenge should be solved is presented.

Our analysis of the surveys indicates that privacy and trust are important topics for future research, both in industry and academia. It is generally agreed that these issues should be tackled in joint collaborations. Other aspects that were mentioned are security in clouds and mobile/IoT scenarios.

3.2 Virtual Networks

Management of virtual networks seems to remain a major obstacle. Academia aims to solve such challenges on a longer term of around 5 years, while industry claims challenges should be addressed on a shorter term of about 2 years. All agree that

Table 4 Main challenges related to Security Management

Challenge title	Time frame years (s)	Context
Academia		
Distributed firewalls	6–7	I, A
Cloud security	3–5	I, A
Network attack detection and mitigation	Ongoing	I, A
Managing security credentials and identities	5	I, A
Cooperative inter-domain security	1–7	I, A
Privacy issues in home environments	10	I, A
Automatic trust management	2	I, A
Self-protection in the Internet of Things	Ongoing	I, A
Privacy in the Future Internet	Ongoing	A
Automatic detection of vulnerabilities	2–5	S, A
Industry		
Big data analysis for anomaly detection	Ongoing	I, A
Trade-off between privacy and data analysis	Ongoing	S, I, A
Self-protection of mobile radio devices	5	I, A
Privacy on the Internet	Ongoing	S, I, A

work should be performed jointly, with major involvement from standardization bodies. Table 5 presents some of the major challenges that were identified as being associated with Virtual Networks.

3.3 Software Defined and Programmable Networks

In line with the results shown in Table 5 for Virtual Network challenges, Table 6 shows that challenges related to Software Defined and Programmable Networks are mostly focused on general manageability, such as software abstractions and configuration simplifications for operators and business people. Other challenges that were mentioned include resource allocation, real-time services, and Software-Defined Networking (SDN) in mobile networks.

4 Analysis of Network and Service Management Paper Landscape

Observing the answers of the questionnaire reported in the last sections allowed us to understand the necessities of updating the original taxonomy, creating the improved version of it. The questionnaire also provides information about the future directions of the field, given the predictions of respondents. Another important tool (in addition to the questionnaire) that helps us draw the landscape of the network and service management field is the records of submitted and accepted papers of major conferences. With such records, one can understand the recent past and present of the field by, for example, spotting popular topics and observing trends.

Table 5 Main challenges related to Virtual Networks

Challenge title	Time frame years (s)	Context
Academia		
Scalable management of virtualized networks	3–5	I
Vertical and horizontal SLAs in virtual Networks	5–10	I, A
QoE management using network virtualization	3–5	A
Support legacy technologies using virtualization	2–5	I, A
Worldwide network virtualization testbed	1–2	I, A
Simple management schemes for NfV and SDN	5	I, A
Management of federated virtual networks	5	S, I, A
Network function virtualization	5–10	S, I, A
Network resource virtualization	3–5	I, A
Industry		
Fault management in virtual networks	3–4	I, A
Automated management of virtual networks	4	S, I, A
Network sharing through virtualization	2–4	S, I, A
Automated problem detection in virtual networks	1–2	S, I, A
Management of virtualized environments	Ongoing	I, A
End-to-end virtual infrastructure management	1	S, I, A
Network function virtualization	2	S, I, A

Table 6 Main challenges related to Software Defined and Programmable Networks

Challenge title	Time Frame years(s)	Context
Academia		
Resource allocation in SDN	2–4	I, A
Network as a Software development kit	4–8	S, I, A
Managing SDN	2–3	S, A
Simple management schemes for NfV and SDN	5	I, A
Dynamic network programmability	5	S, I, A
Consistency management in SDN	3	I, A
Real-time services on SDN systems	4	S, A
Industry		
Policy-based management of SDN	2	S, I
Usable software abstractions for SDN	Ongoing	S, I, A
Better flow management in SDN	1	S, I, A
Management support for SDN	Ongoing	A
SDN abstractions for business people	Ongoing	S, I, A
SDN for mobile networks	3–5	S, I, A
Adoption of SDN for transport layer	1	S, I

In this section, papers submitted to the last editions, from 2010 to 2014, of each of the three major conferences of the network and service management community are mapped into the taxonomy's topics. These conferences are: the IEEE/IFIP Network Operations and Management Symposium (NOMS), the IFIP/IEEE International Symposium on Integrated Network Management (IM), and the International Conference on Network and Service Management (CNSM). A total of 1,397 papers has been used in this study.

4.1 Past and Present

For NOMS and IM, authors were requested to select relevant topics from the original network and service management taxonomy during the paper submission process. That was possible because, as previously mentioned, the taxonomy has been incorporated into JEMS, which is the conference management system used by both NOMS and IM. In order to associate submitted papers to the improved version of the taxonomy, we carried out a paper-by-paper analysis remapping (i.e., analyzing the internal contents of each paper), when appropriate, the topics selected by the authors to the topics of the updated version of the taxonomy. Our manual, paper-by-paper classification was performed for CNSM papers too.

Our study considers submitted, accepted, and rejected papers. The reason for it is that we want to characterize the topics on which current research focuses. In that sense, a rejected paper accounts for a topic on which research was performed just as much as an accepted paper. In Table 7, we present the percentage of submitted (including rejected) and accepted (inside parenthesis) papers in all editions of NOMS, IM, and CNSM from 2010 to 2014, according to our updated taxonomy's specific, individual topic areas. The percentages are obtained by dividing the number of submitted/accepted papers that address a topic by the total number of submitted/accepted papers of each edition.

In the next subsection, we draw the recent landscape of the network and service management field by observing the percentages presented in Table 7.

4.2 Analysis of Important Topics

We consider that an important topic is the one that is addressed by at least 10 % of submitted papers, in at least one conference edition. Important topics are tagged with a "$>$" in Table 7. On Table 8 we rank the 10 topics with high submission percentages, per conference edition.

As can be observed, some topics remained important along all years that we have considered. Wireless and Mobile Networks, for example, is well ranked along 2010 to 2014. Although Wireless and Mobile Networks is a topic widely addressed in several other conferences, in NOMS, IM, and CNSM the topic is extremely well received when management aspects are exploited. Autonomic and Self Management is another popular topic along the years, facing a drop only in 2013. One could believe that Autonomic and Self Management would face a decrease of interest after a peak of conference papers in the area, circa 2006. Because autonomics regained

Table 7 Submitted/accepted papers at NOMS, IM, and CNSM

Topic	2010 (%)	2011 (%)	2012 (%)	2013 (%)	2014 (%)
1. Network Management					
Ad-Hoc Networks	5.56 (2.65)	3.25 (1.95)	5.46 (4.02)	2.37 (1.42)	4.61 (2.63)
>Wireless and Mobile Networks	14.02 (6.88)	11.69 (5.84)	16.95 (10.92)	12.32 (5.21)	19.74 (11.84)
>IP Networks	15.87 (11.38)	8.77 (6.17)	5.75 (2.87)	1.90 (0.47)	8.55 (5.92)
Local Area Networks	1.32 (0.53)	0.65 (0.65)	2.30 (1.44)	1.42 (0.95)	1.32 (1.32)
Optical Networks	1.06 (0.53)	1.62 (0.65)	2.30 (1.72)	1.90 (0.47)	1.97 (0.66)
Sensor Networks	6.08 (1.85)	1.95 (1.30)	6.90 (4.60)	2.37 (1.90)	5.92 (2.63)
Overlay Networks	3.44 (1.59)	1.30 (0.97)	2.59 (1.15)	2.37 (2.37)	2.63 (1.32)
Virtual Networks	3.70 (2.12)	1.95 (1.30)	4.60 (3.16)	6.64 (5.69)	7.89 (5.26)
>Software Defined and Programmable Networks	0.53 (0.26)	0.97 (0.32)	3.16 (2.87)	6.16 (4.74)	12.50 (8.55)
>Data Center Networks	2.12 (1.59)	1.95 (1.30)	12.64 (10.34)	8.53 (8.06)	1.97 (0.00)
Smart Grids	0.53 (0.26)	0.32 (0.32)	0.57 (0.57)	0.95 (0.95)	0.66 (0.00)
2. Service Management					
Multimedia Services (e.g., Voice, Video)	9.26 (6.61)	5.84 (3.57)	7.18 (4.02)	4.27 (2.84)	2.63 (1.32)
Data Services (e.g., Email, Web)	4.50 (2.65)	6.17 (3.57)	2.01 (1.44)	0.47 (0.47)	1.97 (1.32)
Hosting (Virtual Machines)	3.97 (2.91)	4.22 (3.25)	9.48 (8.05)	6.16 (6.16)	5.26 (3.29)
Grids	2.12 (1.06)	0.97 (0.32)	0.57 (0.57)	0.00 (0.00)	0.66 (0.00)
>Cloud Services	2.65 (2.12)	2.60 (1.95)	10.34 (8.91)	12.32 (9.00)	13.82 (9.21)
>Resource Provisioning and Management	3.97 (2.65)	2.27 (2.27)	5.17 (3.74)	19.43 (15.17)	0.66 (0.66)
QoE-Centric Management	0.53 (0.00)	0.97 (0.97)	0.57 (0.29)	2.37 (1.90)	0.66 (0.00)
Service Discovery, Migration, and Orchestration	1.85 (1.32)	0.32 (0.32)	4.89 (4.02)	6.64 (5.21)	3.29 (1.97)
3. Business Management					
Legal and Ethical Issues	0.53 (0.00)	0.32 (0.32)	0.57 (0.29)	0.47 (0.47)	0.66 (0.00)
Process Management	10.85 (5.56)	6.17 (3.90)	5.75 (4.60)	4.74 (3.32)	4.61 (1.97)
4. Functional Areas					

Table 7 continued

Topic	2010 (%)	2011 (%)	2012 (%)	2013 (%)	2014 (%)
>Fault Management	11.64 (7.14)	5.84 (2.92)	10.06 (6.32)	12.32 (9.00)	5.92 (3.95)
>Configuration Management	8.47 (5.82)	7.79 (5.19)	10.63 (7.18)	4.27 (3.32)	11.18 (6.58)
Accounting Management	1.06 (0.79)	3.25 (2.60)	1.72 (0.57)	1.42 (0.95)	1.97 (0.66)
>Performance Management	16.40 (11.90)	12.34 (9.09)	18.97 (15.52)	11.37 (8.06)	27.63 (17.76)
>Security Management	14.55 (7.41)	9.09 (5.84)	12.64 (9.77)	16.59 (11.37)	15.13 (9.21)
SLA Management	3.70 (1.85)	5.84 (2.27)	6.32 (5.46)	1.90 (1.90)	8.55 (6.58)
Event Management	2.91 (1.32)	2.27 (1.62)	1.44 (0.86)	0.47 (0.47)	4.61 (1.97)
5. Management Approaches					
Centralized Management	1.32 (1.06)	1.62 (1.30)	4.31 (3.16)	1.90 (0.95)	1.97 (1.97)
>Distributed Management	11.64 (7.14)	7.79 (4.87)	10.34 (6.61)	5.69 (5.21)	9.21 (4.61)
>Autonomic and Self Management	14.81 (9.79)	9.42 (6.17)	16.38 (11.21)	9.00 (6.64)	13.82 (9.21)
Policy-Based Management	8.47 (5.03)	6.17 (3.25)	6.90 (4.60)	3.79 (2.84)	9.87 (5.92)
Federated Network Management	3.97 (2.91)	1.62 (1.30)	0.57 (0.57)	3.32 (2.37)	0.66 (0.00)
Pro-Active Management	0.00 (0.00)	0.32 (0.32)	0.29 (0.00)	0.95 (0.47)	1.32 (0.66)
Energy-Aware Network Management	3.17 (2.12)	4.22 (2.60)	6.61 (5.17)	6.64 (5.21)	2.63 (2.63)
6. Technologies					
>Protocols	7.14 (3.17)	2.92 (1.95)	4.02 (3.16)	12.32 (7.58)	9.87 (4.61)
Middleware	2.65 (1.85)	2.92 (1.30)	6.32 (4.02)	2.37 (1.90)	5.26 (3.95)
Mobile Agents	0.79 (0.26)	0.65 (0.00)	0.86 (0.57)	0.47 (0.47)	2.63 (1.97)
P2P	6.61 (4.50)	2.60 (1.30)	5.46 (2.87)	1.90 (1.42)	2.63 (1.32)
Grids	0.26 (0.26)	0.97 (0.65)	0.86 (0.57)	0.00 (0.00)	0.66 (0.00)
Data, Information, and Semantic Modeling	10.05 (5.03)	9.09 (5.84)	8.91 (7.18)	6.64 (3.79)	8.55 (4.61)
Cloud Computing	5.56 (3.17)	8.12 (3.90)	8.33 (6.03)	24.17 (20.38)	13.82 (9.87)
Internet of Things	0.26 (0.00)	0.00 (0.00)	0.86 (0.86)	1.42 (0.47)	0.66 (0.66)
Human–Machine Interaction	1.32 (1.32)	0.65 (0.65)	0.00 (0.00)	0.47 (0.47)	0.00 (0.00)

Table 7 continued

Topic	2010 (%)	2011 (%)	2012 (%)	2013 (%)	2014 (%)
OSS/BSS	1.59 (0.26)	0.32 (0.32)	1.44 (0.57)	1.90 (0.95)	0.66 (0.66)
7. Methods					
Control Theories	1.85 (1.32)	0.32 (0.00)	2.30 (1.15)	0.00 (0.00)	1.97 (1.32)
Optimization Theories	2.65 (1.85)	0.65 (0.32)	8.33 (5.75)	0.95 (0.95)	9.21 (4.61)
Economic Theories	1.06 (0.53)	0.97 (0.32)	2.01 (1.44)	0.47 (0.47)	1.32 (1.32)
Machine Learning and Genetic Algorithms	1.59 (0.53)	2.60 (1.95)	4.31 (3.16)	6.64 (3.79)	5.92 (3.29)
Logics	0.00 (0.00)	0.32 (0.00)	0.86 (0.57)	0.47 (0.47)	0.66 (0.66)
Probabilistic, Stochastic Processes, Queuing Theory	1.59 (1.59)	0.32 (0.32)	3.45 (2.59)	1.90 (1.42)	5.92 (3.29)
Simulation	3.44 (2.65)	3.25 (2.92)	5.75 (3.74)	9.48 (6.16)	14.47 (9.87)
>Experimental Approach	2.38 (1.32)	1.62 (1.30)	6.03 (4.31)	9.95 (7.11)	13.16 (9.87)
Design	0.53 (0.26)	1.62 (1.62)	1.72 (0.86)	0.47 (0.00)	3.29 (2.63)
Monitoring and Measurements	4.23 (3.17)	4.22 (2.92)	5.75 (4.89)	10.90 (8.06)	9.87 (4.61)
Data Mining and (Big) Data Analytics	0.79 (0.79)	1.30 (1.30)	0.86 (0.86)	7.11 (6.64)	1.97 (1.97)

Table 8 Important topics from NOMS, IM, and CNSM

2010		2011	
1. Performance Management	16.4 (11.9)	1. Performance Management	12.34 (9.09)
2. IP Networks	15.87 (11.38)	2. Wireless and Mobile Networks	11.69 (5.84)
3. Autonomic and Self Management	14.81 (9.79)	3. Autonomic and Self Management	9.42 (6.17)
4. Security Management	14.55 (7.41)	4. Security Management	9.09 (5.84)
5. Wireless and Mobile Networks	14.02 (6.88)	5. Data, Information, and Semantic Modeling	9.09 (5.84)
6. Fault Management	11.64 (7.14)	6. IP Networks	8.77 (6.17)
7. Distributed Management	11.64 (7.14)	7. *Cloud Computing*	8.12 (3.9)
8. Process Management	10.85 (5.56)	8. Configuration Management	7.79 (5.19)
9. Data, Information, and Semantic Modeling	10.05 (5.03)	9. Distributed Management	7.79 (4.87)
10. Multimedia Services (e.g., Voice, Video)	9.26 (6.61)	10. Data Services (e.g., Email, Web)	6.17 (3.57)
2012		2013	
1. Performance Management	18.97 (15.52)	1. *Cloud Computing*	24.17 (20.38)
2. Wireless and Mobile Networks	16.95 (10.92)	2. *Resource Provisioning and Management*	19.43 (15.17)
3. Autonomic and Self Management	16.38 (11.21)	3. Security Management	16.59 (11.37)
4. *Data Center Networks*	12.64 (10.34)	4. Wireless and Mobile Networks	12.32 (5.21)
5. Security Management	12.64 (9.77)	5. *Cloud Services*	12.32 (9)
6. Configuration Management	10.63 (7.18)	6. Fault Management	12.32 (9)
7. *Cloud Services*	10.34 (8.91)	7. Protocols	12.32 (7.58)
8. Distributed Management	10.34 (6.61)	8. Performance Management	11.37 (8.06)
9. Fault Management	10.06 (6.32)	9. *Monitoring and Measurements*	10.9 (8.06)
10. Hosting (Virtual Machines)	9.48 (8.05)	10. Experimental Approach	9.95 (7.11)
2014			
1. Performance Management	27.63 (17.76)		
2. Wireless and Mobile Networks	19.74 (11.84)		
3. Security Management	15.13 (9.21)		

Table 8 continued

2010	2011
4. Simulation	14.47 (9.87)
5. *Cloud Services*	13.82 (9.21)
6. Autonomic and Self Management	13.82 (9.21)
7. *Cloud Computing*	13.82 (9.87)
8. Experimental Approach	13.16 (9.87)
9. *Software Defined and Programmable Networks*	12.5 (8.55)
10. Configuration Management	11.18 (6.58)

interest in the general networking area after Future Internet initiatives, the topic stayed important in the network and service management field as well.

Older traditional topics can be observed in the top 10 too. Distributed Management, which is a classical topic in the area since in the inception of Management by Delegation (MbD) in the 1990s, also figures along the top 10 topics but faced a drop in 2013 and 2014. This can indicate a decreased interest in the topic, possibly because of the rise of more centralized-oriented solutions based on SDN (Software-Defined Networking). Topics popular in the mid 2000s, however, did not make the top 10 in the considered years. That is the case, for example, of Policy-Based Management and P2P.

It is interesting to notice the existence of topics that are trending upward in popularity. Cloud Computing, for example, became important for the first time in 2011, appeared in the 2012s rank too, and presented a quite significant percentage of submitted and accepted papers in 2013. Data Center Networks is another example. Software Defined and Programmable Networks, on the other hand, seems about to experience a pick up of interest, possibly as a consequence of the great interest on SDN (Software-Defined Networking) and Network Functions Virtualization (NFV) in other communities too.

4.3 Comparison of Questionnaire Results With Conference Results

In this subsection, we observe the similarities and differences between past and future research directions. To achieve that, we now bring together, compare and analyze the results of mapping questionnaire challenges and conference papers onto the network and service management taxonomy. On one hand, conference contributions represent past and present interests of the community. On the other hand, questionnaire answers represent future research directions.

As a first step, we analyze in conferences those topics that are critical to future research, according to both industry and academia. Table 9 shows the popularity in conferences of the important questionnaire topics listed in Table 3. The percentages listed under industry and academia represent the number of participants that mentioned the topic, rather than the number of challenges. Topics tagged with a "◁" are important only in the questionnaires, with a "▷" only in the conferences, and with a "◁▷" being important in questionnaires and in at least one conference edition.

Table 9 shows that out of the 22 important future research directions, 13 have been adequately addressed in at least one of the years. However, QoE-Centric Management, Pro-Active Management, Internet of Things, Human–Machine Interaction, and OSS/BSS are examples of topics that have received little attention in recent network and service management conferences, while they have been identified as very important research directions by experts. The OSS/BSS topic has traditionally been an operational topic, of little interest to academia. Human–Machine Interaction has received very little attention within the network and service management field, but has been thoroughly studied in the broader scientific community. Finally, the increasing interest in pro-active management by industry might present some potentially interesting research directions for academic researchers.

Table 9 Comparison of the popularity of questionnaire and conference topics

Topic	Questionnaires (%)		Conferences (%)				
	Industry	Academia	2010	2011	2012	2013	2014
1. Network Management							
◁▷Wireless and Mobile Networks	46.2	9.1	14.02 (6.88)	11.69 (5.84)	16.96 (10.92)	12.32 (5.21)	19.74 (11.84)
◁*Virtual networks*	53.8	45.5	3.70 (2.12)	1.95 (1.30)	4.60 (3.16)	6.64 (5.69)	7.89 (5.26)
▷IP Networks	0.0	0.02	15.87 (11.38)	8.77 (6.17)	5.75 (2.87)	1.90 (0.47)	8.55 (5.92)
◁▷*Software Defined and Programmable Networks*	38.5	54.5	0.53 (0.26)	0.97 (0.32)	3.17 (2.87)	6.16 (4.74)	12.50 (8.55)
▷*Data Center Networks*	7.7	9.1	2.12 (1.59)	1.95 (1.30)	12.64 (10.34)	8.53 (8.06)	1.97 (0.0)
2. Service Management							
◁▷*Cloud Services*	23.1	18.2	2.65 (2.12)	2.60 (1.95)	10.34 (8.91)	12.32 (9.00)	13.82 (9.21)
◁▷*Resource Provisioning and management*	15.4	45.5	3.97 (2.65)	2.27 (2.27)	5.17 (3.74)	19.43 (15.17)	0.66 (0.66)
◁*QoE-Centric Management*	30.8	18.2	0.53 (0.00)	0.97 (0.97)	0.57 (0.29)	2.37 (5.21)	0.66 (1.97)
◁*Service Discovery and Migration*	7.7	36.4	1.85 (1.32)	0.32 (0.32)	4.89 (4.02)	6.64 (5.21)	3.39 (1.97)
3. Business Management							
▷Process Management	0.0	0.0	10.85 (5.56)	6.17 (3.90)	5.75 (4.60)	4.74 (3.32)	4.61 (1.97)
4. Functional Areas							
◁▷Fault Management	53.8	36.4	11.64 (7.14)	5.84 (2.92)	10.06 (6.32)	12.32 (9.00)	5.92 (3.95)
◁▷Configuration Management	15.4	0.0	8.47 (5.82)	7.79 (5.19)	10.63 (7.18)	4.27 (3.32)	11.18 (6.58)
◁▷Performance Management	23.1	0.0	16.40 (11.90)	12.34 (9.09)	18.97 (15.52)	11.37 (8.06)	27.63 (17.76)
◁▷Security management	38.5	63.6	14.55 (7.41)	9.09 (5.84)	12.64 (9.77)	16.59 (11.37)	15.13 (9.21)
5. Management Approaches							
◁▷Distributed Management	23.1	36.4	11.64 (7.14)	7.79 (4.87)	10.34 (6.61)	5.69 (5.21)	9.21 (4.61)
◁▷Autonomic and Self Management	53.8	36.4	14.81 (9.79)	9.42 (6.17)	16.38 (11.21)	9.00 (6.64)	13.82 (9.21)
◁*Federated Network Management*	23.1	54.05	3.97 (2.91)	1.62 (1.30)	0.57 (0.57)	3.32 (2.37)	0.66 (0.00)
◁*Pro-Active Management*	23.1	0.0	0.00 (0.00)	0.32 (0.32)	0.29 (0.00)	0.95 (0.47)	1.32 (0.66)

Table 9 continued

Topic	Questionnaires (%)		Conferences (%)				
	Industry	Academia	2010	2011	2012	2013	2014
◁*Energy-Aware Network Management*	15.4	27.3	3.17 (2.12)	4.22 (2.60)	6.61 (5.17)	6.64 (5.21)	2.63 (2.63)
6. Technologies							
▷Protocols	0.0	0.0	7.14 (3.17)	2.92 (1.95)	4.02 (3.16)	12.32 (7.58)	9.87 (4.61)
◁▷Data. Information. and Semantic Modeling	30.8	9.1	10.05 (5.03)	9.09 (5.84)	8.91 (7.18)	6.64 (3.79)	8.55 (4.61)
◁▷*Cloud Computing*	30.8	27.3	5.56 (3.17)	8.12 (3.90)	8.33 (6.03)	24.17 (19.91)	13.82 (9.87)
◁*Internet of Things*	23.1	45.5	0.26 (0.00)	0.00 (0.00)	0.86 (0.86)	1.42 (0.47)	0.66 (0.66)
◁*Human–Machine Interaction*	23.1	9.1	1.32 (1.32)	0.65 (0.65)	0.00 (0.00)	0.47 (0.47)	0.00 (0.00)
◁*Operations and Business Support Systems*	30.8	0.0	1.59 (0.26)	0.32 (0.32)	1.44 (0.57)	1.90 (0.95)	0.66 (0.66)
7. Methods							
▷Simulation	0.0	0.0	3.44 (2.65)	3.25 (2.92)	5.75 (3.74)	9.48 (6.16)	14.47 (9.87)
▷Experimental Approach	0.0	0.0	2.38 (1.32)	1.62 (1.30)	6.03 (4.31)	9.58 (6.64)	13.16 (9.87)
◁▷*Monitoring and Measurements*	23.1	72.7	4.23 (3.17)	4.22 (2.92)	5.75 (4.89)	10.90 (8.06)	9.87 (4.61)
◁*Data Mining and (Big) Data Analytics*	46.2	45.5	0.79 (0.79)	1.30 (1.30)	0.86 (0.86)	6.64 (6.16)	1.97 (1.97)

Concerning the overall popular topics, some pertinent observation can be made as well. First, some important future research directions were addressed very little in previous years, but have received much attention in the most recent years (e.g., Software Defined and Programmable Networks and Cloud Computing). This shows a positive evolution towards the alignment of research output and important topics for future research. Second, Protocols, IP Networks, and Process Management are deemed very important in the conferences, but were not mentioned by experts from either academia or industry. This may be explained due to the fact that they are general terms to which a lot of papers relate, while experts referred to more concrete research topics in the questionnaire.

5 Conclusions

In this paper we introduced an enhanced taxonomy for the network and service management research field. With that, it was possible to observe, to landscape and to identify a set of important future research directions in the field. In addition to the introduced taxonomy itself, a questionnaire-based survey was conducted among industrial and academic experts. Given the questionnaire's answers, important topics were then deduced and compared to topics of papers submitted to the most important conferences in the community (i.e., IEEE/IFIP NOMS, IFIP/IEEE IM, and CNSM). In the end, observing the questionnaire's answers together with paper statistics, allows us to determine similarities and differences between current and expected future research directions.

To be able to compare questionnaire results and conference papers in an unambiguous way, we employed our taxonomy, which, as mentioned before, is the result of a join collaborative effort between IFIP WG6.6, IEEE CNOM, IRTF NMRG, and the Emanics network of excellence. Questionnaire challenges and conference papers were mapped onto the taxonomy's topics. A deep analysis of the expert's responses showed that the original version of the taxonomy, proposed in 2008, was not able to represent fully all important research topics. As a result, an updated version of the taxonomy has been proposed and employed, consisting of 17 new relevant topics. Fifteen out of these 17 topics were also deemed important by academic or industrial experts for future research. Twelve out of 17 are also addressed to a significant degree in at least one of the last editions of the evaluated major conferences.

An deep evaluation of challenges reported in the answers of the questionnaire showed that 11 taxonomy topics are considered important future research directions for both industrial and academic experts. In this context, an *important* topic was defined as those being mentioned by at least 20 % of experts. The 6 overall highest ranked topics are: Security Management, Virtual Networks, Software Defined and Programmable Networks, Data Mining and Analytics, Fault Management, and Autonomic and Self Management. Moreover, 8 other topics are important to industry, but not academia: Wireless and Mobile Networks, QoE-centric Management, Semantic Modeling, OSS/BSS, Cloud Service Management, Performance Management, Pro-Active Management, and Human–Machine Interaction. Three

topics are important to academia only: Resource Provisioning, Service Discovery and Migration, and Energy-Aware Network Management. This shows that there is significant overlap of important future research topics, especially for important academic topics. In fact, these topics are a mix of traditional topics and current hot topics. Topics important solely to industry are applied and operational ones, while those important to academia only are mostly algorithmic and theoretical ones.

For conference papers, a similar analysis was carried out. This results in a list of 14 important conference topics, of which 2 were important in all the recent years. These 2 topics are Wireless and Mobile Networks, and Performance Management. The observations of the results from conferences showed that Software Defined and Programmable Networks, one of the main topics identified by experts for future research, has increased significantly in popularity in the most recent organized conferences.

Subsequently, important questionnaire and conference topics were compared, to assess the degree to which future research directions are addressed in current research. This comparison showed that out of 19 topics important to industry, as many as 12 were also important in at least one of the last conference editions too. Among the topics important for academia, 7 out of 13 topics were addressed in conferences. Out of the 11 future research topics important to both academia and industry, Federated Network Management and Internet of Things received little attention in recent conferences. Three other future research topics important to industry only, have also received little attention in conferences: OSS/BSS, Pro-Active Management and Human–Machine Interaction. Finally, Service Discovery and Migration as well as Energy-Aware Network Management are important future topics for academics but also did not receive much attention in recent conferences. We expect the number of conference submissions on these topics to increase during the next years.

The analysis summarized above was only possible because of the common set of topics defined in our taxonomy. Such a set of topics is naturally not fixed. We believe that as more people review our results, a more comprehensive taxonomy will emerge and evolve over time. To reflect such changes, an update of the taxonomy (i.e. addition of new topics) every two years is appropriate, together with a thorough update (including, removing, and potentially merging topics) every 5 years. We plan to perform this update process through the IEEE Technical Committee on Network Operations and Management (CNOM) and IFIP WG6.6 on Management of Networks and Distributed Systems. Proposals for taxonomy updates will be sent prior to the meetings (taking place at least two times a year), contributors can send their feedback, and during the meeting consensus will be aimed at amongst all meeting participants.

We expect the taxonomy presented in this paper to be increasingly employed in efforts related to the network and service management field, including, for example, public or private open calls for funded projects, special issues of journals, as well as future conferences in the networking area.

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