# Towards Autonomic Mobile Network Operators

Fabrizio Granelli[1,2] and Riccardo Bassoli[1]
[1]University of Trento, Trento, Italy
[2]Consorzio Nazionale Interuniversitario per le Telecomunicazioni (CNIT), Parma, Italy
$\{fabrizio.granelli, riccardo.bassoli\}$@unitn.it

***Abstract*—The vision of future fifth generation networks includes an entire ecosystem mainly composed by several different access technologies, virtualization and cloud/edge computing paradigms. Side by side, it also includes full deployment of machine learning for proactive network management and diagnosis. All those elements of such a complex system are used to host the huge variety of verticals the mobile network will have to support. These premises have enforced the idea that fifth generation will be the last one, while future modifications will just represent software/hardware upgrades of that complex ecosystem.**

**This article envisions the realisation of autonomic mobile network operators as the main element, which will significantly change the intrinsic nature of networks, network operators and humans' role in mobile networks, to establish the actual change to a future generation. After presenting architecture and logical-functional structure of such autonomic operators, the paper shows a possible effective model of that future generation as autonomic multi-agent multi-layer system.**

***Index Terms*—Autonomic network, autonomic mobile network operator, 5G, beyond 5G, wireless networks, virtualization, network slicing, cloud computing, edge computing, machine learning, multi-agent system.**

## I. Introduction

The vision of future fifth generation (5G) networks is a revolutionary approach to both wireless cellular networks and wired networks. The evolution from first generation (1G) to fourth generation (4G) cellular networks mainly represented an improvement in the random access network/random access technology (RAN/RAT), which have ensured higher transmission rates to mobile users. In parallel, 3G and 4G networks introduced full data transmission and connection to the internet.

Despite advertisements and marketing announcements limited to new RATs, 5G networks will be a highly heterogeneous 'ecosystem' (or 'pan 5G infrastructure' [1]), achieving demanding requirements and supporting several different verticals. Moreover, it will create a flexible wired-wireless infrastructure via full virtualization, i.e. via complete and actual deployment of software-defined networking (SDN) and network function virtualization (NFV) at all levels.

The key performance indicators (KPIs) of 5G [2], [3] include: (i) 10 times higher data rates to individual end users, (ii) $1 - 10$ms round-trip time, (iii) higher bandwidth per unit of area and enormous number of connected devices, (iv) perceived network availability of 99.999% and (v) reduced time to set up a service from local application to network individual service components. These KPIs will allow the support of several possible end-to-end communication paradigms/services such as Internet of Things (IoT) [4], factory automation (Industry 4.0) [5], smart grids and smart cities, machine-to-machine (M2M) communications, human-to-machine (H2M) communications (e.g. tactile internet [6], [7]), media broadcast (fixed and mobile), autonomous transport systems (e.g. autonomous cars, public transports, drones, ships, etc.), maritime and aeronautical broadband, public safety and governmental communications (for defence, disaster relief, humanitarian aid, etc.), e-health and medical communications, and financial technologies (FinTech). The above verticals are normally grouped into three main categories: Extreme Mobile Broadband (xMBB), ultra-reliable Machine-Type Communications (uMTCs) - also called ultra-reliable low-latency communications (URLLCs) - and massive Machine-Type Communications (mMTCs).

The full integration of cloud and edge/fog computing, SDN and NFV in a unique flexible/reconfigurable and software-based infrastructure will permit efficient and effective network management and end-to-end network slicing [8], [9] (with complete isolation among slices and services). In fact, significant research effort has been focused on the design of a common/unique SDN-NFV system, which arises several complex challenges [10]. Three main approaches for a unified SDN-NFV architecture can be identified. The first one proposed by the European Telecommunications Standards Institute (ETSI) working group [11], is based on the majority of research works. The second [12] differentiates between two layers called network and compute infrastructures. The former is an SDN infrastructure, which provides connectivity enhanced by the additional support of VNFs processing. The latter is responsible for VNFs hosting and processing. Finally, the third [10] is a model with two orientations: a vertical one represents the stack of VNFs for different layers, while a horizontal one includes data and control planes for SDN-based management of all the virtualized layers. Furthermore, extreme flexibility is targeted by the new paradigm of wireless network operating system [13] (WNOS), which will completely abstract network entities by providing also a programmable protocol stack (PPS), thus not only network functions and routing.

Such a complex and heterogeneous system will require 5G to rely less on human intervention and more on machine learning/cognition for network management. An increasing research trend focused on the deployment of cognition to make autonomous network management. Especially, the research community has started the study of self-organised networks (SONs) [14] in parallel to virtualization, by applying machine learning and cognitive algorithms mainly towards self-healing and self-management. This increasing tendency has resulted in high interest from standardisation bodies for 5G cognitive network management. The 5G Infrastructure Public Private Partnership [15] (5GPPP) defined the role of cognition to achieve (i) autonomic SDN, (ii) autonomic diagnosis/anticipation and (iii) autonomic adaptation for proactive network management. In parallel, ETSI group called Experiential Network Intelligence (ENI) has been working on standardisation of a cognitive network management architecture to improve operators experience with artificial intelligence.

5G and beyond 5G (B5G) networks will host end users (mobile and fixed, humans and machines) and telecommunications operators, which will also become future infrastructure providers (InPs). Moreover, internet service providers (ISPs) and mobile virtual network operators (MVNOs) will share and rent the same physical infrastructure owned by InPs.

Given all the above premises, fundamental questions arise: *what is next? Is 5G the last generation/the arrival point of telecommunications networks?* By looking at what research community has proposed by now, it seems B5G networks will be incremental extensions/upgrades of the *5G ecosystem* previously described.

B5G networks [16] will evolve and enhance 5G by including additional RATs and paradigms such as visible light, molecular and quantum communications. Furthermore, B5G can include new kind of devices (e.g. self-powered) and services (e.g. interplanetary internet [17], [18], in-body/on-body/from-body internet communications) to achieve "the invisible Web of everything everywhere" [19]. So, as discussed for example by *Fitzek* [20], the complete/real 'softwarization' of the network will only imply further updates, not future generations.

### A. The Vision of Autonomic Mobile Network Operators

This article intends to describe the essence of Autonomic Mobile Network Operators (AMNOs) ecosystem, the 'next generation' of future telecommunications networks (after 5G and B5G). This novel generation will come from the radical change of humans' role in InPs, ISPs and MVNOs, which will become autonomic entities. The actual realisation of such environment will take to a telecommunications system with *no human in its loops*. The main role of humans in the new generation *pan network* will mainly be the one of external end users, policy makers and shareholders.

The rest of the paper is organised as follows. Section II describes the main characteristics of AMNOs such as architecture, protocols and structure. Next, Section III describes how to model such autonomic ecosystem as a cognitive multi-agent multi-level system. Finally, Section IV briefly highlights principal future challenges to be undertaken.

## II. Autonomic Mobile Network Operator

The vision of AMNOs relies on the presence of a fully virtualized network infrastructure. The network is constituted by a dynamic physical network infrastructure, which includes deployable access points with a remote radio head (RRH) (e.g. UAVs base stations), SDN switches, big/micro/pico datacentres, an their respective satellite-based counterparts (e.g. satellite-based SDN switches, etc.). Above that, an integrated virtualized architecture merges and SDN-NFV-based system

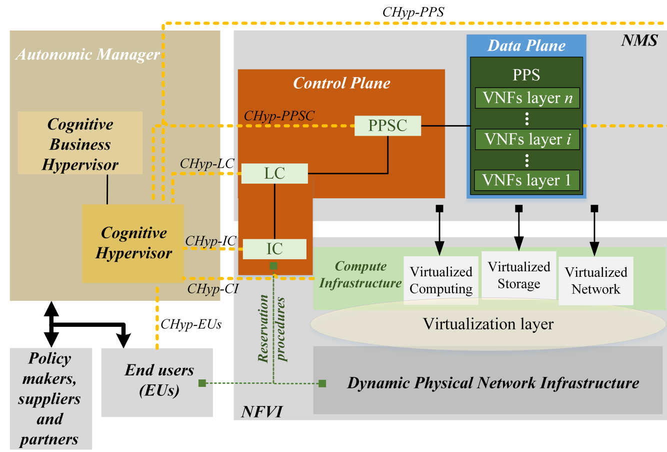



Fig. 1. Logical architecture of an autonomic mobile network operator.

with programmable protocol stacks (PPSs) and reservation procedures. Figure 1 depicts the functional-logical architecture of an AMNO. This novel architecture effectively merges the current main proposed unified SDN-NFV architectures ( [10]–[12]) with the vision of PPS and autonomics towards no human presence. All the elements are artificial entities: the humans are only present as external users (not belonging to the operator).

The core of the system is the *autonomic manager*, which contains the *cognitive hypervisor* and the *cognitive business hypervisor*. The former uses artificial intelligence/machine learning (AI) for all the operations related to network management while the latter uses AI to adapt economical aspects such as pricing and expenses for network expansion. The deployment of machine learning by mobile operators for smarter capital spending, automation and simplification in the back office, predictive analytics in marketing and sales, more efficient customer retention and support was already suggested in 2017 McKinsey&Company's report 'A future for mobile operators: The keys to successful reinvention' [21].

The AMNO exploits stateless/stateful 'cross-layer/cross-blocks' knowledge obtained by SDN-NFV control plane and data plane, virtual network functions (VNFs) and virtual stack layers of PPS. The autonomic manager, via its cognitive and cognitive business hypervisors, uses unsupervised learning (e.g. deep reinforcement learning [22]) to perform the *unsupervised learning circle* operations: sensing, planning, deciding, proactive acting and performance verification.

The cognitive hypervisor performs all the management and orchestration (MANO) and operation/business support (OSS/BSS) functionalities. Moreover, it has complete knowledge of infrastructure's description and characteristics such as all available services, system-level/management applications, VNFs and virtual protocol stack configurations. The cognitive hypervisor has various interfaces to perform managerial and informative functions:

- *CHyp-LC* and *CHyp-IC* connect the cognitive hypervisor with local controllers (LCs) and infrastructure controllers

(IC) respectively. They are both informative and managerial since they are used for data gathering (from controllers) and management of controllers' operations (i.e. SDN control plane management).

- *CHyp-PPSC* connects the cognitive hypervisor with the PPS controller (PPSC). It is both informative and managerial because it collects control information referred to PPS.
- *CHyp-PPS* connects the cognitive hypervisor with the PPS. It is an informative interface to gather information about data plane and VNFs of the PPS.
- *CHyp-EUs* connects the cognitive hypervisor with end users. It is mainly employed for users' data collection.
- *CHyp-CI* connects the cognitive hypervisor with the compute infrastructure. Its main aim is to get information about the status of computing/storage/network virtualised resources.

Next, reservation procedures represent bridges between the control plane and the flexible physical network. Traffic engineering and advanced characteristics of such techniques can enhance physical resource reservation via effective data gathering, resource management and response to network changes.

The cognitive business hypervisor is linked to the cognitive hypervisor so that the exchange of information and their complex interactions can change rules, pricing policies and can eventually adapt network behaviours to different environmental regulations (e.g. allowed transmission frequencies, policies for UAVs geographical deployment, etc.). The interfaces between the autonomic manager and humans (e.g. policy makers), can be used for several purposes such as to provide high-level goals and rules to limit and to lead operational/functional activities of the AMNO.

### A. Cognitive Hypervisor's Learning Circle

The management of network infrastructure, operations and services is responsibility of cognitive hypervisor's artificial intelligence. Figure 2 depicts its learning circle performed for proactive-unsupervised network management. That consists of five main phases:

1) *Sensing* – The cognitive hypervisor collects raw data from different network sources. According to the origin of information, preprocessing guarantees correct data classification, transforming it into labelled data. Next, the cognitive hypervisor performs both online and offline procedures in parallel. The former consists in new data classification and analysis together with model extraction: in particular, the cognitive entity tries to discover eventual frequent/known patterns and to find/to classify network events. The latter consists in model identification via comparison between new and historic data. That allows the identification of network historic behavioural patterns and the possibility of using experience replay (i.e. replicate previous decisions/actions).
2) *Planning* – The unsupervised learning algorithm used by artificial intelligence (AI) in the cognitive hypervisor requires both offline and online training: thus, the processed data (new and historic) of the previous phase are used for this purpose. Moreover, models are used to simulate/to estimate potential effects of actions on network current state. That can also improve existing models and value/reward functions.
3) *Deciding* – Hypervisor's AI uses end-to-end performance evaluations and estimations from previous phases to select the correct set of actions $A_t$ at current time $t$. Such actions have to guarantee the transition from current state $s_t$ to the desired state $s_{t+1}$, which optimises the multivariate function (e.g. latency, throughput, etc.). This description sees deep reinforcement learning (DRL) as a Markov decision process (MDP).
4) *Proactive acting* – Cognitive hypervisor's actions have to be proactive to configure and to prepare the physical

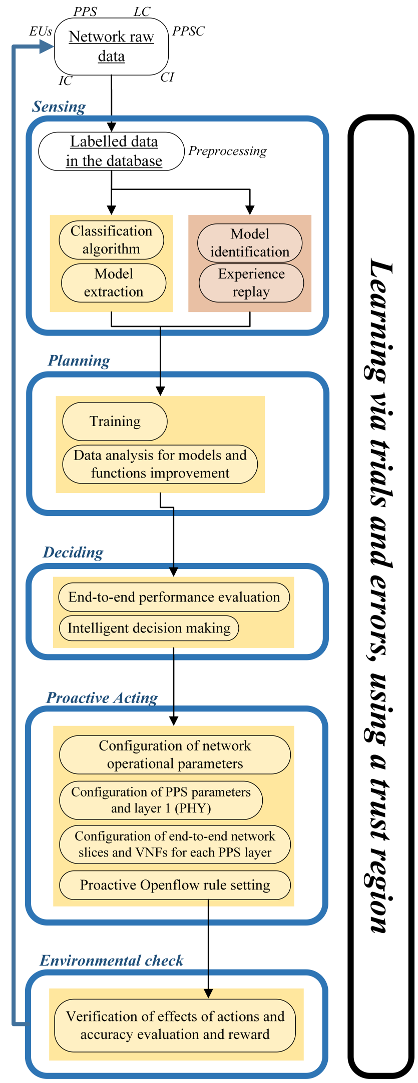



Fig. 2. Diagram of the learning circle performed by the cognitive hypervisor for network management and proactive configuration. The cognitive hypervisor can use unsupervised deep reinforcement learning and markov decision processes.

and virtualized network to satisfy existing verticals' requirements. Especially, services relying on low latency require predictions and a priori actions. The AI configures network slices, PPS and VNFs via their respective controllers. Furthermore, this configuration includes the activation of RRHs via BSs deployment (for example UAVs BS positioning). This phase can also take advantage of Openflow proactive rules setting and proactive PPS configuration with VNFs placement.

5) *Environmental check* – By checking the effects of proactive actions on the network environment, the cognitive hypervisor can get its reward and learn from its successes and errors.

The above phases contribute to AI's learning process, which is mainly based on trials/simulations and errors. The AI can also performs exploratory decisions/actions in cases where sufficient information is not obtained. The cognitive hypervisor activity must belong to a so called 'trust region'. Such a region guarantees that actions are restricted to lie within a region where final results/rewards are always acceptable in terms of performances required by end-to-end services. Network behaviour must not deviate from the boundaries imposed by high-level policies (included in the set of control strategies), stated by policy makers (that can be translated into specific limiting paths between states determined by actions in the MDP).

## III. Future Generation Networks as Autonomic Multi-agent Multi-layer Systems

The environment discussed above will host several autonomic entities, providing/managing services and running businesses without any human intervention. That arises the need to re-think current mobile operators' company/business structure in the context of AMNOs. Novel characteristics and solutions for OSS/BSS [23] and enhanced Telecom Operations Map (eTOM) Business Process Framework are pivotal to clarify how AMNOs manage their internal business/technical functions, how AMNOs interrelate and negotiate and how machines can run businesses, finding motivations to increase their revenues. In that sense, it will also be fundamental the way high-level goals/policies are defined by human organisations and the methods/protocols of policy makers-AMNOs interactions.

The future autonomic ecosystem can be effectively analysed and modelled as a multi-agent (MA) multi-level (ML) system. Figure 3 shows the logical structure and the main parameters of such MA-ML systems.

Figure 3(a) shows the logical-relational model of AMNO-based future generation networks. Each AMNO represents an autonomic agent with its goals and objectives, following rules (policies) imposed by human policy makers. Inter-agent relationships/negotiations are realised via proper communication protocols. The programmable physical network is the environment, which provides actual and virtualized resources. Perceptions refer to sensing operations of network behavioural changes via data mining and classifications.

Next, actions represent the results of machine learning algorithms' decisions, which evolve network characteristics and parameters according to different conditions.

The AMNOs' market can present simple/coordinated collaboration or pure individual/collective competition. Their relation to resources can be different: they can own the physical resources or they can be virtual operators (renting them). Moreover, they can rent resources from another AMNO in a geographic region where they do not have physical resources but they want to have them (for example for security reasons in case of defence communications).

The reason to put AMNOs in action, called *motivations*, can be of different kinds:

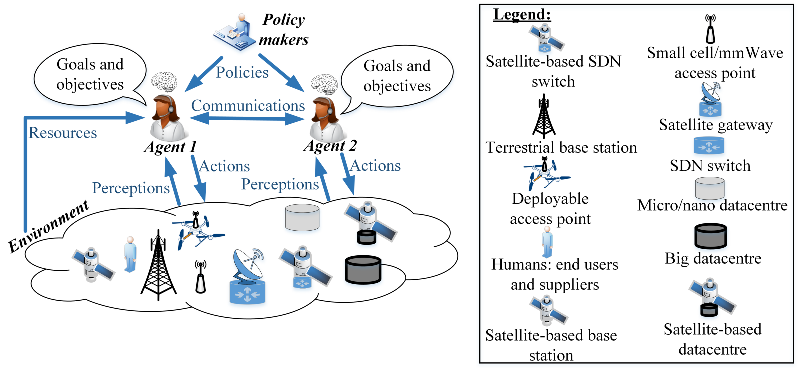
- *Personal* – It includes actions related to agents' contractual commitments, which it has made to itself or which allow persistence of its objectives.
- *Environmental* – It consists in reflex actions addressing external stimulus coming from specific changes in environment parameters/characteristics.
- *Social* – It is referred to motivations such as loss of profits, loss of jobs, means of subsistence and decrease in popularity. Moreover, it can include constraints to reduce accidents, sanctions and prohibited behaviours.
- *Relational* – It means all the actions due to motivations, which are not within an agent but come from the interaction/communication with other agents. It refers to inter-AMNOs relationship.

Finally, *commitments* bind agents via a 'promise' or a contract, to carry out future actions by restricting the set of possible future behaviours. Commitments can be relational, environmental, social, internal (referred to internal functions/agents).

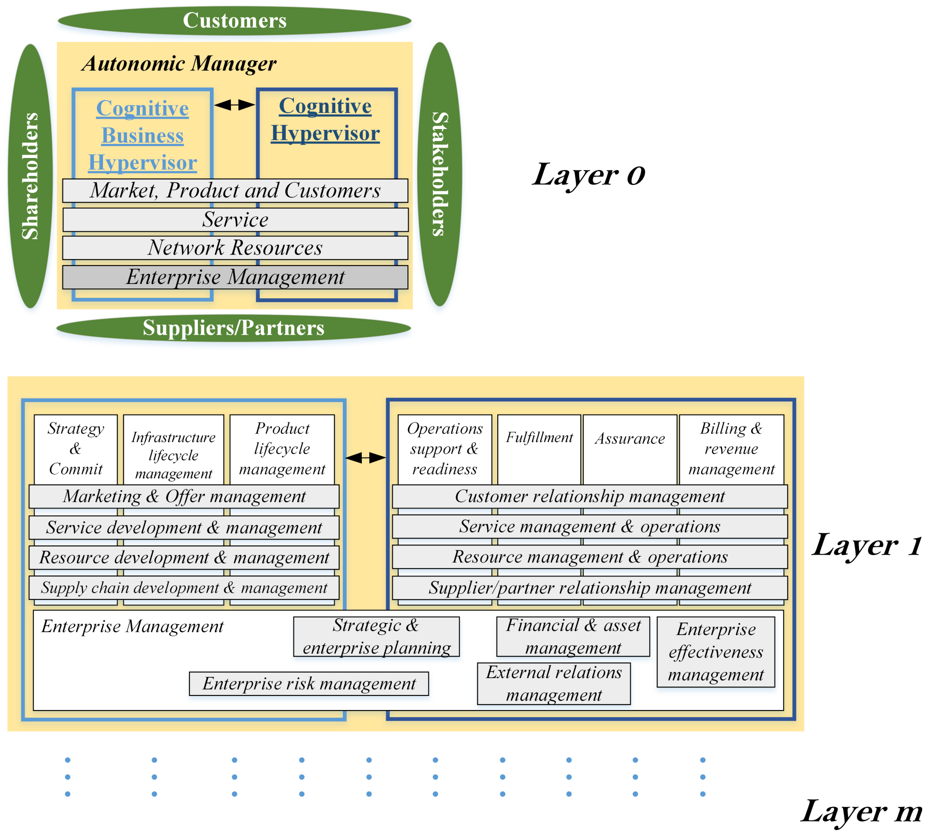
Figure 3(b) depicts the MA-ML internal structure of AMNOs. Blocks represents internal business functions, which interact with each others either horizontally or vertically. This structure is inspired by eTOM explained in [24].

AMNOs are ML organisations, counting from layer 0 to layer $m$ (increasing the number augments the level of detail and granularity). Layer 0 consists of autonomic manager, with its objectives and goals. Then, the autonomic manager is composed by two entities the cognitive business hypervisor and the cognitive hypervisor. The former is mainly responsible for strategy, infrastructure and products, while the latter is principally focused on operations. External entities such as customers, suppliers/partners, shareholders and stakeholders can be either humans or machines. Next, there are business 'cross-hypervisor' functions such as Market, Product and Customer, Service, Network Resource (application, computing and network), Supplier/Partner and enterprise management, which also require inter-hypervisor interaction/negotiation. In particular, AMNOs' eTOM does not include Employees since the enterprise has no human-based functions.

At layer 1, the level of specification of agents increases. The cognitive business hypervisor is constituted by two-dimensional agent architecture. Vertically, there are Strategy & Commit, Infrastructure lifecycle management and product lifecycle management, while horizontally there are Marketing




(a)




(b)

Fig. 3. (a) Multi-agent system to model future generation networks with various AMNOs (b) Multi-layer structure of an autonomic mobile network operator. Each block at each layer represents an agent. Among agents there can be vertical or horizontal logical interactions. This article considers Cisco's eTOM model, however the theoretical principle of MA-ML system is generally applicable to any other business structure.

& Offer management, Service Development & management, Resource and Supply chain development & management. Enterprise management contains various business functions but the difference from legacy eTOC is that it does not contain human resources management.

The cognitive hypervisor deals with operations support & readiness, fulfilment, assurance and billing & revenue management (vertically). Moreover, it handles customer relationship management, service management & operations, resource management & operations and supplier/partner relationship management (horizontally). Enterprise management agents manage enterprise-related functions with exception of the ones related to human resources, which are not needed since there are no employees-related functions.

## IV. Future Challenges

The significant complexity of AMNOs arises several interdisciplinary challenges, which are not banal and require significant research effort. These challenges can be grouped into four main areas: business, law/regulation, scientific and technical/engineering.

The design of proper structures for OSS/BSS in autonomic communications is still at its infancy. Some initial proposed guidelines can be found in [23]. However, in the context of AMNO-based ecosystems, there are important interdisciplinary social/economic/legal questions to be answered: *What are the motivations for an artificial/autonomic entity to raise revenues? What are the social/economic impacts of having artificial enterprises competing with current ones? How revenues of AMNOs can be beneficial for humans?* Moreover, from the legal point of view: *What is the legal responsibility of AMNOs? What is the legal structure of an artificial enterprise without human entrepreneurs/employees?*

From scientific/engineering point of view, it is pivotal to find effective unsupervised AI algorithms for networks and business management. In the context of fully virtualized networks, how unsupervised learning algorithms respond to network hardware upgrades (e.g. new RRH installation) and network software upgrades (e.g. new protocols and layers, new VNFs in the PPS) is new topic. It is also necessary the definition of languages and protocols for inter-AMNO communications and AMNO-humans (either users, suppliers, policy makers, etc.) communications/interactions. Moreover, future network ecosystems will need efficient predictive models, efficient data mining algorithms and implementation of standardised/common application program interfaces (APIs) to provide efficient and effective means for seamless network hardware/software upgrades. Next, effective methods to store and to process big amount of data of different kinds (not only from network devices but also from business agents). Moreover, use of historic data to predict changing network and economic conditions.

## V. Conclusions

At the best of authors' knowledge, this is the first work, which has discussed in detail the vision of AMNOs as main enablers to evolve 5G and B5G networks into future generations. This is expected to reduce costs while changing the role of humans in telecommunications and more generally in enterprises. The article has provided a detailed characterisation of AMNOs by focusing on logical architecture and modelling.

This paper should be intended as a roadmap for the development of an actual AMNO to overcome human limitations in the management of networks and operators via full realisation of a virtualized/flexible network infrastructure. No research and standardisation on AMNOs has been presented yet while the highlighted issues require further investigation before real implementation will become possible.

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