# Table of Contents

1. APEX & Policy ................................................................. 1  
   1.1. Dynamically Adaptive Policies (CNSM'15) .............................................. 1  
   1.2. APEX Engine (NOMS'16) ............................................................. 1  
   1.3. D-MIM (IM'17) ................................................................. 2  
   1.4. COMPA AADM (IM'2017) .......................................................... 3  
   1.5. Unifying Policy Theory (the APEX theory) (NOMS'18) ................. 3  
   1.6. An APEX Testbed (NOMS'18) ................................................... 4  

2. Policy in General ............................................................. 5  
   2.1. HetNets, Big Data, Cloud, SDN ... (Monami'12) .............................. 5  
   2.2. Recommender System (IM'13) .................................................. 6  
   2.3. Drools Performance (Monami'13) ................................................. 6  
   2.4. Towards NFV (CNSM'14) .......................................................... 7  
   2.5. 5G & Autonomic Networking (5G Summit 2015) ............................. 7  
   2.6. 5G Management and Policy (NOMS'18) ......................................... 8
1. APEX & Policy

The following publications discuss APEX and policy aspects, such as

- Adaptive Policies
- SON Use Case with Adaptive Policies
- The APEX Engine, including performance analysis
- Distributed Information Management, also known as the APEX Context management

1.1. Dynamically Adaptive Policies (CNSM'15)

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<tr>
<th>Title</th>
<th>Dynamically Adaptive Policies for Dynamically Adaptive Telecommunications Networks</th>
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<tr>
<td>Venue</td>
<td>IEEE CNSM, Barcelona, November 2015</td>
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<tr>
<td>Abstract</td>
<td>New technologies are changing the world of communication networks and even more so their management. Cloud computing and predictive analytics have removed the need for specialized compute hardware and created products that continuously search for and find insights in management data. Virtualization of networks and network functions, SDN and NFV, are beginning to be mature enough for production networks resulting in much more flexible and dynamic networks. IoT and M2M traffic and new customer demands are driving new thinking and demands for 5G networks. Almost every aspect in the control and management of networks has seen new dimensions of flexibility and dynamicity, with the notable exception of the policies that drive them. This paper discusses the need to add adaptiveness to classic policies, describes a novel approach for adaptive policies, shows how adaptive policies will form part of future network frameworks and architectures, and finally discusses early use cases developed for mobile operators.</td>
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<tr>
<td>Links</td>
<td>Research Gate [accessed Aug 11, 2017]</td>
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<tr>
<td>BibTeX</td>
<td>@inproceedings{DBLP:conf/cnsm/MeerKF15,</td>
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<tr>
<td></td>
<td>author = {Sven van der Meer and John Keeney and Liam Fallon},</td>
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<td></td>
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<td></td>
<td>2015, Barcelona, Spain, November 9-13, 2015},</td>
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<td></td>
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1.2. APEX Engine (NOMS'16)

<table>
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<th>Title</th>
<th>APEX: An Engine for Dynamic Adaptive Policy Execution</th>
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<tr>
<td>Venue</td>
<td>IEEE NOMS, Istanbul, April 2016</td>
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</tbody>
</table>
Abstract
The advent of "Soft Networking", where networks are composed of virtual nodes and links, promises to dramatically ease the definition and deployment of networks whilst allowing network applications that are limited only by the imagination of the developers of those applications. In such a dynamic environment, the Autonomic Management pattern supervised by policies has been recognized as holding more promise for management of Soft Networks than traditional techniques. We have proposed Dynamic Adaptive Policies as an approach to give classic policies the dynamicity and flexibility to manage such networks and whatever applications are running on them. In this paper, we describe our ongoing work on Apex, an engine that executes and administers Dynamic Adaptive Policies in a scalable and distributed manner.

Links
Research Gate [accessed Aug 11, 2017]

BibTeX
@inproceedings{DBLP:conf/noms/FallonMK16,
  author = {Liam Fallon and Sven van der Meer and John Keeney},
  title = {Apex: An Engine for Dynamic Adaptive Policy Execution},
  booktitle = {2016 {IEEE/IFIP} Network Operations and Management Symposium, {NOMS} 2016, Istanbul, Turkey, April 25-29, 2016},
  pages = {699--702},
  year = {2016},
  crossref = {DBLP:conf/noms/2016},
  doi = {10.1109/NOMS.2016.7502880},
  biburl = {http://dblp.org/rec/bib/conf/noms/FallonMK16},
  bibsource = {dblp computer science bibliography, http://dblp.org}
}

1.3. D-MIM (IM'17)

Title
Distributed Management Information Models

Venue
IEEE IM, Lisbon, May 2017

Abstract
The use of information models to share and allow modification of network element state is one of the best and most widely adopted ideas in network management. The formal structure of information models and the controlled manner of accessing and changing such models brings both flexibility and control when managing network elements. However, keeping information models synchronized and consistent across network elements and management systems is also one of the most challenging tasks in network management system development. Today this problem is exasperated with the advent of ephemeral network functions and elements and also by the need for distributed scalable cooperating management functions running in containerized distributed cloud deployments. In computer science, there have been major advances in systems that allow seamless distribution of data across distributed executing entities, and separately in systems that allow highly granular data access synchronization across distributed entities. However, such systems do not place importance on “information model” concepts, with data usually distributed as largely unmodeled unstructured data maps. In this paper, we describe our novel approach for distributed information models. We describe how information models are distributed to dispersed network elements and management systems, how synchronized access to distributed information models is achieved, how information models are persisted, and how lookups and changes to information models are logged.

Links
Research Gate [accessed Aug 11, 2017]
1.4. COMPA AADM (IM’2017)

**Title**

*Using the COMPA Autonomous Architecture for Mobile Network Security*

**Venue**

IEEE IM, Lisbon, May, 2017

**Abstract**

The COMPA (Control, Orchestration, Management, Policy, and Analytics) adaptive control loop realizes an automation pattern that can operate recursively at many layers in a carrier network. An overall COMPA autonomic control loop can orchestrate functions, themselves implemented as COMPA autonomic loops. Thus the COMPA automation pattern can recur right down to resource level in a network. One of the most exciting application areas for the COMPA automation pattern is in assuring mobile network security. The recursive nature of the pattern is the ideal mechanism for automating monitoring and root cause analysis of security threats to networks. In this paper we present a Proof of Concept of a COMPA compliant system for a Distributed Denial of Service (DDoS) scenario. The system monitors, performs root cause analysis, and mitigates a DDoS attack. The system was built by integrating a number of existing components that were deployed as VNFs. Our experiences of using the system were that the system could handle a DDoS attack quickly and automatically. In addition, the system was very flexible to build and deploy.

**Links**

Research Gate [accessed Aug 11, 2017]

**BibTeX**

```bibtex
@inproceedings{DBLP:conf/im/FallonKMQM17,  
author = {Liam Fallon and John Keeney and Mark McFadden and John Quilty and Sven van der Meer},  
title = {Using the COMPA Autonomous Architecture for Mobile Network Security},  
pages = {747--753},  
year = {2017},  
crossref = {DBLP:conf/im/2017},  
doi = {10.23919/INM.2017.7987370},  
biburl = {http://dblp.org/rec/bib/conf/im/FallonKMQM17},  
bibsource = {dblp computer science bibliography, http://dblp.org}
}
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1.5. Unifying Policy Theory (the APEX theory) (NOMS’18)

**Title**

*Taming Policy Complexity: Model to Execution*

**Venue**

IEEE NOMS, Taipei, April 2018
Abstract
Since the 1970's it has been acknowledged that a complex system can be broken into (a) its invariant functional parts (mechanism), and (b) the externalized choices for how the system should behave (policy). Policy-based management's main objective is to separate and externalize the decisions required by a system from the mechanisms provided by the system, and provide a way to define and evaluate these decisions. A few decades later, we have today a plethora of different policy models and even more policy languages – plus tooling – offering policy-based solutions for virtually any use case and scenario. However, policy-based management as a standalone domain has never been evaluated in terms of which parts are variant / invariant, i.e. which parts of policy-based management can be domain-, model-, language-, usecase-independent. In this paper, we introduce and define a formal universal policy model that does exactly that. The result is a model that can be used to design, implement, and deploy immutable policy infrastructure (engine and executor) being able to execute (virtually) any policy model.

Links
Research Gate [accessed Sep 4, 2018]

BibTeX
@inproceedings{DBLP:conf/noms/MeerKF18,
  author    = {Sven van der Meer and John Keeney and Liam Fallon},
  title     = {Taming policy complexity: Model to execution},
  booktitle = {2018 {IEEE/IFIP} Network Operations and Management Symposium, (NOMS) 2018, Taipei, Taiwan, April 23-27, 2018},
  pages     = {1--8},
  year      = {2018},
  crossref  = {DBLP:conf/noms/2018},
  doi       = {10.1109/NOMS.2018.8406172},
  biburl    = {https://dblp.org/rec/bib/conf/noms/MeerKF18},
  bibsource = {dblp computer science bibliography, https://dblp.org}
}

1.6. An APEX Testbed (NOMS'18)

Title
A Testbed For Policy Driven Closed Loop Network Management

Venue
IEEE NOMS, Taipei, April 2018

Abstract
Due to the increase in the dynamicity, programmability, scope and complexity of modern networks there is a greatly increased requirement that network management systems control, orchestrate and manage networks in a much more automated and dynamic manner. This drive towards automation and dynamicity requires autonomic network management that continuously analyses network state and continually steers the network in accordance with changing high level goals and policies. As dynamicity increases, it is proving increasingly difficult to test and validate the analytics routines and policies that drive today's network management systems. With more automation, the potential for unanticipated network incidents increase, for example where multiple automation features interact and conflict.

There is no substitute for seeing how a network management feature actually performs in a real network, ideally allowing iterative authoring/validation development cycles. However, due to the high stakes involved in degrading or disrupting network performance, this is not usually feasible until the very final testing and deployment stages. The next best option is a testbed that accurately represents a live network scenario to support authoring and validation development cycles in a low-risk environment.

In this work we present our experiences of building a networking testbed that incorporates an emulated network, a production-grade network controller, an analytics function, and a policy execution environment. This allows users to develop policies for adaptive (closed loop) management of a realistic emulated network. We also present two scenarios where the testbed is used to emulate and mitigate against a temporary and prolonged failure occurring on a network.

Links
Research Gate [accessed Sep 4, 2018]
2. Policy in General

The following publications discuss general policy aspects, such as

- Policy as part of Autonomic Networks
- Policy as part of a closed control loop, mainly COMPA
- Policy and Semantics

2.1. HetNets, Big Data, Cloud, SDN ... (Monami'12)

**Title**
*HetNets, Big Data, Cloud, SDN...all problems solved and your lunch served, right?*

**Venue**
Keynote, 4th MONAMI, Hamburg, September, 2012

**Abstract**
What happens when you get a huge increase of devices and cells (i.e. Heterogeneous Networks - HetNets), all of which have to be monitored and managed, and our current OSSs are already overburdened, handling their existing workloads? In other domains, there are many promising techniques, such as smart filtering, complex event processing, and predictive analytics, but they are not as effectively applied to network management. Why is that? Can we do better? Instead of being overloaded with all of the hype (BigData and Cloud and Software-Defined Networking) and hoping that by mixing some combination of these magic ingredients a solution will emerge, a combination of science and engineering might be a better way to solve the problem! This keynote will discuss a number of common misconceptions with regard to technologies, all of which cause us to spend money on useless mechanisms and services. Focusing on the actual problems, which are a combination of current state of business, foreseeable future, and customer demands, we will be able to point to a number of real problems that require a solution. As with many things, there is no silver bullet but a combination of social and behavioral, technical and methodological advances that will facilitate a networked society, and in the process change the nature of OSSs from Operation Support Systems to Opportunity Support Systems.

**Links**
[Research Gate](accessed Aug 11, 2017)

2.2. Recommender System (IM'13)

**Title**
*A Recommender-system for Telecommunications Network Management Actions*

**Venue**
IEEE IM, Ghent, May 2013
Abstract

Research and products in telecoms network management have long been focused on the automation of processes to keep complex managed networks in an operational state, while being profitable to operate for the network operator. Due to the ever increasing scale and complexity of the problem domain, coupled with specific constraints (legal, regulatory, technological change), a fully automated management approach is virtually impossible. It remains the responsibility of human Network Operations Centre (NOC) operators to oversee and manage the running of the network, where their main task is to respond to huge numbers of messages, errors, warnings and faults constantly flowing from the managed network. In the past, network operators either employed expert systems or became very dependent on expert knowledge of their operational staff. Considering the current explosion in size and complexity of managed telecoms network, it is widely understood and accepted that current manual and semiautomated approaches cannot scale. In this paper we investigate the applicability of recommender systems as an approach to assist NOC operators to correctly respond to indications of incidents in the network they are actively managing.

Links

Research Gate [accessed Aug 11, 2017]

BibTeX

@inproceedings{DBLP:conf/im/KeeneyMH13,
author = {John Keeney and Sven van der Meer and Gabriel Hogan},
title = {A Recommender-system for Telecommunications Network Management Actions},
pages = {760--763},
year = {2013},
crossref = {DBLP:conf/im/2013},
url = {http://ieeexplore.ieee.org/document/6573072/},
biburl = {http://dblp.org/rec/bib/conf/im/KeeneyMH13},
bibsourcel = {dblp computer science bibliography, http://dblp.org}
}

2.3. Drools Performance (Monami’13)

Title

Cloudifying Mobile Network Management: Performance Tests of Event Distribution and Rule Processing

Venue

Monami, Cork, November 2013

Abstract

The explosion in consumer devices has resulted in a significant increase in the number of mobile telecommunications nodes. As a result of increased device and node numbers, network operators have experienced a large increase in associated events. In such an environment, scalability and performance of event handling become important aspects for Operation Support Systems (OSS). A traditional approach has been to centralize monitoring and decision functions. The scale of events in a modern mobile telecommunications network means such centralized implementations are performance limited. What is required is a remodeling of Complex Event Processing (monitoring) and Policies (decision making) towards a distributed yet coordinated system. This paper describes an extensible architecture for such a distributed policy-based event processing system. Our approach provides a pluggable mechanism into which various event handling functionality can be integrated. In order to illustrate the applicability of our approach we evaluate the performance of 2 message queuing protocols, Advanced Message Queuing Protocol (AMQP) based RabbitMQ and Java Web Sockets. Our performance evaluation illustrates the ability of our architecture to transparently integrate alternative event processing technologies.

Links

ResearchGate [accessed Aug 11, 2017]
2.4. Towards NFV (CNSM'14)

**Title**
Towards Real-time Management of Virtualized Telecommunication Networks

**Venue**
IEEE CNSM, Rio de Janeiro, November 2014

**Abstract**
The idea of virtualizing network functions is driven by recent advances in network-focused hardware. In 2012, several large telecommunication operators issued a call to action for Network Function Virtualization (NFV) [1]. The underlying idea is that every network service currently delivered on proprietary, application specific hardware should be deliverable using virtual machines. This means that routers, firewalls, load balancers and other network devices run virtualized on commodity hardware. Consequently, ETSI is extending this idea to mobile networks. Here, parts of the core and the radio access network will be virtualized. The immediate advantage is that any Virtual Network Function (VNF) can now be deployed, redeployed and un-deployed in the same way as any traditional virtual machine. Thus, NFV will result in more dynamic and agile networks than seen heretofore. However, this will raise a number of serious issues in managing these future networks. In this paper, we examine issues and challenges in orchestrating these virtualized functions and their interconnections to provide a more agile mobile telecommunication network.

**Links**
Research Gate [accessed Aug 11, 2017]

2.5. 5G & Autonomic Networking (5G Summit 2015)

**Title**
5G & Autonomic Networking - Challenges in closing the Loop

**Venue**
Abstract

This presentation outlines the problems with existing policy based management systems and why we now need adaptive policy based management systems enabling networks to be self-governed. The talk focuses on the integration of key technologies shaping the future of the ENM Automation Framework, including control theory, predictive analytics, policy-based management context aware computing, knowledge engineering and semantics, modelling of adaptive behavior.

Links

- [Research Gate](accessed Aug 11, 2017)
- [Recorded Talk at IEEE TV](accessed Aug 11, 2017)

BibTeX

```bibtex
@article{VanDerMeer2015b,
  Author  = {van der Meer, Sven},
  Journal = {IEEE First International 5G Summit},
  Month   = may,
  Title   = {{5G \& Autonomic Networking - Challenges in closing the Loop}},
  Year    = {2015}
}
```

2.6. 5G Management and Policy (NOMS'18)

**Title**

*5G Networks Must Be Autonomic!*

**Venue**

IEEE NOMS, Taipei, April 2018

**Abstract**

5G networks will be the first real converged networks supporting a plethora of different services, each with their own requirements. A static best-effort approach is no longer sufficient. Extreme flexibility and dynamicity is required, yet costs must be drastically reduced. The only way that these conflicting goals can be achieved is with vastly increased automation in the provision and operation of our future 5G networks. In this paper we briefly discuss the facilitators, goals and challenges for 5G networks. We identify some of the places where automation is not just helpful, but is in fact required for 5G to become a reality. We go on to present a conceptual approach for modeling and achieving autonomic operations and management in 5G networks positioning modern policy-based management as a key enabler for autonomic 5G network management.

**Links**

- [Research Gate](accessed Sep 4, 2018)

**BibTeX**

```bibtex
@inproceedings{DBLP:conf/noms/MeerKF18a,
  author    = {Sven van der Meer and John Keeney and Liam Fallon},
  title     = {5G networks must be autonomic!},
  booktitle = {2018 {IEEE/IFIP} Network Operations and Management Symposium, (NOMS) 2018, Taipei, Taiwan, April 23-27, 2018},
  pages     = {1--5},
  year      = {2018},
  crossref  = {DBLP:conf/noms/2018},
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}
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