5G on the Horizon

© PHOTO F/X2

Key Challenges for the Radio-Access Network

© ISTOCKPHOTO.COM/RICH VINTAGE

Panagiotis Demestichas, Andreas Georgakopoulos, Dimitrios Karvounas, Kostas Tsagkaris, Vera Stavroulaki, Jianmin Lu, Chunshan Xiong, and Jing Yao

Digital Object Identifier 10.1109/MVT.2013.2269187
Date of publication: 25 July 2013

Toward the fifth generation (5G) of wireless/mobile broadband, numerous devices and networks will be interconnected and traffic demand will constantly rise. Heterogeneity will also be a feature that is expected to characterize the emerging wireless world, as mixed usage of cells of diverse sizes and access points with different characteristics and technologies in an operating environment are necessary. Wireless networks pose specific requirements that need to be fulfilled. In this respect, approaches for introducing intelligence will be investigated by the research community. Intelligence shall provide energy- and cost-efficient solutions at which a certain application/service/quality provision is achieved. Particularly, the introduction of intelligence in heterogeneous network deployments and the cloud radio-access network (RAN) is investigated. Finally, elaboration on emerging enabling technologies for applying intelligence will focus on the recent concepts of software-defined networking (SDN) and network function virtualization (NFV).

The wireless world is increasingly calling for the effective management of heterogeneous infrastructures to meet the future Internet (FI)

1556-6072/13/$31.00©2013IEEE

requirements [1]–[4] in an energy- and cost-efficient manner. Wireless network operators are trying to satisfy the growing traffic demand [5] by deploying cells of various sizes (mostly small cells), instead of utilizing only typical macro-base stations (BSs). All these cells constitute the elements of heterogeneous infrastructures, which should be effectively managed by introducing intelligence.

Accordingly, wireless communications have to properly address key challenges and requirements driven by multiple perspectives of society, environment, economy, users, and operators so as to successfully achieve the vision of an inclusive, cohesive, and sustainable society. The future networks should be capable of handling the complex context of operations characterized by a tenfold increase in traffic [6], various mobility levels, and interference. In addition, multiple requirements need to be met including quality of experience (QoE) satisfaction, energy-efficient operation (90% improvement by 2020 [7]), resource efficiency, and cost efficiency.

Taking into account a comprehensive approach with respect to the determination of requirements, complexity, and heterogeneity of the infrastructures, there is a holistic presentation of the key challenges stimulating next-generation wireless networks. To address the key challenges, there is a need for enhanced, next-generation mobile broadband through intelligence, so as to find the optimal system configuration that will maximize the benefits of the intelligence and proceed to successful deployment and realization of a powerful wireless world.

An Overview of the Wireless World Toward 5G

Figure 1 depicts an overview of the wireless world toward the 5G of wireless/mobile broadband. Specific technical directions have been identified, so as to achieve cost-efficient resource provisioning, proper application provisioning, and augmentation of the intelligence.

Evolution of Radio-Access Technologies

A first direction for improving the service provision and cost efficiency has been the evolution—from the second generation (2G) to the third generation (3G) and the fourth generation (4G) or long-term evolution (LTE)-advanced—of mobile/cellular communications. 3G and 4G technologies have been the focus of the 3G Partnership Project (3GPP) standardization [9]. In parallel, there has been the introduction of various other wireless local-/metropolitan-/personal-area broadband systems, standardized in the context of the IEEE [10]. This evolution has primarily been the outcome of the development of advanced radio-access technologies (RATs), which led us from the frequency/time division multiple access (FDMA/TDMA) and wideband code division multiple access (WCDMA) to the orthogonal frequency division multiple access (OFDMA) schemes. Regarding cost efficiency, this direction is primarily targeted to the improvement of resource use (spectrum and other radio resources).

Decreasing Cell Size

A second evolving direction is the constant decrease in the sizes of the cells that are being deployed. This direction

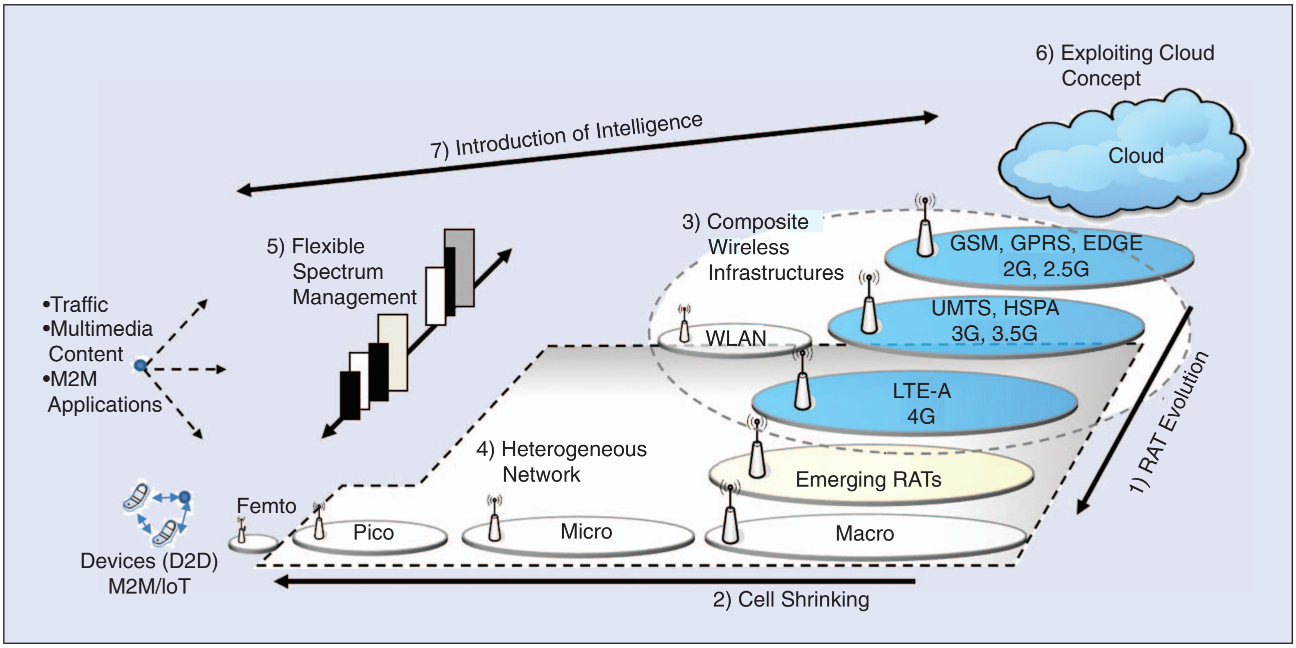

FIGURE 1 A view of the wireless world; seven technical directions aiming at the proper application provisioning, cost-efficient resource provisioning, and at the augmentation of the wireless world's intelligence. GSM: global system for mobile communications. GPRS: general packet radio service. EDGE: enhanced data rates for GSM evolution. UMTS: universal mobile telecommunications system. HSPA: high-speed packet access.

aims at improving the capacity and cost of the resources that are deployed as well as resource (e.g., spectrum) use. Therefore, there are cells with sizes that range from macrocells to the most modern small cells [11], which are able to provide significant capacity improvements (with a lower cost compared to macrocells).

Composite Wireless Infrastructures

A third direction, which emerged about ten years ago, was aimed at the joint operation and exploitation of a heterogeneous, in terms of the RATs it comprises, wireless access infrastructure. This direction led us to the concept of composite wireless infrastructures. A significant portion of this work has been on the interworking of cellular systems with wireless local area networks (WLANs). This direction is primarily targeted at the improvement of application provisioning (e.g., applications that can be offered through the most appropriate wireless network).

Heterogeneous Network Deployments

Related to the direction above is the fourth direction of heterogeneous networks [12], which is primarily aimed at increasing cost efficiency. Unlike the composite wireless paradigm, which comprises diverse RATs, a heterogeneous network is based on one cellular standard, i.e., in our assumptions, 4G/LTE-advanced (even though, under certain conditions, especially operator governance, there can also be IEEE standards).

According to the 3GPP [12], a heterogeneous network may consist of different types of infrastructure elements (BSs), such as macro-, micro-, pico-, and femto-BSs. The mixed usage of all these types in an operating network is necessary. Low-power BSs like pico will be used to enhance coverage and capacity by covering areas that are much smaller than a macro-BS coverage area. Thus, it is expected that all these elements need to be properly managed while the configuration requirements for the cellular network supported by low-power nodes are still very similar as for macrocells.

Heterogeneous networks offer multiple options (e.g., numerous and diverse access points in terms of their capabilities, different spectrum portions that may be used, and various transmission power levels) for satisfying application requirements (situations in general). This direction positively impacts the cost of the deployed resources and their use/utilization.

Flexible Spectrum Management

A fifth direction, also targeted to improved resource utilization, is flexible spectrum management [13]. According to [13], network operators have the freedom to flexibly allocate spectrum to the RATs they operate and to operate a RAT at various spectrum bands. It is worth mentioning some key elements to provide this flexibility, such as spectrum refarming, which allows having technology neutral spectrum bands and setting up communication on a specific RAT in different frequency bands. Also, another key element is opportunistic spectrum access, in which secondary users are allowed to independently identify unused spectrum bands, at a given time and place, and use them while not generating harmful interference to primary license holders (e.g., through the exploitation of the so-called TV white spaces, which refer to portions of spectrum that are unused either because there is currently no license holder for them or because they are deliberately left unused as guard bands between the different TV channels).

In addition, concepts such as authorized-shared access (ASA) and licensed shared access (LSA) enable dynamic sharing of spectrum bands in space and time. Also, the collective use of spectrum (CUS) allows spectrum to be used by more than one user simultaneously without requiring a license. This would be particularly useful in short-range devices, e.g., radio frequency identification devices (RFID) that can support automation in the supply chain process and machine-to-machine (M2M) applications [14].

Device-to-Device and M2M Communications

Another important direction, which is expected to characterize beyond 4G and 5G networks, is the creation of dynamic networking constructs consisting of interconnected end-user equipment [the device-to-device (D2D) concept] or several machines/sensors/actuators [in the context of the Internet of Things (IoT)]. All these dynamic network constructs will coexist with evolved access infrastructure. Additionally, traffic generated from various M2M applications will have to be properly assigned to access points without causing congestion issues. Therefore, cognitive, intelligent management mechanisms will be necessary to efficiently control and manage all these networked devices as proposed by [15].

Exploiting the Cloud-RAN and Mobile Clouds Concepts

Another direction has been recently pursued to further improve cost efficiency. This direction capitalizes on cloud concepts. The rationale is that there can be total cost of ownership (especially, capital and operating expenditures) savings if wireless networks are based on cloud principles. This is possible through the shared use of storage or computing resources. Therefore, common repositories for networking functionality will be used to avoid multiple deployment of the same component. Figure 2 presents such a concept, where macrocells and small cells (e.g., attached to lamp posts) can use shared resources by exploiting the cloud-RAN concept.

In addition to the cloud-RAN concept, other cloud concepts are foreseen to gain ground in the future wireless networks domain. In [16] and [17], the concept of mobile clouds is proposed to achieve significant energy savings on both the network and the user's side through

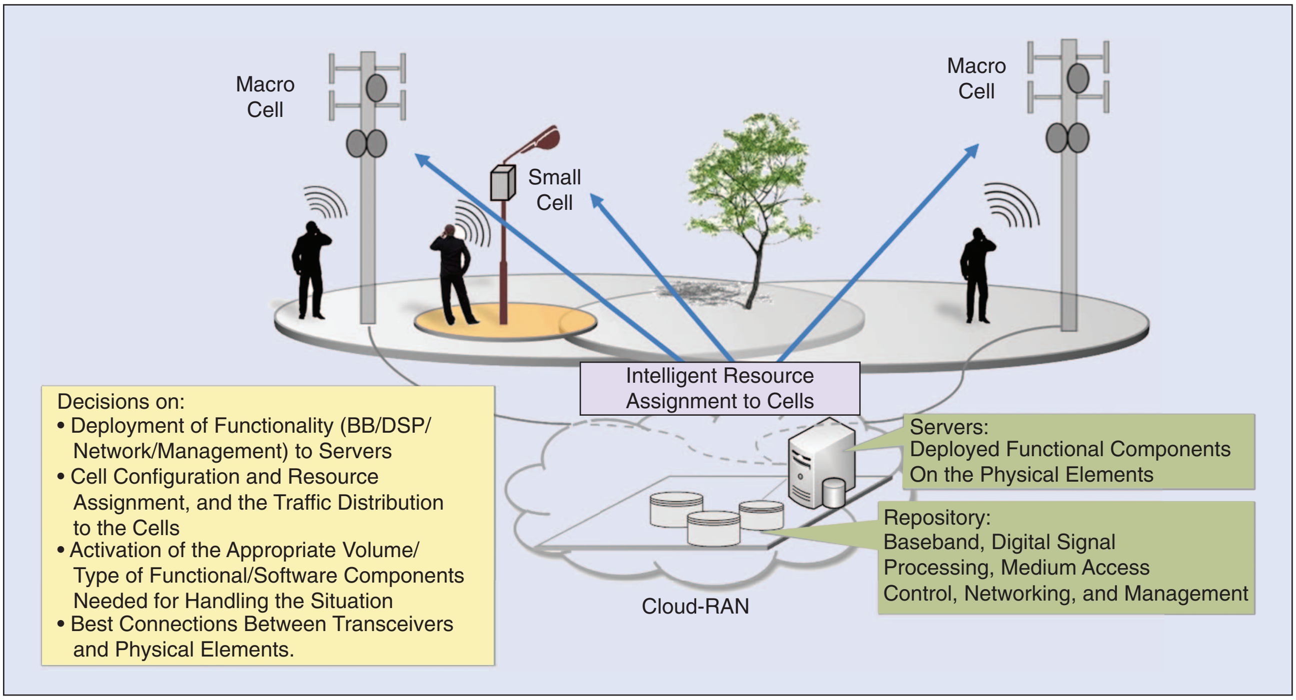

FIGURE 2 The role of essential intelligence for realizing the cloud-RAN concept.

the exploitation of network coding and user cooperation techniques. The performance of the suggested theory has been tested through test cases, which consider a single cloud, multiple homogeneous clouds, and multiple heterogeneous cloud deployments.

Introduction of Intelligence

Introduction of intelligence toward 5G can address the complexity of heterogeneous networks and cloud-RANs by specifying and providing solutions for the efficient handling of these concepts. Therefore, the intelligence that is needed for the management of cloud-RAN functionalities is related to the optimal cloud-RAN configuration given a specific situation. The input in such situations comprises information on the traffic, mobility levels, and interference levels (which corresponds to the complex context of operation discussed earlier), regarding transceivers and physical elements on the cloud. Intelligence shall then lead to decisions related to: 1) the cell configuration and resource assignment, and the traffic distribution to the cells; 2) the activation of the appropriate volume/type of functional/software components needed for handling the situation; 3) the allocation of functional components to the physical elements; and 4) the best connections between transceivers and physical elements and the best interconnections between the physical elements. Through these decisions, there is the derivation of the wireless network configuration that is appropriate for handling the situation faced.

Regarding the introduction of intelligence to heterogeneous network elements, intelligence is expected to facilitate decisions related to the: 1) transceivers that will be involved in the handling of a situation; 2) spectrum (band, channel width) that will be assigned to be operated by the transceivers; 3) transmission powers that will be allowed per transceiver; and 4) the distribution of traffic to the resulting cells that are involved in the handling of the situation.

Additionally, the notion of the fusion network (Fusion Net) is being exploited so as to increase performance of heterogeneous network deployments by taking advantage of powerful features of intelligence. The term Fusion Net is used to propose a multilayer and multistream aggregation (MSA) technology, according to which a host layer, consisting mainly of macrocells, shall guarantee the ubiquitous and reliable basic user experience. In addition, a boosting layer, consisting of many infrastructure elements (e.g., boosting port from the small cell), spectrum (e.g., boosting carrier), and multitechnologies (e.g., boosting RAT), can provide the best possible performance, as depicted in Figure 3. MSA is the technology that can aggregate all the streams from the above three boosting sublayers (port, carrier, and RAT) and the host layer to achieve the maximization of the user experience.

The user is anchored to the host layer so as to minimize the risk of handoff and interference, while the traffic is dynamically transmitted and aggregated from a boosting layer to be able to adapt to network context alterations. Moreover, by layering the network, the operator has the flexibility to accurately deploy the boosting layer to where the traffic is generated without having to worry about the coverage issue since this is handled by the host layer.

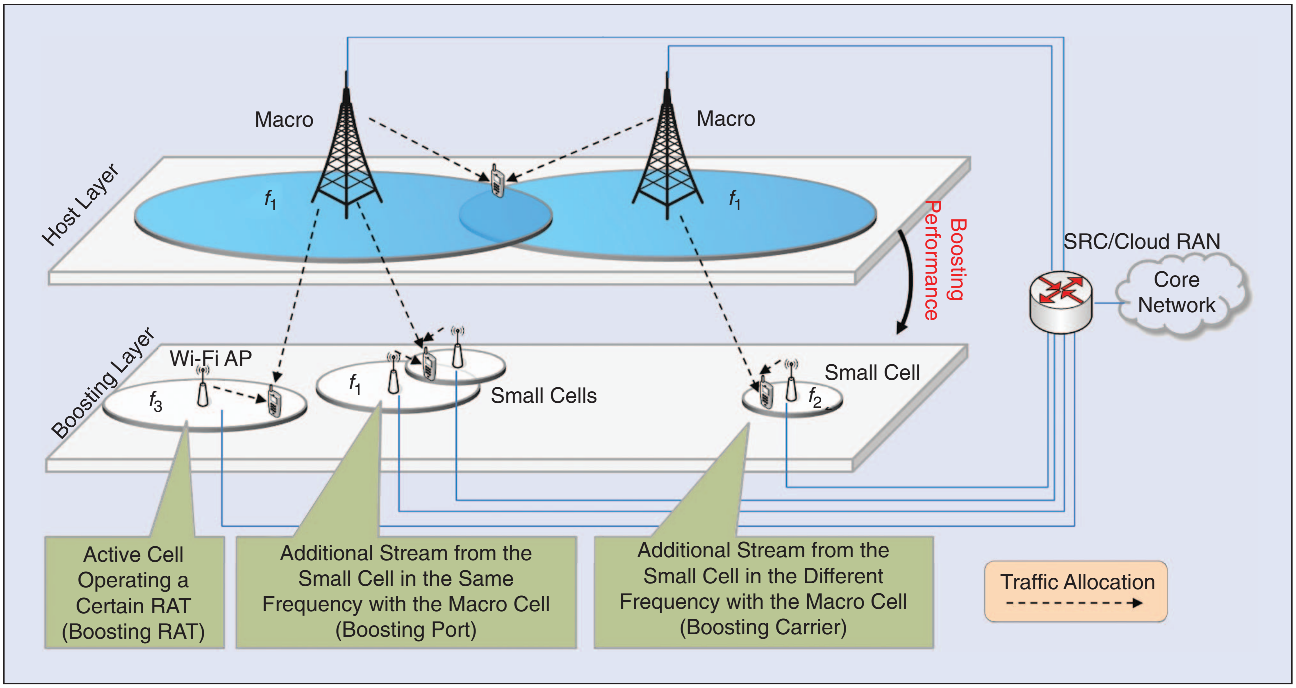

FIGURE 3 The role of essential intelligence for heterogeneous networks.

Therefore, the Fusion Net can avoid over-provisioning of resources and maximize the energy and cost efficiency by using decisions related to the combination of allocation of traffic to various RATs and spectrum. The decision-making entity will be located centrally in the RAN, e.g., a single radio controller (SRC) or Cloud RAN, where all the information of the air interface as well as the backhaul and computing resources are available and intelligent algorithms can be implemented. This central entity shall then make the complexity of the RAN architecture and technology transparent to the user and the core.

Main Emerging Enabling Technologies

In the subsections that follow, specific emerging technologies for applying intelligence toward 5G communications are elaborated. These technologies include SDN and NFV. Both technologies are expected to have a significant impact on forthcoming research. Through SDN and NFV, one of the top benefits is being focused on satisfying the need of network operators to speed up the services innovation. A corresponding reduction in equipment costs, as well as reduced power and space costs (because one server can host several virtualized network devices), are also benefits that are possible through NFV [18].

Software-Defined Networking

According to [19], SDN is an emerging network architecture with a centralized network controller in the control plane, which is responsible for allocating traffic to network elements in the separated data plane of the network, as described in Figure 4. The network controller centrally maintains the intelligence and state of the entire network. Therefore, the network controller can output the best fine granular flow routing control rules to the heterogeneous network devices from different vendors. Through the northbound interface, the network controller provides a global united view and resources of the network to the upper layer network applications as a single, logical switch. Thus, novel network applications can be easily created, tested, and deployed in a short time.

Open flow [20] is defined by the Open Networking Foundation (ONF) and is broadly accepted as the dominating SDN protocol in the southbound interface between the network controller and network devices. It is widely supported by various device manufacturers, service providers, and operators. Additionally, ForCES [21] and PCE [22], defined by the Internet Engineering Task Force (IETF), are alternative southbound SDN protocols. SDN protocols for the northbound interface are currently still under development.

Toward Network Function Virtualization

A complementary technology to the previously mentioned SDN is NFV, which can provide the infrastructure on which SDN can run. NFV technology is a new way to build an end-to-end network infrastructure with evolving standard IT virtualization technology so as to enable the consolidation of many heterogeneous network devices onto industry standard high-volume servers, switches, and storage [23].

The network function of a network device is implemented in a software package, which is running in virtual machine(s). Therefore, it would become easier to introduce or test a new network function by simply installing or

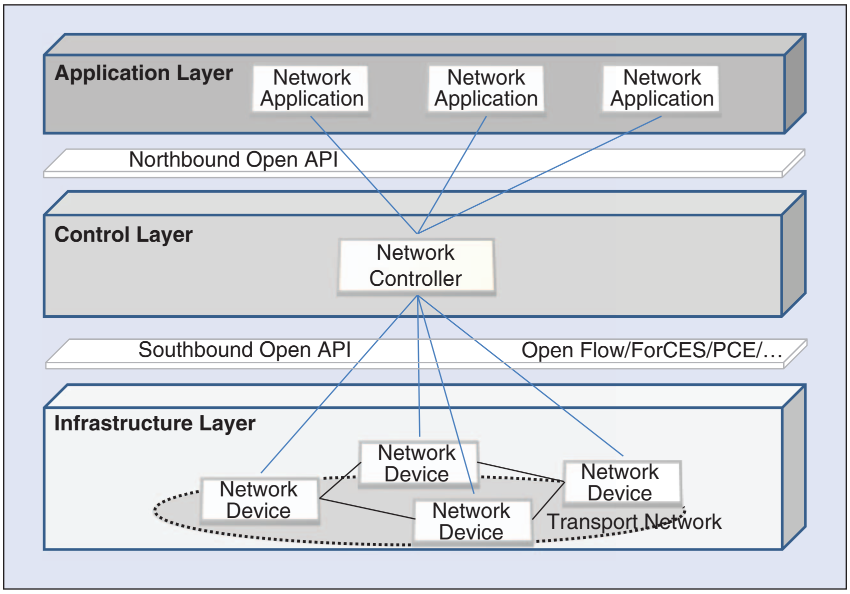

FIGURE 4 SDN layering concept overview.

The main benefits of NFV technology include the fact that carriers can build and operate a network with reduced equipment costs and reduced power consumption, thanks to consolidating equipment and exploiting the economies of scale of the information technology (IT). The carriers can also benefit from new services that are easy to create, test, and deploy with a short time to market, as well as easy management of the network infrastructure and services.

upgrading a software package, which is run by the servers. The architecture of NFV is described in Figure 5, and the following key features apply:

- virtual infrastructure into which virtual machines are created on generic high-volume hardware servers and storage devices, connected by generic high–volume network switches and organized by the orchestration
- separation of the software that defines the network functions for network devices from generic hardware
- automated orchestration, which automates installation and management of the virtualized network functions on the generic hardware.

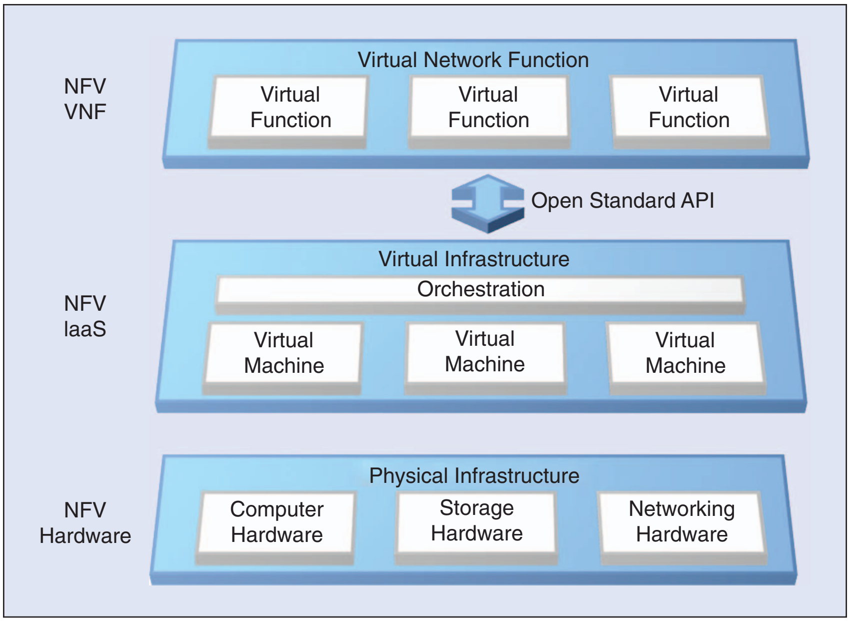

FIGURE 5 NFV concept overview.

Conclusions

This article provided an overview for delivering intelligence toward the 5G of wireless/mobile broadband by taking into account the complex context of operation and essential requirements such as QoE, energy efficiency, cost efficiency, and resource efficiency.

Based on these assumptions, the work contributes with approaches that can be characterized as evolutionary that evolve legacy and emerging reference features of wireless networks. At the same time, the introduction of intelligence to heterogeneous infrastructures as discussed in this work is essential to strengthen the position of operators in a competitive telecommunications environment.

Intelligence related to heterogeneous network deployments includes decision making on the cells of various sizes to be used and their spectrum and transmission power allocation. On the other hand, intelligence related to cloud-RAN decision making includes the volume/type of functional components that should be activated, the physical elements of the cloud on which functionality should be deployed, and their interconnections.

Additionally, the main emerging enabling technologies are described, including SDN and NFV. Both technologies are expected to have a significant impact on the near future, since they will lead to the improvement of network intelligence and programmability. At the same time, they are expected to lead to better utilization and sharing of hardware resources through virtualization. Also, a positive impact on the capital and operational expenditures of operators is expected as a result of the more efficient utilization of resources.

Finally, adoption of 5G from the market could be realized in a twofold manner. It could be gradual or disruptive. The gradual approach would be characterized by the introduction of the aspects related to intelligence. On the other hand, the disruptive approach can be considered, e.g., in the long term (after a decade), when sufficient profits and return on investment will be achieved by matured-by-then 4G/ legacy systems. Operators will then be willing to invest in radically updated equipment (hardware and software).

Acknowledgment

This article has benefited from discussions within the Wireless World Research Forum (WWRF) related to communication architectures and technologies. The views expressed in this document do not necessarily represent the views of the entire forum.

Author Information

Panagiotis Demestichas (pdemest@unipi.gr) is a professor at the University of Piraeus, Greece. He is the head of the Digital Systems Department and the director of the M.Sc. degree on technoeconomic management and security of digital systems. He also leads the Laboratory of Telecommunication Networks and Integrated Services. His research interests include wireless/mobile broadband (5G, heterogeneous networks, and cloud RANs), high-speed networking, smart FI infrastructures and services, SDN, and NFV.

Andreas Georgakopoulos (andgeorg@unipi.gr) conducts research at the University of Piraeus. His main research interests include the specification of cognitive management mechanisms for the creation and maintenance of dynamic access networking paradigms in the FI era, such as opportunistic networking.

Dimitrios Karvounas (dkarvoyn@unipi.gr) conducts research at the University of Piraeus. His main interests are cognitive and autonomous management techniques of the FI and bioinspired optimization algorithms.

Kostas Tsagkaris (ktsagk@unipi.gr) is a senior research engineer and adjunct lecturer at the University of Piraeus. His current research interests are in the design and management of autonomic/cognitive networks, optimization algorithms, and learning techniques.

Vera Stavroulaki (veras@unipi.gr) is an assistant professor at the University of Piraeus. Her main research interests include cognitive management functionality for autonomous reconfigurable user devices (operating in heterogeneous wireless networks), service governance, and virtualization.

Jianmin Lu (lujianmin@huawei.com) is leading the research on RAN at Huawei Technologies Ltd. His research interests are design and performance evaluation of the next generation of wireless network architecture, PHY, and MAC beyond LTE.

Chunshan Xiong (sam.xiongchunshan@huawei.com) is a senior standard and research engineer at Huawei Technologies Ltd. His main interests include 3GPP service and architecture, SDN, NFV, and mobility management and security and standards in 3GPP and IETF.

Jing Yao (yaojing@huawei.com) joined Huawei Technologies Ltd. in 2001 after receiving her master's degree from Shanghai University. She worked on the Huawei UMTS product line until 2004 and then became involved in wireless research and standard work.

References

[1] European Future Internet Portal. (2013, May). [Online]. Available: http://www.future-internet.eu
[2] R. Jain, A. Durresi, and S. Paul, "Future Internet architectures," *IEEE Commun. Mag.,* vol. 49, no. 7, pp. 24–25, 2011.
[3] Future Internet-PPP. (2013, May). [Online]. Available: http://www.fi-ppp.eu/
[4] Global Environment for Network Innovations (GENI), National Science Foundation (NSF). (2013, May). [Online]. Available: http://www.geni.net/
[5] Cisco. (2013, Feb.). Visual networking index: Global mobile data traffic forecast update 2012–2017 [Online]. Available: www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.html
[6] Actix. (2013). Data growth will transform mobile infrastructure by 2015 [Online]. Available: www.emlwildfire.com/primages/acts-smallcells2015.pdf
[7] GreenTouch Consortium. (2013, May). Global study by GreenTouch consortium reveals how communications networks could reduce energy consumption by 90 percent by 2020 [Online]. Available: www.greentouch.org/index.php?mact=News,cntnt01,detail,0&cntnt01art-icleid=26&cntnt01origid=15&cntnt01detailtemplate=press_release_detail&cntnt01returnid=105
[8] European research cluster on the Internet of Things. (2013, May). [Online]. Available: http://www.internet-of-things-research.eu/
[9] Third (3rd) Generation Partnership Project (3GPP). (2013, May). [Online]. Available: www.3gpp.org
[10] Institute of Electrical and Electronics Engineers (IEEE). (2013, May). 802 standards [Online]. Available: www.ieee802.org
[11] Small Cell Forum. (2013, May). [Online]. Available: www.smallcellforum.org/
[12] 3GPP, "Study of heterogeneous networks management," Tech. Rep. 32.835, Release 12 March 2013.
[13] V. Sridhar, T. Casey, and H. Hammainen, "Flexible spectrum management for mobile broadband services: How does it vary across advanced and emerging markets?" *Telecommun. Policy*, vol. 37, no. 2–3, pp. 178–191, 2013.
[14] European Commission. (2012, Sept.). Promoting the shared use of Europe's radio spectrum [Online]. Available: http://ec.europa.eu/digital-agenda/en/promoting-shared-use-europes-radio-spectrum
[15] FP7/ICT iCore project. (2013, May). [Online]. Available: www.iot-icore.eu/
[16] F. H. P. Fitzek, J. Heide, M. V. Pedersen, and M. D. Katz, "Implementation of network coding for social mobile clouds," *IEEE Signal Processing Mag.*, vol. 30, no. 1, pp. 159–164, 2013.
[17] J. Heide, F. H. P. Fitzek, M. V. Pedersen, and M. Katz, "Green mobile clouds: Network coding and user cooperation for improved energy efficiency," in *Proc. IEEE 1st Int. Conf. Cloud Networking (CLOUDNET)*, Paris, France, 2012, pp. 111–118.
[18] M. Leonard. (2012, Dec.). Network functions virtualization is changing how services are delivered [Online]. Available: http://forums.juniper.net/t5/Data-Center-Directions/Network-Functions-Virtualization-is-Changing-How-Services-are/ba-p/171784
[19] Open Networking Foundation. (2012, Apr.). Software-defined networking: The new norm for networks [Online]. Available: www.opennetworking.org/images/stories/downloads/white-papers/wp-sdn-newnorm.pdf
[20] Open Networking Foundation. (2011, Feb.). Open flow switch specification [Online]. Available: www.opennetworking.org
[21] *Forwarding and Control Element Separation (ForCES)*. IETF, 2013, IEEE Standard RFC 5810, 2010.
[22] *Path Computation Element (PCE)*, IETF, 2013, IEEE Standard RFC 5440, 2009.
[23] ETSI NFV ISG. (2012, Oct.). Network functions virtualization, white paper [Online]. Available: http://portal.etsi.org/NFV/NFV_White_Paper.pdf

VT