# The Network is the Robot

**Antonio MANZALINI**
Innovation, Future Centre, Telecom Italia, Turin, Italy

**Alexandros STAVDAS**
Dept. of Informatics and Telecommunications
University of Peloponnese Tripolis, Greece

***Abstract:*** Ultra-broadband diffusion, information technology (IT) advances and the market mass decreasing costs are determining a growing adoption of processing and storage resources at the edge of current telecom networks that, untimately, are the end-users. The number of devices connected to the network is growing at an exponential rate: embedded communications are everywhere. "Machine intelligence" is rapidly migrating towards the end-user, determining a number of socio-economic implications. Smart cities are going to become populated by any sort of mobile terminals, devices, machines, smart things, sensors, actuators, drones, robots etc. In general, ICT will basically become accessible to enterprises in any part of the world on an (almost) equal basis. In turn, this will reduce the thresholds for new players to enter the ICT services markets, moving the competition towards Opex-based models. This tendency is progressively accelerating and, from a socio-economic perspective, it is going to determine a transition from our society and the economy of resources towards the digital society and the digital economy. In this evolutionary scenario, telecommunications services are likely to be packaged with other services, and new services paradigms will be exploited: as an example, this paper proposes the model "anything-as-a-service", where any devices, machines, smart things, robots, drones, etc. will look like edge intelligent nodes providing the end-users with "any services". This transformation will require an highly flexible and pervasive 5G network, embedding processign and storage and providing high bandwidth, ultra-low latency links so as to create, literally, an innovative "nervous system" for the digital society. Eventually, this evolution will be capable of modernizing urban services such as transport, energy, water, food, education and will create new business opportunity, by integrating, systemically, 5G, big data and robotics.

***Key words:*** smart cities, SDN, NFV, 5G, cloud robotics, big data, machines.

Socio-economic drivers (e.g., the markets globalization, the hyperconnection of the economic variables), progress in IT technologies (i.e., processing and storage), tumbling hardware costs and availability of open source software are steering the evolution of telecom-ICT industrial sectors. From the technology perspective this evolution will lead to a deeper integration of IT and Networks resources and functions. The so-called "IT-zation" or "Softwarization" is a key factor of this evolution: in fact, in the short/medium term it will be possible to develop in software, and even virtualize, any network and service functions, by using IT systems and methods capable of processing large amounts of data. Future ICT infrastructures will fuse IT and telecom facilities by amalgamating systems providing vast processing and storage capability (hosted on low-cost powerful hardware) with ultra-low latency (radio and fixed) links (e.g., in 5G). In this sense 5G will be more than the next step beyond 4G networks

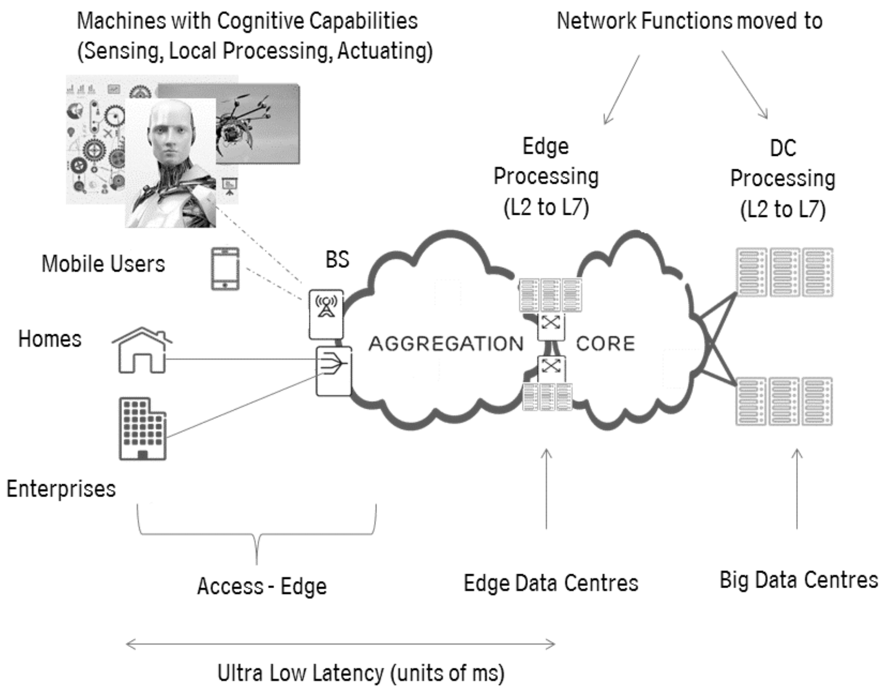
As a matter of fact, today, the paradigms proposed by Software Defined Network (SDN) and Network Function Virtualization (NFV) are under the spot world-wide, both in industry and academia: even if the concepts behind SDN and NFV are not new, they are indicators of a systemic trend (other indicators are cloud-fog computing, cloud networking, C-RAN, etc.), which is becoming mature and sustainable from a business viewpoint.

Software defined networks is based on the concept of decoupling hardware from software in telecom equipment and executing said software not necessarily in the equipment, but potentially in the cloud or in any standard processing resources (e.g. servers). As an example, today routers are mainly based on specialized/propriatary hardware whilst the corresponding software comes, alike with hardware. The adoption of SDN principles in tomorrow's router would mean decoupling control plane (software) from data plane (hardware). Another key aspect about SDN is about providing a wide number of abstractions and application programmable interfaces (e.g. API) to program/control the functions and the services of the network resources.

SDN should not be confused with NFV, which is about virtualizing some network functions that, in turn, could be executed on standard hardware, and that could be moved and instantiated in various locations. SDN and NFV could be seen as mutually beneficial but they are not dependent on each other: e.g., network functions can be virtualized and deployed without an SDN being required and *vice-versa*. As mentioned, SDN and NFV are not new principles, as they were already proposed and demonstrated many years ago (the former in the 90's and the latter even before). So if SDN and NFV basic paradigms are not new, why are they so popular today, often being seen as the most advanced innovation opportunity for future Internet?

The reason stands in the novelty of the techno-economic landscape: there are the conditions making the potential adoption of said principles really feasible at competitive costs and with high levels of performance. In fact, it can be argued (Figure 1) that in a few years time it will be possible to extract and virtualise any network function and service (i.e., spanning from L2 to L7 from switches to middleboxes); it will be possible to execute said functions either logically centralised in the cloud or in clusters of mini-data centres, located at the edge of the current network (e.g. like the current aggregation routers, e.g. BNG, that, however, would be enriched with processing and storage capabilities) (MANZALINI & SARACCO, 2013). Adoption of SDN and NFV in 5G design and deployment will manifest a change of paradigm with far-reaching implications.

**Figure 1 – Example of future network scenario**




The outline of the paper is the following: the 2nd Section elaborates the vision and proposes its exploitation in a digital single market scenario in Europe; the 3rd Section provides an example of network architecture capable of supporting ultra-low latency links: a strict requirement for developing an infrastructure becoming the "nervous systems" of the digital society; the 4th Section discusses socio-economic impacts and new business models. Finally; the last Section gives conclusions and discusses future work.

## A digital single market in Europe

It is foreseen that the aforementioned changes will have deep techno-economic impacts: roles and models telecom businesses will be redefined for both operators and technology providers; new players will enter the arena whilst competition will migrate towards OPEX-centric models. Last but not least, new value chains and new forms of cooperation and competion will emerge.

For example, software-defined operators could be seen as operators owning basically software networks and services platforms, i.e., platforms whose functions (from L2 to L7) are fully developed, executed and operated in software, (logically centralised) in the cloud. Considering the acceleration which we are witnessing in the performance and cost reductions of IT systems, the "IT-zation" of all network functions and services is possible in the medium-term horizon, i.e. in about five years. Clearly, the speed at which these changes may occur is also dependent on a number of other factors, such as business models sustainability, proper regulation rules, users' adoption, etc. As a matter of fact, there are already feasibility demonstrations of C-RAN implementation exploiting schemes like these.

In general, software-defined operators could benefit from dramatic energy savings (e.g. in the order of 40%-50%), CAPEX reductions, due to improved efficiency in using resources and delays in new investments, OPEX reductions, due to automated and optimised processes (e.g. estimation of 25%-35%), shorter time-to-market in creating and deploying services (e.g., comparable to the OTT dynamics).

Let's consider, as an example, a scenario in Europe where, in each country, there will be some (e.g., two or three) software-defined operators "renting" hardware resources (e.g. antennas, L0-L1 transmission and processing power) from some Infrastructure providers. Indeed, the adoption of interoperable (network and service) platforms will create the conditions to evolve towards a digital single market (the grand objective of the EU digital Agenda). Moreover software-defined operators will also be potentially capable to "upload and execute" their networks and services platforms anywhere there will be infrastructure providers willing to rent hardware (e.g. processing and storage) and L0-L1 transmission resources. This is a disruptive way to enter new markets with limited investments, thus creating new value chains.

In fact, adopting the model "anything as a service" (MANZALINI *et al.*, 2014), the software-defined operators could be able to provide all EU citizens and enterprises with ICT services. This could happen by leveraging any terminals, devices, machines, smart things, robots or drones… or mini-data centers around the end-users. This trend would be further reinforced from the wide deployment and availability of ultra-fast and low-latency access networks offering a true competitive advantage with respect to the OTT.

As a matter of fact, we are realizing that the number of devices connected to the network is growing at an exponential rate. For every cell phone today we have already a few sensors and by the end of this decade there will be more than a hundred sensors per individual cell phone, increasing dramatically the number of connected objects. Here there will be the first change of paradigm. Today, operators still keep a distinction between the "network" and what connects to it, the "terminals". Tomorrow, this distinction/border will blur, as more and more network functionalities will be executed both in the network (partly centralized in the cloud and partly distributed in Edge PoPs) and in the end-users terminals/devices. The edges will become the arena of very dynamic software environments created in an application-driven way, as a result of the aggregation (the so-called "Edge Fabric" as illustrated in MANZALINI & SARACCO, 2013) of a variety of nodes, devices, terminals, machines, drones and robots.

In this direction, this paper argues that network "IT-zation or softwarization" will facilitate creating a new and pervasive "machine intelligence" capable of reshaping the economy equation and contributing to the development of smart cities. As a matter of fact, today "information" is reaching every corner of the world at an immense speed that is swiftly processed and actuated. Internet penetration contributed to this globalization. But, on the other hand, this is also about the definition of "intelligence": i.e. the capability of processing and exchanging information to understand what's happening in the environment, to adapt to changes and to learn. So, "machine intelligence" supported by highly flexible (liquid) software networks will exploit the model "anything as a service", capable of going beyond the commoditization of communications services, thus creating new business ecosystems.

Clearly this change of paradigm will be complimented with new and different business models, different kinds of jobs, workers and skills than the economy of the 20th century. In fact, in our society, a main "control variable" of our "complex" economy is still human intelligence, attention, efforts and time: humans are still the most productive part of current economy and industries are always migrating where there are lower labor costs. In general, "machine intelligence" will help optimizing any processes (e.g., in industry, agriculture, education, etc) also by reducing human efforts and mistakes. "Anything as a service", exploited through intelligent terminals, devices and machines, will allow, for example, improving industrial and agricultural efficiency, developing new models of decentralized micro-manufacturing (MANZALINI, 2014) (e.g. also through 3D printers), improving efficiency in public processes, saving energy, supporting ageing citizens' lives better (e.g. with machines and robots), providing a richer education (for all at low costs), "digitalizing" Europe (to optimize processes) or enabling new sustainable ICT ecosystems.

In particular, citizens will see the quality of life improved and there will be new opportunities to address the multitude of challenges society is facing today. So, not only the big players, but also SMEs and citizens will be impacted and will have the chance of taking benefits from this new technological and business landscape.

The progressive accelaration of enterprise digitalization will create a global business environment where enterprises can play multiple roles cooperating and competing in global markets in a more effective, dynamic and flexible way. Feedback mechanisms (based on almost real-time big-data processing) will improve performance and productivity of processes by self-corrections of (internal and external) actions. This knowledge sharing process is substantiated and mediated from the fusion of highly flexible and ultra-low-latency networks with machines having vast processing power capabilities. Moreover, innovations like holons (ULIERU & COBZARU, 2005; KOESTLER, 1967; ULIERU, 2002) which in the past were used for modeling enterprise entities (machines, devices, …) will be exploited for decentralizing manufacturing. Enterprises processes will be mapped in huge data sets, which can processed with big data analytics to make then optimized actuations.

As another example, let's consider the use-case of the agricultural drones: even today these drones are being adopted, just like a "tool" like any other consumer electronic device. In fact, the availability of cheap and easy to use drones is largely due to the remarkable advances in technology: tiny sensors (accelerometers, gyros, magnetometers, and often pressure sensors), small GPS modules, powerful processors, radio communications. These devices will transform the job and working skills of peasants in an unprecedented way, introducing changes that we haven't witnessed since the agrarian era: agriculture will be transformed to a robot-intensive, data-driven process optimizing the use of resources like water while reducing the pesticides needed so for a given effort, there will be a significant increase in the output using fewer resources. Tomorrow, drones and robots (made more intelligent and controlled through the softwarised network and the cloud) will provide farmers with a lot of customised services, e.g. detailed views revealing patterns from irrigation problems to soil variation, pest and fungal infestations, differences between healthy and distressed plants. And this at any time the farmer may want, even every hour. These changes will be complemented with changes in genetic engineering that will eventually transform a muddy, low-skilled profession to a high-tech, research-lab level activity. Again the agricultural production and distribution processes will be mapped in huge data sets, employing big data analytics to make optimal decisions.

In summary, the aforementioned changes in economy and society have their roots in important changes in technology and they will bring in the so-called "Second Machine Age", well-represented in (Capgemini Consulting: *Digital Transformation Review*, 2014). More and more intelligent devices, terminals, machines and robots will be operated and controlled through the 5G network, playing as a "nervous system".

## ■ A zero-latency network architecture

One of the main challenges of vision reported in this paper is: how to develop the network "nervous system" for a pervasive machine intelligence?

The network should be very flexible but ultra-low latency is the key requirement: in fact, very short reaction times (order of units of ms) are required to actuate actions by these intelligent machines providing services. In this sense, the capability of controlling and minimizing "latency" will offer a significant competitive advantage. Simply the equation "Throughput = Window Size / RTT" is intuitively showing that minimizing latency would require to move processing and storage towards the users. In order to achieve this, part of the processing and control of intelligent machines should be moved at the edge, for example in mini-data centers located in the current aggregation nodes (e.g., Edge PoPs).

As a matter of fact, OTTs, like Google, are already progressively moving processing towards the end-user to reduce the "overall latency" (which includes the processing response time); Akamai Edge Computing is another example in this direction. Even more, when considering that HTTP was not particularly designed for latency, OTTs – in this "rush" towards reducing latency – developed and used application-layer protocols (e.g., SPDY), for the web, which greatly reduces latency.

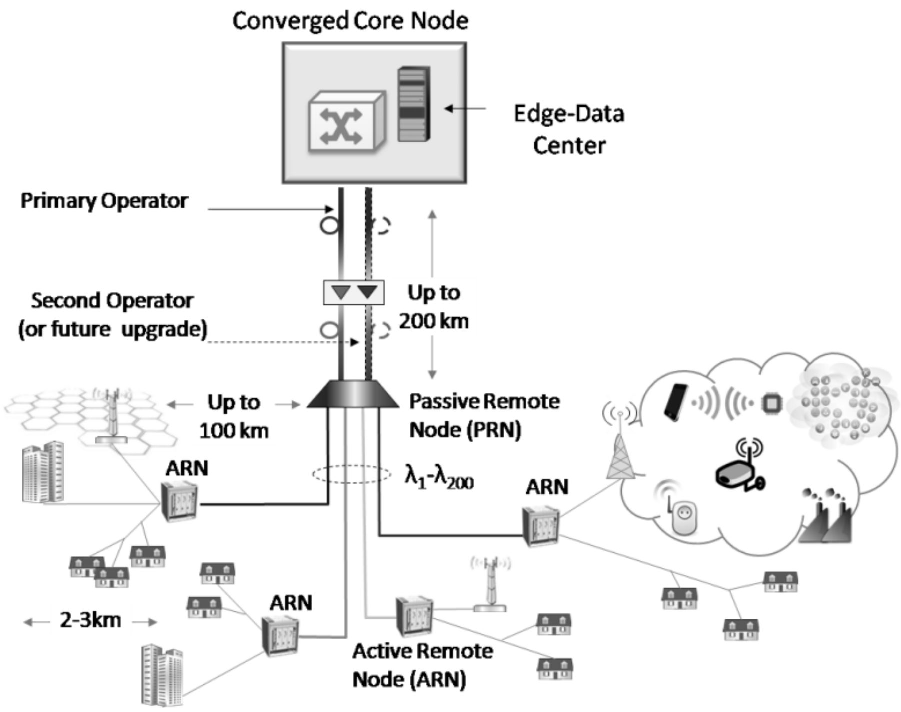
Operators may have a strong competitive advantage in this "rush" towards reducing latency: they may transform their telephone exchanges to mini-data centers. This, coupled with a 5G network architecture offering ultra-low latency links, will create the condition for deploying new service models (such as "anything as a service") at very competitive costs with high quality of service/experience.

In the future, the transport networks will be characterized by an optical core, interconnecting multiple edge networks (wired and wireless) supporting any sort of services by exploiting local processing and storage resources. The edge (access-aggregation) will be, in this perspective, the most challenging area of innovation.

New architectures capable of properly integrating 5G with optics (with IT resources) are required. As an example, the HYbriD long-reach fiber access network architecture (HYDRA) (ORPHANOUDAKIS *et al*., 2014) is a potential solution tailoring this vision (Figure 2). Key to the concept is the introduction of an active remote node (ARN), located in the vicinity of the end-use/point. In fact, the ARN could be housed where the existing DSLAMs/cabinets are located at a distance that is typically up to 2-3 km from the end-point (with a maximum distance 10 km). The re-use of the existing DSLAM housing facilities will not only minimize introductory cost, but also it will allow seamless migration from legacy fiber/copper access networks.

An important, and differentiating aspect, of HYDRA compared to other approaches is that the last-drop from the ARN to the end-point may exploit "any" of the existing technologies: a power-splitting TDMA xPON, point-to-point optical lines (including multimode fiber links for the shorter distances), wireless access, xDSL schemes, etc.

**Figure 2 – An example of network architecture minimizing latency**




The criterion for selecting a given last-drop technology would be solely cost-effectiveness and availability proliferating a "technology-agnostic last drop". It is worth stressing the fact that given the very short distance between the end-user terminal and the ARN, the physical layer limitations of the transmission medium (loss, dispersion etc.) are not of a primary concern anymore. This may have important consequences at system level: the terminals are simplified and they are also stripped off from the expensive, complex and power consuming parts that are necessary in other alternatives like long-reach PON (LR-PON) solutions. As such, HYDRA allows to exploit truly low-cost/low power consumption end-user terminals, lowering overall network cost. The ARN is the point where the whole range of services and access technologies are converging i.e. the point where traffic from/to a number of heterogeneous networks is terminated and (de)aggregated either at protocol-level or service-level as shown in Figure 2. Service integration can be based on transparent payload encapsulation over the integrated access-core optical transport network supporting multiple access side interfaces to transparently funnel traffic from the access segments towards the core. A number of virtual network functions (VNF) can be implemented in the ARN including considerable processing should this be beneficial to a said application.

This architectural pathway is bypassing the metropolitan area network (MAN), making this segment redundant. This has important consequences to the overall network architecture. The end-to-end network architecture is simplified (e.g., network delayering) whilst a significant cost associated to the MAN segment is obviated (e.g., CAPEX and power consumption). Moreover, this allows to consolidate many MAN nodes to a single core node whilst the networking functions carried previously in MAN could now be implemented in a scheme of coordinated processing between the ARN, to bring processing functions closer to the end-point/user and the Core nodes. It is worth pointing out that, given the short distance between the ARN and the end-user, whenever processing is carried out in the ARN, the latency is significantly lower compared to any other scheme, whilst when processing is to be carried out at the Edge-data-centre, the HYDRA solution allows again for the minimum delay which corresponds to propagation delay only. The details for a converged platform incorporating a telecommunications core node and an Edge data centre are elaborated in (STAVDAS *et al*., 2014).

As a concrete example, robot farms, may explore the two alternatives for the processing-location the HYDRA is offering: for time-critical applications, which by default should be light-weight processing wise, the processing can be carried out in the ARN whilst more processing intensive functions are carried out in the converged utility core nodes. The longest round-trip delay is at the order of 3 msec, which is the propagation delay for 300 km. Most importantly, the jitter is zero since all packets follow a single path, unlike network architectures which exploit a MAN segment. Therefore, management/orchestration capabilites may decide to migrate, making use of the advances in NFV and SDN, time-sensitive/critical functions to the ARN while keeping the s/w intensive ones in the core converged node.

It's quite obvious that it will not be possible anymore to keep adopting traditional management approaches (with declared objectives and observed behavior) for said networks. As an example, any network functions and services (e.g., L2-L7) could be executed and controlled according to three hierarchical levels, thus simplifying the "operations" even in dense network environments: i) at the device level (for very local decisions), ii) at the edge level (for edge orchestration), and iii) at the cloud centralized level (for global orchestration of multiple edges). An edge controller can be instantiated and executed in a mini-data center, located in a kiosk, or in a small exchange (edge PoP). The ambient (logically) seen by said edge controller is a dynamic aggregation of devices and machines (embedding local controllers actuating device decisions, based on the local context). At the cloud centralized level, global orchestration functions will control larger edge ambient, or a combination, of them and device-level decisions (such as a smart city, or regional geographic area). In general, we may argue that complexity and dynamism of "intelligent machines" will be too high. Dynamic or static modeling for (open or closed loop) control will become very complicated and unstable if not supplemented with a variety of methods and control techniques, including (nonlinear) dynamic systems, computational intelligence, intelligent control (adaptive control, learning models, neural networks, fuzzy systems, evolutionary and genetic algorithms), and artificial intelligence. This represents key areas of investigation which have to identify the proper balance between centralization (cloud) and distribution (edge PoPs, or edge local devices) of execution and control, which is required for minimizing the overall latency (i.e., reaction time).

## ■ Techno-economic impacts and business models

The diversified socio-economic needs and the astonishing progress in the IT sector are driving the evolution of Telco business in a way that is impacting several aspects of our society, far beyond just simple communication needs. It has been already mentioned that software-defined operators will see dramatic costs reductions (e.g. estimation of 40%-50% savings in energy), CAPEX reductions, improved efficiency in the overall operations (e.g. 25%-35% OPEX savings only by automating processes), reduced time-to-market when deploying services.

In this evolutionary scenario, telecommunications services will exploit new services paradigms: a promising proposition is the "anything-as-a-service", a model where devices, machines, smart things, robots, drones, etc. will and can be considered as edge nodes providing the end-users with "any service".

In general it can be argued that, the fusion of telecommunications with IT services, and the much expected, in the near future, commoditization of voice services, will turn 5G Telcom infrastructructures into the "nervous system" of the digital society. The smart city will become one of the new environments built on this said "nervous system", enabling scenarios such as "anything as a service" or even "city as a service".

Space-time dimensions of life will be impacted, as the physical direct presence of humans will be less and less required to perform certain production jobs or professional, educational tasks. Let's analyse this in deeper detail with some examples. Human production includes perceivable and abstract products: a piece of furniture is an example of a perceivable product; a design process is an example of an abstract product. These two products are often strictly related, being nevertheless produced by different skilled people. The act of production is achieved through a combination of mental activity, manual activity and through tools, performing a transformation of the natural resources which are available.

Assuming that the equation of production is based on these three variables, during human evolution these have changed both the weight of use (mental vs manual) and the form (by using more and more advanced tools), requiring different skills and determining different jobs. This equation impacted also the space-time dimensions of human life: think about the migration of people to the cities, where factories have been centralized; think about the evolution of ratio free time, time dedicated to work, etc.

IT-zation of industries, and the evolution of the telecommunications and ICT in general, is changing dramatically the balance of the variables of the equation of production and distribution. When intelligent machines will "flood the landscape", exploiting paradigms such as "anything as a service", there will be a number of socio-economic impacts: pervasive robotization; reduction of human efforts in jobs subjected to computerization; increase of local production; reduction of long distance transportation; optimization of socio-economic processes. And industries will not need to migrate, as today, where the human labor costs are less expensive. Clearly this trend will require developing different business models, and different kinds of jobs, workers and skills should be created, also to face an initial increase of unemployment. As mentioned in FREY & OSBORNE, 2013:

> "[…] as technology races ahead, low-skill workers will have to reallocate to tasks not-susceptible to computerization – i.e., tasks requiring creative and social intelligence".

Finally, because of this evolution, several economists, as well as technologists, have started to wonder if the usual representation of relationships among a myriad of players in a certain industrial area can still be modeled on the bases of value chains. There is a growing consensus that value chains modeling shall be complemented by a broader view considering business ecosystems. Current regulation should evolve to support this digital economy, making it sustainable.

## ■ Conclusions and future work

Socio-economic drivers, ultra-broadband diffusion, progress in IT technologies, tumbling hardware costs and availability of open source software are steering the evolution of current networks towards a highly dynamic and flexible environment of virtual resources, to serve multiple applications. Emerging paradigms such as SDN and NFV are part of the so-called "IT-zation or "softwarization". This is moving competition from hardware to software (and towards OPEX-centric models) and creating favorable conditions for a sustainable digital society and digital economy. Eventually, this evolution will create new business opportunity by integrating systemically software defined networks, big data and robotics.

Ubiquitous machines embedding vast processing and storage capabilities paired with ultra-low latency 5G links will create, literally, the "nervous system" of the smart cities in a digital society. SDN and NFV will be two enabling technologies hooking the nodes and terminals at the edge (i.e., all hyper-connected devices, such as smartphones, cars, robots and drones) together and to the cloud, thus building a pervasive software infrastructure capable to execute (as applications) any virtualized function and service. So, if SDN is seen today as a sort of "network operating system (OS)", looking at the future the 5G OS will be the big technical challenge. The 5G OS will be a sort of decentralized OS allowing the convergance of the beyond-the-last-mile fixed-line and wireless infrastructures, supporting mobility, embedding security – by design – and spanning from the terminals (meaning also robots and drones), to the network to the cloud.

One of the main challenges we are facing is to conceive and elaborate the details for developing this "nervous system" allowing the proliferation and control of such "machine intelligence". For sure 5G should ensure both flexibility and ultra-low latency in order to ensure the very short reaction times – at the order of units of ms – these intelligent machines need to execute and complete a diverse set of services and applications. Part of the processing and control of intelligent machines should migrate at the edge, for example in mini-data centers located in the current aggregation nodes. It is argued that the capability of controlling and minimizing the "latency" (including transmission, networking and processing/storage) will actually be the competitive advantage upon which we could build new forms of cooperation and competition!

In smart cities, and in general in all these new smart environments, space-time physical dimensions of life will be impacted, as the physical direct presence of humans will be less and less required to perform certain productions jobs or professional, education tasks. In other words, assuming that the equation of production is roughfly based on the three variables (mental work, manual work and tools), this evolution is offering "new digital tools" to humans.

Future work is directed to the study, development and feasibility demonstration of some use-cases, for example self-driving cars, robots and drones in the context of a smart city. The use of automated vehicles is expected to quadruple by 2050. Automobile manufacturers are heavily investing in R&D for the new generation of autonomous cars. A smarter and autonomic framework for handling and control of a multitude of parameters necessary in "driving" possess several advantages: improved safety, simpler skills to advanced driving, maximising the efficiency of fuels, optimizing transportation traffic in smart cities, reducing pollution, etc. car-to-car communications and cars ad-hoc Networking have already been demonstrated and several telecom vendors are already developing pre-commercial prototypes for specific application use-cases. In our vision, cars could be seen as 5G nodes at the edge, equipped with processing and storage and radio (e.g., Wi-Fi, 4/5 G) connectivity. Cars may be equipped also with an increasing number of sensors and actuators so they can download/upload information of the traffic in the streets. Nevertheless the self-driving intelligence could not be fully located in the cars: the need for cost-effective light-weight chassis and the need for constant upgrades to support heavy and complex processing systems, set natural limitations on the processing and storage power that can be placed in a single car prohibiting, for example, to visualise the global parameters of the entire smart city. Some level of intelligence should be centralised (e.g. at the edge PoPs or in the cloud) and "zero-latency connectivity" should be available to allow to monitor and dynamically adjust the driving variables with the proper time scales. This is not possible today, with the application-controlled solutions proposed by the OTTs. Also there are not yet appropriate systems and methods for implementing this partly distributed control in such complex systems as cars driving and traffic. It is argued that this is also a good example to demonstrate all the technological and business implications, including new forms of competition-cooperation between operators and OTTs. It is argued that a fully autonomous car or a robot won't be sold as a finished product, rather it will evolve and be enriched as "services" for assistance, control and optimization through the cars, so it fits into the vision "anything as a service" (one can even imagine creating a virtual clone of a car – surrounded by its data – on a cloud, and third parties offering services through that virtual clone). A possible scenario that may further extend the benefits of each innovation in isolation could be the fusion of robots - and in particular modular robots (YIM, ZANG & DUFF, 2002) – vehicles and 3D printers. Especially hydrogen-based vehicles are not subjected to the chassis restriction of their internal combustion counterparts and as such they might be deployed as truly convertible and software upgradable machines.

The automated and networked robots would have the capability of self-assembly and they might be transformed to a plethora of fabrication systems. When such systems are orchestrated through an "ultra-latency network" they would redefine the meaning of "distributed manufacturing" since they would allow a great number of individuals to own and operate these agile and multi-tasking production tools.

To conclude, it is argued that "waterfall" innovation finished about fifteen years ago: the model was moving from research activities to standardization, from systems development by technology providers to service providers deployments, up to services provisioning to consumers. Today (and tomorrow) innovation is likely working the other way round: it is starting from the needs of the digital society, from the massive consumers, users and from the challenging requirements of the new digital economy. Today cloud Computing and ICT platforms are easily accessible in any part of the world (almost) on an equal basis. This is making a big difference as it this will reduce the thresholds for several new players to enter the digital economy ecosystems and to provide ICT services for the digital society. Eventually, this evolution will create new business opportunities by integrating systemically 5G, big data and robotics.

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