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Aspirations, challenges, and open issues for software-based 5G networks in extremely dense and heterogeneous scenarios

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Abstract

An upsurge of heterogeneous wireless devices and wide-ranging applications on extremely dense urban scenarios has led to challenging conditions that cannot be easily handled by 4G systems, such as the inefficient use of the frequency spectrum and the high energy consumption. In order to address those challenges, the 5G system design demands new architectures to cope with specific requirements, such as scalability, resilience, and energy efficiency. These requirements play a fundamental role in extremely dense scenarios. In addition, when jointly addressed, they have distinct priorities depending mainly on the specific user application demands. In this context, this article presents a management architecture for 5G system, called Wireless Software-basEd architecture for Extremely Dense networks (WiSEED). It is grounded on a software-based perspective of management and jointly manages three key operational services, as follows: routing, mobility, and spectrum usage. Such perspective of management is possible due to programmable network technologies, i.e., network function virtualization and software-defined networking. The architecture mainly intends to provide a better trade-off between the 5G requirements themselves and a high quality ubiquitous and seamless services, as well as efficient mobile broadband Internet for end users. Trace-driven simulation results from a case study show improvements when the management architecture is employed over conflicting requirements.

Keywords: 5G Networks; Software-defined networking and network function virtualization; Extremely dense and heterogeneous scenario; Routing, mobility, and spectrum management

1 Introduction

Wireless communication technologies have benefited different sectors of society supporting the development of broadband and ubiquitous interconnected cities. Along the years, these technologies have promoted the evolvement of various activities, such as healthcare, transportation, and energy saving, resulting in a better assisted life, alleviating traffic jams, preventing and controlling crime, and efficiently managing the power distribution. Each time more these applications need to handle increasing dense scenarios and their challenges, particularly in urban areas, in which different wireless technologies are simultaneously employed.

Some scenarios in medium and big cities are highlighted to illustrate the employment of these applications in smart cities [1, 2], such as large events in a football stadium, traffic jam in highway and downtown streets [3], and intelligent environments [4] (machine-to-machine communication- sensors/actuators/back-end servers). In all these scenarios, these applications need to address the new requirements brought by the highly dense areas in order to promote the exchange of some kind of content by people and devices. However, although there has been a continuous improvement in wireless link capacity, the radio frequencies used by the 4G system under high density can often be overloaded and subject to interference, resulting in poor quality of service and in a waste of wireless network resources.

The fifth generation (5G) of cellular system [5] envisages being able to make a significant disruption in the 4G-paradigm shift, in order to promote ubiquitous mobile

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broadband wireless access and to improve the handling of extremely dense and heterogeneous scenarios (EDHs). For example, CROWD [1] and METIS [2] are FP7 projects for the 5G system in EDHs that propose high level architectural models (i.e., it is not much detailed). CROWD proposes a novel network architecture accounting for MAC control and mobility/routing management through software-defined networking (SDN), but it does not concern spectrum management and network virtualization. CROWD considers the following requirements: scalability, energy efficiency, and link reliability.

METIS's architecture focuses mostly on hardware communication technologies of 5G system. However, it discusses the spectrum usage but it does not mention anything about what kind of approach/technique will be employed to reach an efficient and secure spectrum sharing and it does not deal with routing as well. In addition, METIS takes into account increased data rate, energy efficiency, link reliability, and latency performance requirements. However, both projects do not argue how to balance these requirements, which are conflicting each other. The goals of those projects lie on combining heterogeneous wireless communication technologies in terms of cell range for a wide range of devices, such as Long Term Evolution (LTE) evolved Node B eNB macro-cell, nano/phanton/pico/femto/LTE eNB small-cell, and small-cell Wi-Fi Mesh networks. In this article, these systems are referred to as 5G networks, being also concerned with making improvements in offloading, power efficiency, low-cost effectiveness, dynamic spectrum allocation, flexibility, and interoperability. The 5G networks envisage to significantly increase the resource demand for all the current applications, as well as those that are emerging every day more, such as big data and multimedia.

5G networks should not only focus on continuously enhancing peak service rates like 2G, 3G, and 4G, but they also ought to support the development of futuristic wireless networks that could connect the whole world in a seamless and ubiquitous way. Therefore, 5G networks should provide communications between anybody (people-to-people), anything (people-to-machine, machine-to-machine), wherever they are, whenever they need, and by whatever electronic devices/services/networks they require. In the emerging context of EDHs, we believe that the 5G networks must be able to deal with the following requirements: scalability, resilience, and energy efficiency. The requirements play a crucial role in providing high quality ubiquitous and seamless services for mobile broadband Internet access, but their goals are conflicting since it is very hard to achieve all of them at the same time [6]. The importance of each requirement can vary depending on the specific application demands and/or degree of user satisfaction.

On the one hand, most of the 5G approaches concentrate on hardware factors rather than on those that are software-based, such as mobile femtocells [6], massive-user MIMO [7, 8], and millimeter-wave beamforming [9, 10]. On the other hand, the emerging software-based network technologies have key factors that can support the EDH requirements in 5G networks, such as software based on general-purpose processors via programming interfaces and virtualization technology, that can improve scalability and energy efficiency. It is worth pointing out that a sofware-based 5G architecture enables that the managers to customize some network configurations through programming according to the policies of the mobile operators. Therefore, a sofware-based network architecture can make easier the network management while it makes possible to reach higher degree of requirement's efficiency. Hence, a new management architecture must be proposed in light of the recent software technologies.

In this challenging and promising context, this article highlights the challenges raised by extremely dense and heterogeneous scenarios that still constraint high performance and restrict ubiquitous online access to mobile user applications and the attainment of the EDHs requirements. In addition, a flexible management architecture is outlined that takes EDHs into account, called Wireless Software-basEd architecture for Extremely Dense networks (WiSEED). The proposed architecture is based on a synergy of three main operational services and entails the following: routing and mobility management for load balancing, and dynamic spectrum management to manage the wireless medium. It is worth noting that these operational services are software-based and a proposal of synergy between these services are also proposed in this article.

The WiSEED operational services seek to maintain a tradeoff between requirements based on specific user application demands. Its main goal lies on providing ubiquity and a high degree of efficiency in the services for mobile end users. Each operational service intends to gather the most recent and adequate techniques and approaches, as well as to deal with challenges in order to integrate these different solutions in WiSEED. Furthermore, WiSEED employs advanced concepts as enabler network technologies, such as software-defined networking (SDN) and network function virtualization (NFV). The employment of SDN and NFV in wireless and mobile networks is still under development. Therefore, there are some open issues of these software-based technologies in future wireless networks that will also be described in this article. To the best of our knowledge, WiSEED provides a more complete 5G network architecture based on a software perspective than the current approaches, since it has considered requirements in a more complete way and programmable network technologies, as well as a joint of three operational services.

This article proceeds as follows. Section 2 discusses the software-based perspectives for EDHs in 5G networks. Section 3 outlines the proposed architecture. Section 4 describes the preliminary numerical results of the proposed architecture. Open issues and challenges in 5G networks based on a software perspective are discussed in Section 5. Finally, Section 6 summarizes the final considerations.

2 5G Software-based network perspectives for extremely dense and heterogeneous scenarios

This section presents our perspective of the 5G networks for EDHs with three main parts: requirements (subsection 2.1), software enabling technologies (subsection 2.2), and related work on software-based 5G networks (subsection 2.3).

2.1 Requirements of extremely dense and heterogeneous scenarios

Providing high quality services in extremely dense scenarios requires the efficient management and the creation of approaches offering scalability, resilience, and energy efficiency while taking into account the specific user application demands. These requirements are outlined in this section, together with the challenges that they raise.

Scalability. EDHs provide a networking environment for future networks that is based on a higher degree of density and heterogeneity from the standpoint of wireless networks, and, in practice, allow an ubiquitous mobile Internet access. Density and heterogeneity require solutions that take full advantage of their benefits to handle the growing amount of traffic load and nodes in a dexterous manner. Hence, scalability is a critical management issue for the EDHs [11]. For instance, the increasing demand in traffic data [5] of mobile users grows much faster than the capacity of the near-future wireless technologies (LTE-Advanced) [12]. A similar relationship exists between interference and deployed cells, where the overall throughput is not in line with the number of deployed cells [13]. Superfluous overload in Evolved Packet Core (EPC)—all the packets of user equipments (UEs) could be forwarded to the central entity of the EPC-LTE, instead of being forwarded to the other UEs in a direct path. This results in longer paths and a superfluous overload in the central entity.

Resilience. EDHs also need solutions that take full advantage of their density to improve network resilience, while keeping energy consumption under control. Although security may seem to be an objective that conflicts with scalability and energy efficiency, it can help improving the network resiliency that it is also an important requirement for improving the reliability of wireless networks. In many cases, the protocols employed in the wireless networks provide weak reliability, since in general, they may have been designed to improve performance. Hence, when faced with a sudden burst of events, such as exchanged messages, packages, and frames, they become points of failure. For example, the wireless link quality may suffer disturbances due to unwanted interference, such as noises or even several kinds of attacks. These disturbances harm real-time applications by adding delays or even interrupting their communications. The anomalous operation of these applications generates traffic that become useless, and affects the regular operation of other applications.

Energy efficiency. Solutions for EDHs should take into account different factors when seeking to improve efficiency in energy consumption, including an overlap with almost all of the requirements for EDHs. Nevertheless, energy efficiency should be observed from two perspectives: base stations and UEs. From the perspective of the base station, it is worth designing solutions that reduce energy consumption by associating UEs into as few eNBs as possible or frequent reconfiguration of the power cycling pattern of eNBs, Wi-Fi access points, and backhaul network elements. Hence, base stations can be turned off when they are not used. This perspective requires mechanisms that can maximize energy efficiency by achieving a better tradeoff between the estimated traffic-load and the available resource. From the perspective of the UEs, the energy-aware routing approaches can increase energy efficiency by taking advantage of the multi-hop and direct communication schemes between the UEs.

It is a highly demanding task to handle scalability, resilience, and energy efficiency simultaneously, since these requirements are in conflict with each other [5, 6, 14] so that improvements in one requirement lead to degradation in the other requirements. For instance, if security is improved, it can result in greater communication and processing overhead, which can reduce scalability and energy efficiency. If the energy efficiency is increased by turning off some eNBs or Wi-Fi mesh routers, the network scalability and robustness can be harmed. This article reinforces the necessity to seek a tradeoff between these requirements by an optimized management of network resources in 5G networks in order to improve the QoS/QoE for final mobile users anywhere and anytime.

2.2 Software enabling technologies for 5G networks

This subsection highlights the software-enabling technologies that can be employed to achieve the requirements expected for the 5G networks on EDHs. SDN improves 5G network performance by separating the control and data planes and providing an optimized control of resources and users in dense scenarios through a centralized approach. The Open Networking Foundation (ONF) proposes to apply SDN in order to improve the usage of wireless resources and thus increasing the satisfaction of users. The Wireless SDN can offer flexibility and complete information that support decision-making towards some aspects of WiSEED, such as offloading routing, energy efficiency, and spectrum allocation.

The flexibility offered by the centralized approach of SDN can foster innovation in the joint mobility, routing, and spectrum management provided by the WiSEED architecture, thus achieving an optimization of the shared and restricted resources. Hence, distinct optimization techniques can be employed to improve the performance at different locations at any time by separating the control and data planes, as shown in Fig. 1. Currently, there is a lack of specifications in SDN for wireless networks, since SDN cannot fully support mobile and wireless communication. However, the ONF Wireless and Mobile Working Group [15] established in 2013 to discuss the specific characteristics of wireless networks and to identify use cases ranging from mobile backhaul to mobile core issues. Hence, WiSEED will take into account a software-defined wireless networking core architecture similar to [16].

Network function virtualization (NFV) [17] can enhance 5G networks by allowing a flexible design, deployment, and management of networking services. NFV has recently emerged as a new paradigm for providing network and telecommunication services, i.e., network functions offered by virtualized services for servers with a general purpose. For instance, the elements of LTE mobile architecture can migrate to data centers in the mobile cloud networking, thus the network functions (NFs) can be elastically provisioned through the re-engineering of mobile architecture, as shown in Fig. 1. In this context, some physical network functions (PNF) may be implemented in the software domain, i.e., virtualized network function (VNF). Thus, they rely more on other software systems, such as operating systems and network virtualization tools than the physical network infrastructure.

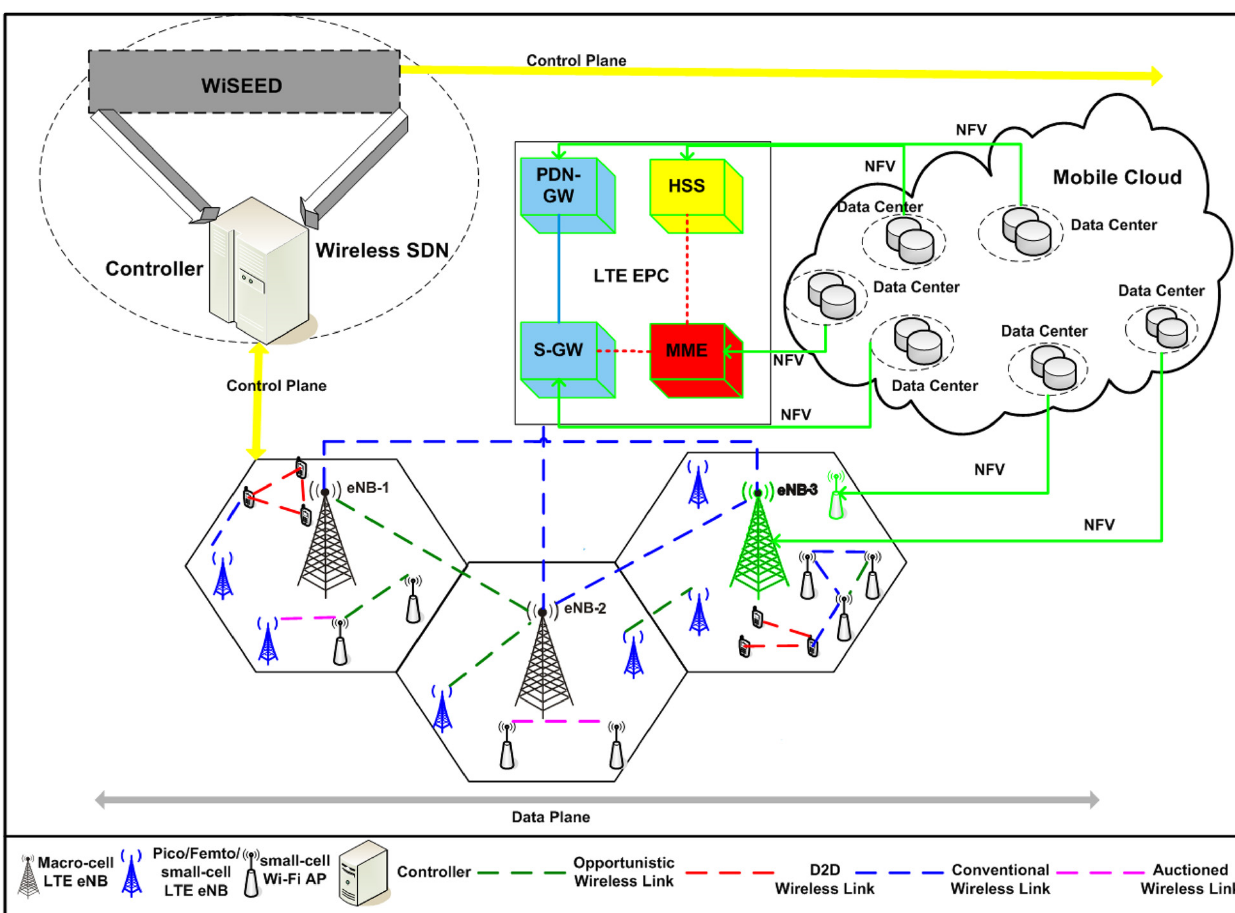

Fig. 1 Scenario of 5G Networks with WiSEED, SDN, and NFV

The reference architecture of NFV is still being developed by the European Telecommunications Standards Institute (ETSI) [17]. However, some interesting features to EDHs can already be highlighted: monetary cost, energy efficiency, and interoperability, for example, a reduction of CAPEX/OPEX costs (when compared with the implementations devoted to hardware implementations) and, furthermore, the flexibility, scalability, and dynamism when designating NFs for general hardware; on the other hand, lower power consumption through migration loads and shutdown of idle hardware; and, finally, standardization and open interfaces between virtualized functions, which makes it easy for the NFV to integrate different technologies.

Currently, it is well-known that the costs of the physical infrastructure for LTE are high. Moreover, the average utilization is overestimated to support peak load situations, which often occur in EDHs. Due to the versatile management provided by NFV, the virtualized features of LTE can provide better scalability and resilience, while seeking to minimize costs and energy consumption. For instance, virtualized services like Home Subscriber Server (HSS) and PDN/Serving Gateway (P/SGW) of Evolved Packet Core (EPC) in a mobile cloud enable scaling to the specific requirements of these services, such as situations where there is a need to increase resources for the user plane without affecting the control plane. Thus SDN and NFV can work in a complementary way to the WiSEED architecture by managing and orchestrating NFs [18]. Figure 1 gathers the employment of NFV and SDN in 5G networks that can better support WiSEED. The service chain in EDHs can be built combining PNF and VNF through the control plane defined by WiSEED in the controller.

Multiple mobile network operators can cooperate with each other through distinct ways of infrastructure sharing [8] based on new business models, i.e., the owners of infrastructure and the operators are different. For example, sharing some active elements could be interesting when rolling out small-cell networks, such as antennas, base stations, radio access networks, and the even NFVs of HSS or P/SGW of EPC. In addition, small cells may be operated by a mobile virtual network operator that does not own any spectrum but has entered into an agreement with another operator to obtain access to its spectrum within the small cell. It is worth pointing out that sharing a service chain of NFVs and PNFs could be attractive to different mobile virtual network operators and virtual organizations of mobile cloud in EDHs, since the dense scenarios of each mobile virtual network can occur in distinct regions and times. Therefore, they should establish an agreement for virtual infrastructure sharing. Furthermore, SDN and NFV must be deployed widely, getting as close as possible to the mobile user. We believe that is the right choice to enjoy the flexibility and increase the efficiency provided by this new integration.

Opportunistic spectrum management has emerged as a practical application of software-defined radios (SDRs) to enable the management of the radio frequency spectrum in LTE [19], LTE-Advanced [20], and Wi-Fi Mesh Networks [21], since it can enable the opportunistic use of idle licensed frequency bands (LTE, TV band, radar, and wireless microphone) that are allocated for transmitting mobile Internet traffic. In order to achieve this goal, spectrum holes are dynamically and intelligently selected by secondary users (i.e., cognitive radio) to avoid causing any interference to primary users, users that can exploit licensed frequencies. In view of this, there are some useful scenarios for cognitive radio (CR) technology [19]. For instance, although adding cell sites is an effective way to add capacity, a small cell requires more spectrum. The small cells of LTE and Wi-Fi Mesh Networks will employ more available white space spectrum with CR, to mitigate the co-channel interference to the adjacent small cells or reduce the interference between small cells and a macrocell. It is worth noting that SDR has been combined with SDN in order to inscrease the flexibility and efficiency of the spectrum management [22–24].

2.3 Related work

There are a few 5G network architectures considering concepts regarding the software network perspective [6, 7, 16, 25–27]. Chih et al. [7] take note of the cloud radio access network and varied cell sizes but are more concerned with hardware communication than software perspectives, such as Massive MIMO. Cheng et al. [6] propose a cellular architecture for 5G networks that deals with software defined radio through cognitive radio techniques and green communications, but it is also more concerned with hardware, such as Visible Light Communication (VLC). In addition, they point out that the 5G network architectures raise a challenge in the future since they only consider one or two performance requirements while neglecting others once dealing with many requirements in the same architecture is a matter of great complexity. Bernados et al. [16] describe a multi-operator wireless network architecture for the next generation by combining SDN, NFV, and quality of experience, but it is not concerned with EDHs. On the other hand, Rost et al. [25], Yazici et al. [26], and Trivisonno et al. [27] discuss how SDN, NFV, routing, mobility, cloud technologies, and flexible assignment in radio access networks can support EDHs, but they do not consider the question of dynamic spectrum management neither all its requirements.

It should be pointed out that the architectures described above fail to meet all EDH requirements, programmable network technologies, and joint management of the operational services proposed in WiSEED. Furthermore, none of the analyzed architectures examines how the user profiles can assist the definition of each requirement. This can make it easier to strike a balance between the conflicting requirements while offering a more customized service for the mobile users.

3 Wireless software-based architecture for 5G networks in extremely dense and heterogeneous scenarios - WiSEED

This section describes WiSEED which comprises three planes, namely energy efficiency, scalability, and resilience, and two main operational services, namely routing, mobility, and spectrum management. The architecture provides a high degree of efficiency for the ubiquitous and seamless access of mobile users through the management of the planes and operational services. The planes represent the requirements of the 5G networks. Each operational service combines mechanisms, techniques, algorithms, and technologies to cooperate with each other and thus supporting a tradeoff between the planes. In addition, each operational service will run at SDN controller as software. Figure 2 illustrates the overview of the proposed conceptual architecture. The operational services of the routing management, mobility management, and spectrum management work jointly in a cross-layer optimization synergy to achieve the equilibrium between the planes.

The traffic load increases rapidly in the EDHs and hence the routing decisions should offload both at the intra-cell and inter-cell levels in the LTE and Wi-Fi Mesh Networks, since the wireless base stations (e.g., Wi-Fi access points or eNB LTE antennas) in the core network are potential bottlenecks. It is worth pointing out that overload nodes or bottlenecks can cause a malfunction of the EDHs. It is a very complex task to achieve a load balancing solution for this context. In light of this, the routing and mobility operational services focus on load balancing the traffic and users in different communication schemes and spectrum resources available for 5G networks in order to achieve the EDHs requirement planes.

It is worth noting that the future 5G network architectures should combine all the available alternative communications in order to attend the requirement planes, while allowing a more complete performance optimization of the wireless medium without too much additional CAPEX for EDHs. In view of this, the WiSEED firstly seeks the routing operational service that will employ multi-hop and direct communication schemes that can compute the best routes in terms of signal quality, lightly loaded links, and energy efficiency, as well as taking into consideration distinct kinds of multi-hop communication, such as Wi-Fi Mesh and Device-to-Device (D2D). Beyond the Wi-Fi Mesh, some recent communication initiative for offloading in LTE has been proposed to explore the multi-hop structure between the mobile devices, such as LTE-direct and D2D, in which the mobile user can directly communicate with other mobile devices through LTE radio interface. Since the mobile users have restricted battery

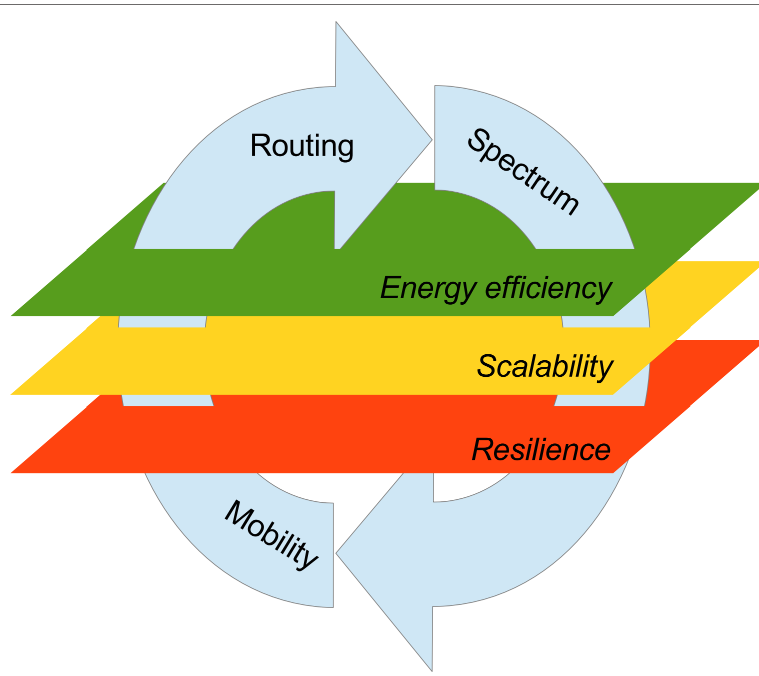

Fig. 2 WiSEED - architectural model

consumption, WiSEED takes into account energy-aware routing solutions for D2D communication [12].

The routing operational service of WiSEED proposes to distribute the session flows initializing from a local neighborhood through D2D, and whether it is not attend the requirement's planes, the routing service will start a more holistic view through the Mesh Wi-Fi communication. If all the previous routing schemes fail to attend the requirements, the mobility operational service will perform handover of mobile users between cells, initializing by the small cells (pico/femto/phanton/nano)). After that, if it is not also enough, it will run handover between LTE eNBs macro-cells. Figure 3 shows how the routing and mobility operational services of WiSEED seek to distribute the traffic load and mobile devices incrementally and sequentially in the communication schemes from a micro-level (D2D) up to macro-level (LTE enB), as well as interacting with dynamic spectrum management. It is worth to point out that each action in Fig. 3 is managed by its respective WiSEED software module in the SDN controller.

The routing and mobility services can require spectrum for the selected paths and mobile devices to the dynamic spectrum management service and thus the joint of routing, mobility, and spectrum occurs. It is important to stress out that an adaptation layer will be needed between the routing service and spectrum management service to translate the requirement planes for the wireless links of every path in which the spectrum management service will select the channel frequencies. For instance, the performance requirements of each path are specified for the spectrum management, such as signal strength and power transmission that every link should support for every path.

Although there are some kinds of wireless networks (e.g., LTE) that use a licensed frequency band in 5G networks, a wireless link in EDHs may not always have a dedicated bandwidth and, as a result, the neighboring node transmissions may also compete for the same bandwidth. Thus, a transmission in one wireless link interferes with transmissions in neighboring links. Instability is an intrinsic problem caused by interference that has an effect on link quality in any wireless network. Moreover, the neighboring links with a high traffic load cause interference (i.e., self-interference) and increase the congestion in the wireless links [13]. In this context, the routing and spectrum management operational services must also be aware of the link quality by taking into account the interference and wireless channel load between the neighboring nodes and thus being able to achieve a resilient and scalable routing decision and spectrum selection, respectively. In view of this, WiSEED will employ most precise cross-layer measurements [28] in order to estimate the link quality, such as SINR and channel busy time.

We include the spectrum management service in WiSEED to allocate the spectrum dynamically in accordance with the requirement planes and spectrum availability. For example, the number of non-overlapping channels of unlicensed and licensed frequencies may be not enough in dense scenarios, which means there will be a high degree of contention because of the repetitive assignment of the same channel in links that are close to each other. As a result of this, the load balancing of flows in the multiple paths achieved by the routing service, may

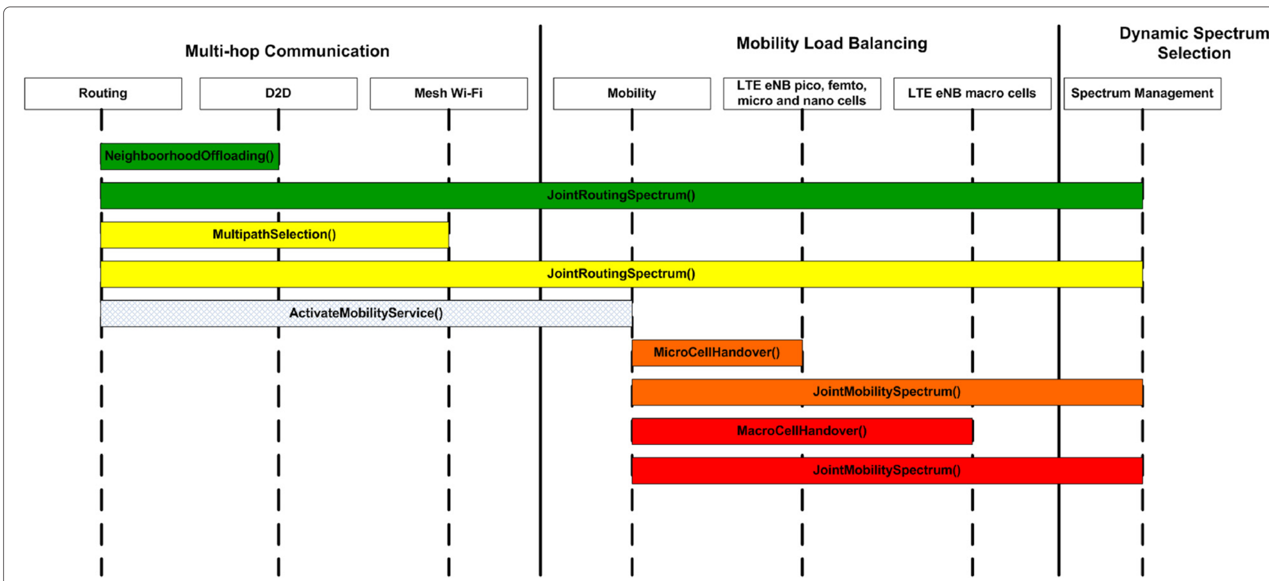

Fig. 3 Joint of routing, mobility, and spectrum

not have the expected effect, since it fails to take full advantage of network density to offload the traffic. For this reason, the operational service of spectrum management should work together with the routing and mobility services in a cross-layer optimization, this provides additional channels available for cognitive devices by means of the database of the spectrum. In addition, the spectrum management can offer shortcut links for devices that are able to change their communication features, such as channel bandwidth, transmit power, or beamforming.

The regulatory agencies of some governments have employed a geolocation spectrum database to include the information about the spectrum. Thus, it is possible to control the way that the unlicensed and licensed frequencies are allocated, particularly the latter. For this reason, the geolocation database has to understand all the regulatory requirements that determine the coexistence of a primary user with those who are sharing. The dynamic spectrum management service will query this database that contains a master list of assigned or available frequencies or predefined rights and obligations at a given time in particular locations. Therefore, the dynamic spectrum management service needs to be location-aware, as well as able to access to the database.

Figure 4 shows the main features and mechanisms of dynamic spectrum management. It should be pointed out that this service will mainly take into account dynamic spectrum selection based on artificial intelligence. For this reason, we will adopt the evolutionary strategies for dynamic spectrum selection proposed in [21] for the WiSEED architecture, since they can adapt quicker to the high variation of the wireless link quality in EDHs. The dynamic spectrum management operational service is based on new methods of sharing access spectrum techniques to manage the unlicensed and licensed frequencies and establish a synergy with the routing and mobility service. This service is a modular component of the WiSEED architecture which provides a spectrum for selected paths of routing and mobility management services and can operate in accordance with the specific demands of Mobile Operator Networks (MONs), i.e., selling the spectrum. This means that the spectrum management services work on a proactive and reactive way. It proactively selects the spectrum in unlicensed and licensed frequency bands for the LTE pico/femto/nano cells to support the requirement planes.

A new spectrum-sharing system has recently emerged, where the primary users can opt to rent/auction some idle channels to the secondary users through an auction process [29]. As a result of this, the scalability and resilience can be improved while costs to customers are kept at a fairly constant rate. For this reason, the spectrum management employs the auction process to sell and buy spectrum in a reactive way. Figure 5 describes how the auction mechanism and dynamic spectrum management service interact to attend the requirements' demands. If there is no spectrum available in the spectrum database for a specific link of selected path or cell antenna by the routing and mobility management services, respectively, the auction mechanism for buying spectrum is activated by the spectrum management service. In addition, if there is idle spectrum licensed and the MON can opt to rent/auction it, the auction mechanism for selling spectrum is activated by the spectrum management

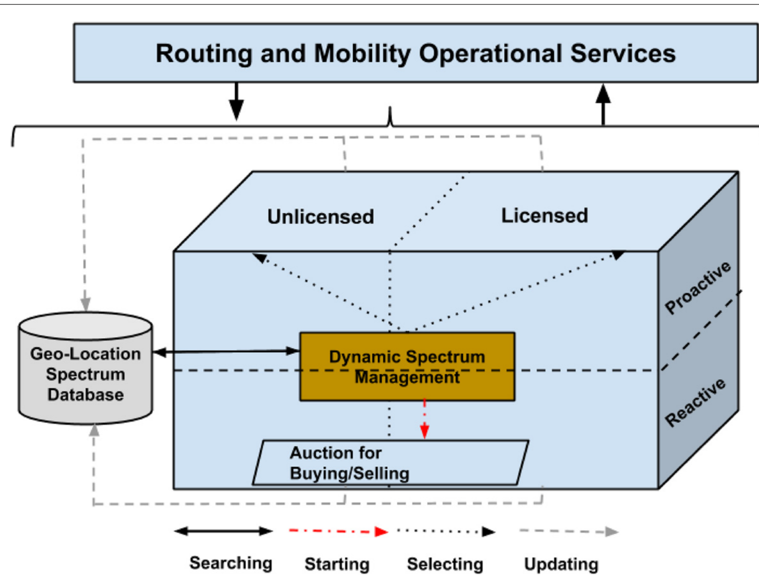

Fig. 4 Dynamic spectrum management

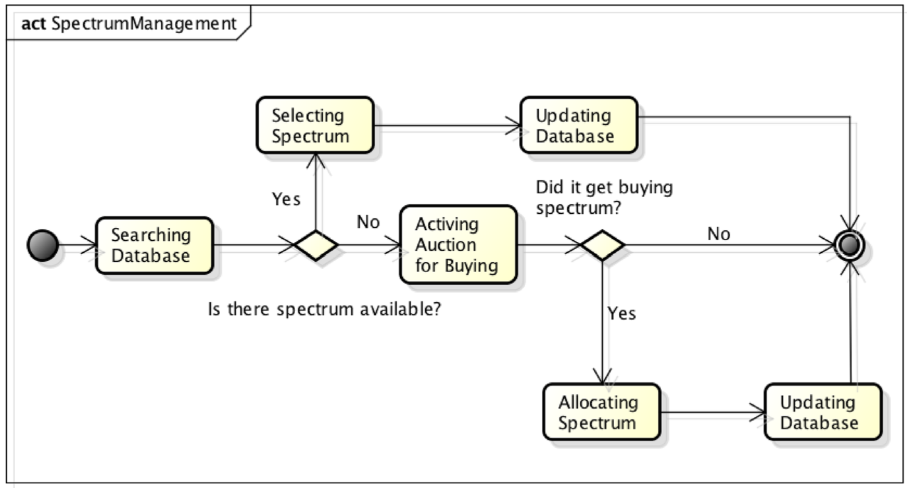

Fig. 5 Activity diagram of spectrum auction

service, which is very similar to the mechanism for buying spectrum.

4 Preliminary results

In view of all the requirements that have to be met in the previous section, we present a preliminary study that is outlined here on the correlations between these requirements so that the selection of a Wi-Fi access point can be assessed in terms of the performance that it provides for mobile users. This is important because it handles the selection of an access point or even LTE base station among the requirement planes. A real-world data set has been employed to assess the potential problem discussed in this article. We adopted the Virgil data set of mobility traces in which people desire to select the best access point in Chicago, USA [30]. A representative neighborhood in Chicago's downtown district was chosen as one of the scenarios in the Virgil data set, since it is a very densely populated scenario (Workday population density: $235{,}000/km^2$). In the course of this field study, the trace logs and access points (AP) databases have been made freely available to the community through the CRAWDAD web site. The people literally walked up and down on the streets in the "downtown" neighborhood in a grid fashion.

The collected information has been deployed to represent the requirements described in the WiSEED architecture. Some equivalences were established between the requirements and measurements of the Virgil data set. First, the signal strength of the wireless links represents the degree of *link quality*, because a weak signal strength means the communication is unreliable. Secondly, the transmit power at the access point is linked to the *energy efficiency*, as the greater the transmit power, the greater the energy consumption. Next, cryptography represents the degree of *security*, and in this case the Virgil data set notes whether or not the WEP cryptography is ON/OFF. The *link quality* and *security* represents the *resilience* requirement. Finally, the bit rate can denote the degree of *scalability*, due to the fact that when there is more link capacity, the AP can support a greater amount of traffic load. The requirements are based on the following values in accordance with the Virgil data set: signal strength (40/92–80/92 dBs), transmit power (−60/153–140/153 dBs), cryptography (ON/OFF) and bit rate (1–11 Mbps). These requirements directly influence the traffic performance.

The future cellular system should seek to satisfy the mobile user by optimizing performance from the network and the user perspective. However, when the increased requirements in the 5G networks are considered, especially those in the EDHs, as well as the conflict between these requirements, it is a good idea that the user application demands in the cells can assist in the resource optimization process by defining the requirement planes for their connections. For example, a user who is using a healthcare application may desire robustness and security rather than a high transmission rate. Alternatively, another user who wants to share an entertainment video in a stadium or in a car during a traffic jam by using a smartphone where the battery power is low, will probably give priority to connections with a lower transmission rate (but not less than the minimum) that will consume much less energy during the transmission (particularly if this user is less concerned with robustness and security).

WiSEED will make the 5G network operators more customized for the mobile users, by taking into account the user's views when defining the requirement planes and providing support to allow the operational services to cooperate by achieving an equilibrium the requirement planes. It is worth noting that the definition of requirement planes involves employing statistical prediction techniques, as well as the requested requirements of most of the mobile users in the macro- or micro-cell taking into account some historical information. In this context, the technique of optimizing multi-objective problems in Matlab, (called goal attainment), seeks to reduce the number of values which can be used to solve the problem to achieve a user-profile goal in which the user preferences will define the weight or priority for each objective function.

By employing this technique and the database from CRAWDAD, we show the results of the requirement planes as hypothetically established by users A and B to select a Wi-Fi access point that can offer a better performance from the perspective of the user preference. Figures 6 and 7 present achieved solutions that are very similar to those requested by the users. Figure 6 illustrates that the requirement of power transmission was overachieved, whereas it can be noted that in some situations the signal strength and power transmission requirements were underachieved (see Fig. 7). The degree of underachieved and overachieved solutions can trigger for each operational service or establish synergies between operational services or for revising the resource management in WiSEED. For instance, when D2D communication is being used but the requirements are underachieved, the Mesh Wi-Fi communication is employed by the routing service, even if requirements are still underachieved, then the handover of UEs between small cells is used.

5 Challenges and open issues in 5G networks based on a software perspective

This article proposes to establish a future network architecture through software-based technologies and solutions. Some of these technologies already comply with standards such as LTE and LTE-Advanced, while others are still under development. Hence, we will take a look at some of the open issues and research challenges that these new technologies and operational services pose.

SDN. There is a need for different reconfiguration policies that can apply to the network elements in EDHs at different time scales due to the dynamicity and density of this network, and this can also result in high signaling overhead. Moreover, the centralized nature of the conventional SDN approaches creates a bottleneck and thus reduces resilience and scalability. Owing to the fact that 5G networks are deployed in a dense and heterogeneous area, the wireless link quality is very unreliable and unstable and this may temporarily prevent communication with the controller, if the controller communication channel uses in-band signaling. This lack of communication can result in isolated wireless networks. Furthermore, 5G network can have cells with particular configuration policies. Therefore, it is evident that the flat organization of the conventional SDN controllers does not provide an effective and flexible management solution for EDHs that can meet the requirements for resilience and scalability. Moreover, which functions must exactly be implemented in each plane is still an open issue in the SDN paradigm, particularly in the wireless networks. Furthermore, the heterogeneity of EDHs that includes D2D, M2M, and Vehicle-to-Vehicle (V2V) communication results in very

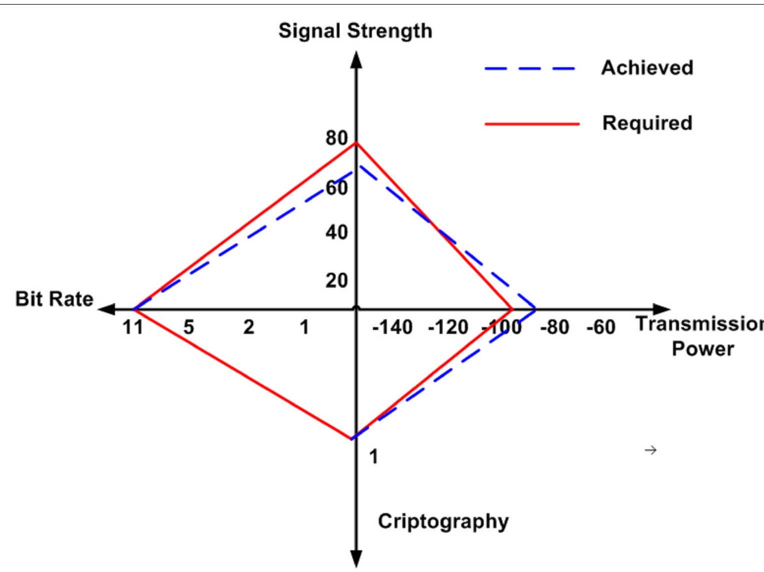

Fig. 6 Requirement plan of user A

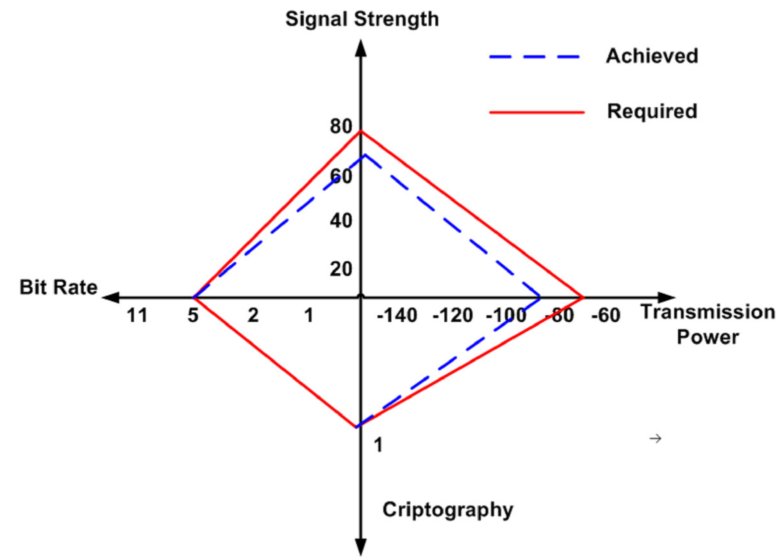

Fig. 7 Requirement plan of user B

diversified and dynamic topologies, so that SDN and NFV are very complex to plan due to distinct mobility models and hardware constraints. In such scenarios, how the SDN controller advertises the edge Open-vSwitch (OVS) device or network hypervisor that which terminal node should forward packets. To answer this question, we identified two alternative approaches that could possibly be applied in this case. Former, a broker/middleware could be used to intermediate the messages between controller(s) and OVS devices. Last, standard protocols should be employed in order to reach a transparent communication, such as HTTP.

NFV. There are open issues that arise when attempting to integrate NFV and SDN. For instance, the programmability of the SDN network needs to be ensured by standardizing the northbound and southbound interfaces between PNF and VNF that form a single network service chain. In addition, the virtualization has a negative impact on the performance of the virtual LTE and Wi-Fi services, and as a result of this, the performance of virtualized network functions leaves much to be desired when compared with performance of the physical network functions. Cloud computing offers potential computational environments to virtualize the network functions, such as mobile cloud and Cloud Radio Access Networks (C-RAN), but there may be significant latency to migrate the processing and traffic load of PNFs to the cloud environment. This is even more the case if the wireless links are used for this purpose; otherwise, wired links are not always available in EDHs. Global standardization is still on-going and a unified cellular programmable interface for implementing SDN and NFV is under development, including a service chain through the integration of SDN and NFV.

Channel quality estimation in wireless links. Although WiSEED seeks to use the most precise metrics to assess the wireless link quality, it is quite difficult to estimate the wireless channels load and interference in wireless networks. For instance, the state of the wireless channel changes frequently, especially during a crowded event such as a soccer game in a stadium, where fading, shadowing, or multiple paths affect the link quality. A channel status can be affected by transmissions at close access points and also by small events in the scenario such as people or a car passing by. Moreover, some studies [28] have shown that it is very difficult to calculate or collect precise metrics in a real wireless network.

The spectrum auction process requires a new business model for the multiple MONs. Even though the auction can increase the spectrum pool, it also makes even more difficult to carry out spectrum management—for example, how radios can sense white spaces, use databases to classify spectrum, and use dynamic auctions of all kinds in spot markets or in longer time scales and trade spectrum [29]. In addition, it is necessary to define a novel and sustainable business model to support this context which is a daunting task. It is also necessary to determine how new business models should be engaged in multi-operator interactions to share and allocate physical and virtual resources while reducing CAPEX/OPEX, such as virtual or physical Wi-Fi hotspots and LTE base stations.

User profile specification. Cellular network architectures based on user preferences are not very common in current cellular network generation, this is because there a few number of applications and services offered by mobile operator networks. Therefore, there are few user profiles as well. However, there is a tendency that the most of traffic in cellular networks will be IP traffic soon. Hence, the future MONs have to support several kinds of users and the wide-ranging applications, since the user profiles will increase. The WiSEED architecture will take into account the user profiles to assist the requirement planes. Nonetheless, there are some challenges that need more discussion, for example, how to define a user profile (taking into account localization, available resources in the wireless networks, application demand, and user preferences) and how to translate/represent a user profile in 5G requirement planes so that routing, mobility, and spectrum management services can achieve these planes.

6 Conclusions

In this article, we have proposed the WiSEED architecture for 5G networks in the context of extremely dense and heterogeneous scenarios. The aim of WiSEED is to tackle the conflicting requirement planes, i.e., scalability, resilience, and energy efficiency in order to provide a high quality and ubiquitous services for mobile broadband Internet access. WiSEED concentrates on the perspective of software networking, and thus, it employs enabling technologies and operational services based on concepts put forward in the market and within the research community to support the envisaged architecture, such as SDN, SDR, NFV, mobility, and routing.

We have presented a critical analysis of the requirements and challenges in WiSEED environments, including the operational services and their synergies, such as routing, mobility, and dynamic spectrum management, the aspirations for the enabling technologies and challenges of being able to carry it out. Some preliminary results were shown based on real-world data set of crowded populated urban area to select a Wi-Fi access point taking into the requirement planes for different user preferences, which is of paramount importance for building the proposed architecture.

Although most approaches and techniques have already been chosen as modules to compose each operational service of the WiSEED architecture, there are some aspects in WiSEED that need further discussion and working. For instance, there is the question of whether the spectrum-sensing technique is suitable for the database that is used for dynamic spectrum management. Later, the operational services and their modules will be integrated and tested in simulation studies and prototypes.

Competing interests
The authors declare that they have no competing interests.

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