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The Role of Small Cell Technology in Future Smart City Applications
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ABSTRACT
Meeting citizens’ requirements economically and efficiently is the most important objective of Smart Cities. As a matter of fact, they are considered a key concept both for future Internet and ICT. It is expected that a wide range of services will be made available for residential users (e.g.: intelligent transportation systems, e-government, e-banking, e-commerce, smart management of energy demand, etc.), public administration entities, public safety and civil protection agencies, etc. with increased quality, lower costs and reduced environmental impact. In order to achieve these ambitious objectives, new technologies should be developed such as non-invasive sensing, highly parallel processing, smart grids and mobile broadband communications. This paper considers the communication aspects of Smart City applications, specifically, the role of the latest developments of LTE-A standard, which forecast the increase of broadband coverage by means of small cells. We shall demonstrate that the novel concept of small cell fully meets the emerging communication and networking requirements of future Smart Cities. To this aim, a feasible network architecture for future Smart Cities, based on small cells, will be discussed in the framework of a future smarter and user-centric perspective of forthcoming 4G mobile technologies. Copyright © 2013 John Wiley & Sons, Ltd.

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1. INTRODUCTION
Following the operational definition of “Smart City”, reported at page 6 of [1], a city is said to be “smart” when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources and through participatory governance.

It is clear that the fulfillment of such ambitious goals requires synergic efforts in terms of research and innovation that should be strongly coordinated with social requirements of citizens and municipalities. To this aim, various business models are proposed with the objective of defining an effective service planning in ecosystems that are becoming smarter and smarter [2] [3]. An interesting cooperative model, targeted at supporting the creation of innovative services and applications with real value to economy and citizens, has been proposed by the consortium of the EU OUTSMART project [4]. The model is based on a stakeholders’ triangle (see Fig. 1), whose vertices are represented by citizens, utilities and cities:

- **Citizens** are one of the main beneficiaries of smart cities. They will benefit of various smart services provided by utility companies and city authorities, with the aim of enhancing their life in terms of security (e.g. better street lighting, prevention of muck corners), health, wellbeing (e.g. reduced CO2 emission) and economically (e.g. resource optimization or employment as developers). Moreover, citizens shall be empowered with more control for resource management by collaborating in economical and environmental issues.

- **Utilities** are the infrastructure to be developed for Smart Cities. More specifically, we can identify under such category mainly the two following entities: service providers and network providers. The first ones are responsible for offering a service useful to the citizens or the smart city at large,
while the second ones have the responsibility to operate the network infrastructure that will enable the services. Their aim is to allow utility companies to improve the management of their resources: optimization of resource distribution, prevention of resource outages, easy and rapid maintenance actions, etc. Besides this, utility providers will benefit from the new environment, becoming able to develop and deploy added-value network-facilitated services for users. This will simplify and accelerate service delivery, reducing the operational costs and enhancing a faster return of investment. The collaborative ecosystem and interactions will make services tailored for customers specific needs and preferences.

- Cities are where around 80% of the European citizens live: urban areas at a very high density. Cities are experiencing many problems (security, pollution, traffic congestion, infrastructure maintenance, asset management, etc.) related to this unprecedented citizens number growth. This has led to an increased strain on utilities providers and services necessary to facilitate daily life. Using smart services with networked sensors and actuators deployed in the city, authorities will be able to monitor the environment in real-time, enabling a prompt response, and to establish automated control processes with less or even without human intervention. At the same time, the municipality will be able to provide enhanced services to the citizens (e.g., assisted living).

The deployment in urban areas of smart infrastructures would allow not only to improve environmental sustainability, but also to offer new services targeted at improving quality of life, promoting commercial business and tourism, assisting elderly people, providing educational services, leisure, etc. In such a model, the beneficial effects of the developed technology are exploited in “closed loop” by cities, citizens, and utilities together.

In the model described above, ICT technologies and, specifically, wireless networking technologies play a key role. Recently, some examples of ICT-based experimental facilities for Smart Cities have been presented in literature.

In [5], a Smart City testbed, namely SmartSantander (located in the city of Santander in Spain), is presented. The application considered is related to distributed environmental monitoring using wide-area WSNs based on IEEE 802.15.4.

Another testbed, explicitly targeted at ubiquitous computing, is shown in [6] and is operational in the city of Oulu (Finland). A middleware layer has been created on top of the Oulu metropolitan WiFi access network in order to allow ubiquitous computing with sensing and communication resources embedded in urban elements.

A cloud architecture for Smart Cities based on Near Field Communication (NFC) technology is proposed in [7].

All the solutions proposed in [5, 6, 7] are based on local area networking infrastructures, providing hot-spot rather than ubiquitous broadband connectivity. Broadband connectivity available anytime and anywhere will be one of the key requirements of future intelligent cities, where people will be totally connected. As stated in [8], people living in cities that are really smart must no longer be worried about incompatible networks or applications that break when used “on the go”.

In such a perspective LTE-A technology [9] will configure itself as one of the main pillars of future Smart Cities in order to guarantee broadband access and efficient service mobilization. Innovative LTE-A PHY and MAC layer solutions, i.e., carrier aggregation, enhanced MIMO support, Coordinated Multi-Point (COMP) transmission, relaying, etc., should effectively support system bandwidth up to 100 MHz, with potential throughput of 1 Gb/s for downlink and 500 Mb/s for uplink. We believe that the concept of small-range cells forecasted in LTE-A [10] will represent a technological breakthrough in the wireless networking design for Smart Cities.

Small cells are already considered as an enabler due to their lower energy consumption and broadband coverage capacity (see [11]). Some recent works (e.g., [12]) have already considered the integration of macro, micro and small cells with the aim of building service platforms for Smart Cities.

Another technology that is clearly emerging in the framework of LTE-A is the Cloud Radio Access Network (Cloud RAN) [13, 14]. The virtualization of radio access obtained by means of real-time cloud infrastructures would allow network providers to increase spectrum efficiency, and reduce power consumption. From the point of view of service providers, Cloud RAN should enable easier delivery of new rich wireless services cost-effectively.

The aim of this paper is to analyse and critically discuss the role of small-range cells in the service provision for citizens and business companies in future smart cities. Potential breakthroughs and open challenges
related to such technology will be investigated. A viable architectural view for a fully-networked wireless Smart City based on the small-cell concept will be presented in the framework of the ecosystem described above. In such a framework, the communication tasks to be fulfilled should not only address personal, commercial and administrative data exchange among citizens, administrators, business managers etc., but also transparent communication among heterogeneous sensors and actuators together with efficient data transmission from these devices to control units spread along the monitored areas. As clearly stated in [15], utilities need to evolve their existing system architectures to enable the flexible creation of this kind of advanced services integrated with the existing commercial services. Thanks to the potentialities offered by small cells and Cloud RAN, we believe that the proposed architecture should provide the flexibility, reconfigurability, throughput enhancement, delay and latency reduction needed to achieve the above mentioned ambitious goals.

2. EMERGING COMMUNICATION AND NETWORKING REQUIREMENTS IN FUTURE SMART CITIES

The Smart City paradigm is a vision for future cities centered around the concept of connectivity. Indeed, connectivity is the core requirement for Smart Cities to exist, enabling tight integration among citizens, devices and service providers. However, it is also a mean for interoperable access and interconnection among different services.

Looking back at the history of Internet, it took twenty-two years (i.e., from the first ARPANET to the WWW development) to have a consumer application allowing the commercial exploitation of the technology. Hopefully, the services for Smart Cities will need less time to be finalized, since several communication infrastructures already exist and operate in many cities. As an example, in a typical city we can find optical or copper cables used by ISPs to deliver Internet access to the citizen as well as 3G/4G cellular infrastructure for mobile users. However, the presence of existing communication infrastructures represents on one side an advantage (in terms of faster deployment), but also a constraint (as the integration of some communication facilities could be hindered by local regulations or ownership, or by architectural issues).

Moreover, it is still unclear which will be the “killer application” that will drive the explosion and growth of the Smart City concept. Several existing testbeds and pilots are mainly focused on simple services for either the community (e.g., public transportation, street lights, etc.) or citizens (e.g., parking services, smart metering, etc.). However, the most advanced examples of ‘Smart’ Cities (Singapore, Rio de Janeiro, etc.) are currently focused on services based on the concept of big data, i.e., integration and processing of big amounts of data generated by heterogeneous sources (e.g. weather, traffic conditions, crimes, best routes across the city, etc.). Nonetheless, the offered services are rather traditional.

As a consequence, the prediction of traffic patterns at network level remain extremely speculative. Thus, the design and dimensioning of a proper communication infrastructure should take into consideration the capacity of easily adapting to the needs of this multi-faceted and ever-changing scenario. Therefore, it is possible to define the following communication and networking requirements:

1. Interoperability: a clear trend is to interconnect all the possible data sources through a global infrastructure (e.g., a cloud-based service, or the Internet at large) to support new services.
2. Scalability: the communication and networking infrastructure of a Smart City should provide bandwidth and performance using architectures able to scale and be upgraded easily as users grow and services reach maturity.
3. Fast deployment: deployment of new solutions or upgrades of the existing infrastructure should be as fast as possible, favouring small and easy-to-install devices. Some sections of the communication infrastructure can be mobile or installed ad-hoc in case of specific requests (e.g. big events, emergencies).
4. Robustness: living in a Smart City will require a number of services. As a consequence, communications should be robust enough to provide guarantees in availability even in extreme conditions.
5. Limited power consumption: smart resources management and limited environmental impact are another important aspect to look at in Smart Cities. Following the recent activities in the field of green communications, the infrastructure should have limited environmental impact and low power consumption to minimize operating and management costs.
6. Multi-modal access: users should be empowered by the services of a Smart City regardless of the devices they are using. Access to Smart City services should follow the AAA principle: Any-time, Any-where, Any-device.

3. SMALL CELLS AND LTE-A: BASIC CONCEPTS AND POTENTIAL BREAKTHROUGHS

Considering communication requirements listed in Section 2, Smart Cities will heavily depend on the network infrastructure. The broadband mobile connectivity will have to support increased coverage and superior quality-of-service. In this framework, small cells will represent a suitable technology to address such unprecedented requests.

For some time, the concept of “small-cell” was somewhat confused with that one of “femto-cell”. A “femto-cell” is a specific typology of small-cell targeted at improving short-range indoor coverage [16]. Recent developments of LTE-A standardization radically updated
the concept of small cell. In the LTE-A perspective, a small cell is a low-power and low-cost radio base-station, whose primary design target is to provide superior cellular coverage in residential, enterprise and hot-spot outdoor environments. Four main typologies of small cells have been identified in [17]:

- **Pico-cells**, smaller, lighter base-stations that plug directly into an operator core network;
- **Femto-cells**, mentioned above;
- **Trusted WLAN cells**, integrated into the LTE-A system;
- **Relay nodes**, that have been primarily defined in LTE Release 10/11 in order to extend the macro-cell coverage or fill a coverage hole.

Early feasibility studies about LTE-A systems and beyond [18] assigned to small cells a key role in enabling future broadband coverage up to 25 Gb/s/km² (urban environment). In such a perspective, the intensive use of dynamic time-division duplexing, carrier aggregation, interference coordination and massive MIMO systems should increase the available capacity of some orders of magnitude. Moreover, users exchanging data in each small cell will experiment an increased quality-of-experience due to the fact that the transmission resources are shared by a minor number of mobile users in comparison to the macro-cells case. Additionally, if we consider that each small cell site can host also M2M gateways, richer applications can be conceived targeting both communication and city governance services.

Recently, LTE Release 12 focused on small cell enhancement to accommodate the expected huge traffic growth, especially for hot spot areas [10]. Multiple scenarios have been conceived for small cell enhancement by the 3GPP group in December 2012: deep indoor scenarios, mobile outdoor scenarios, wireless and wired backhaul, synchronized and unsynchronized scenarios. Some of the objectives expected from small cell improvements are [10]:

- Supporting increased throughput both in uplink and in downlink;
- Keeping a fair distribution of throughput among users;
- Reducing backhaul delays;
- Improving integration among macro-cellular and micro-cellular nodes in order to provide ubiquitous real-time services.

Small cells are also considered as a valuable solution to the problem of ecological sustainability for future broadband wireless access [11]. The idea of a very dense deployment of self-organized, low-cost, low-power based stations has been shown to have the potential of significantly increasing the capacity of cellular networks while reducing their energy consumption. In fact, the radio coverage using small cells deployment shall allow a better control of the territory and a reduction of the electromagnetic emission in urban areas. The resulting dense grid of cellular coverage shall enable greener services (i.e., cell broadcasting alerts & news) selecting specific urban districts of the Smart City (for comparison see figures 2 and 3). As matter of fact, since the path loss increases exponentially with coverage radius (i.e., the size of the cell), small cells enable relevant energy saving: halving the coverage decreases the transmitted power by a factor of four.

Considering the additional push given by LTE-A standardization process, the potential of small cells appears very important, but not yet fully exploited. There is still the need for a step ahead in the design of small cell technology. Small cells should be thought as the last-mile broadband access infrastructure of Smart Cities and not just an “ancillary” and “stand alone” network segment. This novel view of small cells fully responds to the emerging requirements of Smart Cities in terms of a wide plethora of ubiquitous and pervasive services (from health to education, from safety and emergency management to social networking) readily available anytime and everywhere. The communication infrastructure should provide very high capacity and reliability as well as the capability of configuring itself around the real users’ needs.
As network nodes, small cells may, in addition, provide “smart caching” services. This feature is extremely interesting. It enables to provide local caching services in order to reduce the load on the network backhaul (e.g., in the case of video traffic). Smart caching capabilities can be largely extended to cloud based architectures. The storage resources may be initially deployed within the LTE evolved NodeB (eNB) infrastructures, and, afterwards, moved towards servers in the cloud (rack).

This architecture type (mini data centers in eNB) is now possible due to the broadband capability of both the radio interfaces and backhauling lines. The result is an enhanced user experience and an increased flexibility offered by cloud architecture.

In fact, virtualisation can lead to further improvements as shown in the “Cloud RAN” scheme for small cells. In this scheme, the radio access functionalities are deployed into the cloud providing virtualisation of these functionalities for deployed eNBs. The ultimate objective of the Mobile Cloud projects is to move from current mobile networks to a fully cloud-based mobile communication system. This will extend cloud computing, in this way enabling the support for on-demand and elastic provisioning of novel mobile services. This will have implications on new business models and sharing of the infrastructures.

Small cells are also a very promising candidate for the backhauling of Wireless Sensor Networks (WSNs), since terminals can use less power in comparison with other wireless systems. WSNs have been, so far, based on proprietary communication stacks. However, recent developments are moving the WSN communication towards IP-based systems, according to the Internet of Things (IoT) paradigm. Wireless LTE-based backhauling at the WSN gateways is the most promising solution to further enhance WSN capabilities.

Additionally, eNB functions can be extended in order to become standardized communication gateways and to enable interoperable operation and information gathering from a wider plethora of “sensors” (e.g. vehicle counting systems embedded in the streets, sensors and actuators connected to lights, etc.).

From the point of view of architecture and deployment, small cells represent a modular solution easily upgradable. As they need low maintenance, they represent a sustainable solution for quick deployment of high capacity. Moreover, they can act as gateways for enabling seamless integration of different sensor technologies within the Smart City infrastructure.

A graphical representation of the possible usage of small cells in Smart Cities is provided by Fig. 4, where many types of services for mobile customers, IoT, Personal Area Networks are presented.

**4. A SERVICE-DRIVEN NETWORK ARCHITECTURE FOR SMART CITIES BASED ON SMALL CELLS**

As outlined in the previous sections, future Smart Cities will be mainly based on offered services (see Fig. 5). In order to enable these services, the network will need to embrace the concepts of broadband wireless, green communications, reconfigurability, replication, Machine to Machine communications and quality of experience.

A key role in this kind of network is played by the wireless access, specifically by LTE-A, even if other technologies could and will be used (Fig. 6). Main LTE-A capabilities driving toward this technology are different cell sizes (macro, pico, femto), machine-to-machine and device-to-device communications, efficient spectrum utilization, etc.

It should be stressed that the Smart City scenario can not be based just on one technology. As an example, Sensor and Actuator Networks (SANs) might use completely different technologies, e.g., RFID, IEEE 802.15.4, etc. However, these networks should be integrated in the Smart City. The integration is made possible by the IoT paradigm, and LTE-A can play a crucial role as access technology for the SAN gateway.

**4.1. Small cell networks**

Smart City wireless networking requirements can not be met with traditional macro-only networks. This is due to a number of reasons ranging from spectrum efficiency and regulatory issues to indoor coverage. As outlined in Section 3, the Small Cell and, more generally, the Heterogeneous Network concepts are gaining wide acceptance. An example of heterogeneous network is shown in Fig. 7) [19]. Due to the peculiarities mentioned in Section 3, small cells are able to fulfill Smart City requirements in terms of interoperability, robustness, limited power consumption and multi-modal access with improved quality of experience.
4.2. Application enhancers

Small cells architectures enable mobile service providers to leverage network capabilities (e.g., location, presence, quality of service, trusted security, etc.) for applications’ development, either by the operator or third parties. By providing application programming interfaces (APIs) that can be integrated with applications and service frameworks, small cells enhance the potential for innovative service creation. As an example, they have presence information APIs, making it possible to build services like One Family Number, Home Notes, Child Tracking, Emergency support, location based advertisement, product search, augmented reality, etc.

Other features allow users to redirect data sessions from the core network to their local home network, providing higher throughput for media sharing applications and gaming. They may also enable secure payment transactions by using secure access over licensed spectrum.

From the point of view of operation and maintenance, site visits are avoided and, beside physical installation, many of these radio equipments, after installation, automatically come into service without any further intervention. At registration, location is determined and constantly kept up-to-date, allowing the mobile service provider to control it. This is critical for emergency calling and other location-associated services. Auto-configuration reduces the cost of small cells deployment and decreases the need for large customer support teams. It also lessens the need for massive re-provisioning following macro network re-planning. In this way, fast deployment and scalability requirements can be fully satisfied.

4.3. A possible Smart City service architecture

Services that are offered by Smart Cities can easily be virtualized. Most of the services will use telecommunication network infrastructures to access data and services hosted in the cloud. One of the requirements of service provisioning in such a scenario will be an easy provisioning process. The architecture that we propose in this section aims at removing the entry barrier for new smart services by incorporating cloud principles into the traditional telecommunication stack. Since almost 80% of the telecommunication stack (including LTE-A) is software, it simply makes sense to cloudify it, thereby making the overall architecture more compliant to cloud principles. This will help achieving better energy efficiency due to better resource sharing and will bring ease of provisioning and deployment and, additionally, reduction / remotion of service entry barrier.

Figure 8 shows the prerequisite for enabling Smart City services and applications. It assumes the existence of Radio Access Networks (RAN), micro and macro datacenters, together with mobile core networks. Micro datacenters may be spread at various strategic locations in any smart city, and macro datacenters could be located at key geographic locations to provide additional resource boost to individual cells in case of flash crowd like scenarios.

Figure 9 presents the overall architecture that would support easy provisioning of Smart City applications and services. It shows how the cloud principles should be applied to the traditional telecommunication stack by virtualizing RAN in order to allow better available spectrum sharing. It also shows how major software components of EPC and IMS can be put into virtual...
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architecture should support application scenarios like M2M communication along with QoS requirements in a more cohesive manner.

The virtualization and cloud RAN potentialities mentioned above should greatly increase scalability, robustness and interoperability of the Smart City network.

5. TECHNOLOGY CHALLENGES

As described in the previous sections, there are a lot of open issues belonging to technical, management and security areas. In this section we will roughly divide them in macro-areas.

5.1. Machine to Machine communications

At present, communication standards are mainly oriented towards user-based communications, with little support for M2M communications. These short-lived, low data rate flows might pose serious problems to core network and service providers. The IPv6 and IoT paradigms are not helping either, and they could even exacerbate the current issues. The whole EPC architecture derives from the previous mobile systems, where the focus was on voice communications with time-constrained data flows. The technological advancements has been centered on higher data rates, neglecting the support for the M2M systems. As seen previously, these devices have typically long duty cycles and low data rate, but they require permanent reachability and (in some cases) guaranteed QoS.

In order to allow the M2M communications, it is imperative to enable in the mobile network (LTE-A and beyond) a strong support for the M2M paradigm, with the following points being the most urgent ones:

- **Device to device communications.** Most services will be based on proximity communications and D2D can greatly increase the network utilization while reducing energy waste.
- **Data offload.** LIPA and SIPTO are promising technologies. However, they may break service reachability or, at least, make it hard to keep devices in reachable state.
- **Direct small cells communications.** This point is conceptually similar to LIPA and SIPTO, but it involves the multi-cell scenario.
- **Protocol harmonization.** IoT should enable an all-IPv6 communication, however the application-level protocols are jeopardized. It is of paramount importance to minimize the need for application-level gateways.

Moreover, managing the devices and their status is an important aspect in Smart Cities. Data should be verifiable and the devices classified according to their sensing reliability. From a management perspective, smart environments will be made by a plethora of sensors, actuators, etc. Furthermore, devices may belong to machines and provided as a service to any potential smart-city application/service.

The proposed architecture supports inclusion of actors such as light-Mobile Virtual Network Operators (light-MVNOs). These actors in reality could be entities such as a company providing smart meter reading service, hospitals providing wearable devices to patients to enhance real time health monitoring and so on. Since the proposed architecture is guided by cloud principles, it allows on-demand, self-service, elasticity management, and pay-as-you-go billing models. It removes the entry barrier to service creation as a new Smart City service provider does not need to worry about setting the telecommunication support infrastructure or even worrying about entering into complicated long-term contracts with ‘traditional’ Mobile Network Operators.

The shown architecture, as it supports virtualization, will support easy service migration, and provide mechanisms through the cloud-controller layer to better meet the target consumers’ expectations. It also provides systems to monitor service usage and react to overload and under-load situations in almost real time.

By combining elements from telecommunication and traditional datacenters, and harmonizing the overall architecture thanks to cloud computing principles, this
differently, different management entities, ranging from citizens (e.g., smartphones) to service providers (e.g., smart grids) and municipalities (e.g., traffic monitors). All these data can contribute to the Smart City system. However, the device management should be able to tackle devices’ differences and provide flexible and personalized access to data, while maintaining user’s privacy and system reliability.

The Machine to Machine communication issue is being addressed by the latest LTE-A development, and, specifically, by the Device-to-Device paradigm [21], particularly efficient in small cells.

5.2. Security

The security area is also very important for future Smart Cities. Any system should increase citizens’ Safety by allowing a greater consciousness of the environment and a faster response to emergencies. In order to accomplish this goal, the system’s Security should allow a prompt isolation of misbehaving elements (e.g., a malicious device).

Moreover, citizens’ privacy should not be forgotten. Collecting more data could easily lead to a privacy loss (either real or perceived), potentially blocking citizens’ willingness to be part of a smart environment. These problems stimulate more interesting research activities, ranging from automatic behavior detection to distributed firewalling and social interactions willingness.

The current LTE-A security framework is very interesting. However, the same principles should be extended to IoT systems and the user’s devices. This is currently an open issue and an active research topic [22].

5.3. Spectrum utilisation

Efficient utilisation of the resources of the wireless spectrum for Smart Cities’ applications involves the usage of two emerging communication paradigms:

- **Cognitive radio networking.** Efficient utilisation of the spectrum is vital to support an incremental deployment of additional communication capacity. In this framework, a cognitive spectrum access represents the enabling technology for the development of opportunistic access techniques and the exploitation of the unused resources in an efficient manner.

- **Green wireless.** Communications and networking should be efficient also from the energetic point of view. This involves using energy-efficient communication protocols and devices as well as renewable sources (i.e. solar, wind, etc.) to power communication nodes.

We believe that the two paradigms mentioned above can coexist and cooperate. Indeed, cognitive and opportunistic features of small cell networking can be exploited to optimize radio resource utilisation and coverage, and, at the same time, minimize energy consumption and electromagnetic pollution. Moreover, the Cloud approach can enable further optimizations, particularly concerning the dynamic system spectrum management.

5.4. Backhauling

A potential bottleneck of small cell networking is related to the backhauling, as stated in [10]. Connecting each small cell to the wired backbone is not an efficient solution, in particular when the number of small cells is significant. In order to obtain an acceptable performance, complex mechanisms of dynamic distribution of the backhaul capacity among the existing heterogeneous networks should be forecasted, considering both radio and backhaul bottlenecks [23]. The concept of “relaying” is most important standardised technology for efficient backhauling, as formalised by the LTE-A [9]. 3GPP standardisation committee has decided to study different alternative solutions for small cell backhauling [24]: dedicated point-to-point fiber connections, LOS microwave connections (commercial products for 1Gb/s small-cell LOS backhauling in the E-band have been recently launched on the US market [25]), xDSL backhauling, non-LOS microwave solutions, etc. The backhauling will be one of the key issues for future small cell networking deployment in Smart Cities and all the mentioned above solutions should be carefully evaluated, considering the different application scenarios.

Additionally, increasing the number of cells may introduce more frequent handovers in case of terminal mobility. This issue can be addressed by employing macro-(or micro-) cells for maintaining the connectivity, while resorting to small cells for improved performance. The cloud approach can effectively enable new and enhanced solutions also in this case. However, this matter is an ongoing research topic and will be debated in the future among academic and standardization bodies.

6. CONCLUSIONS

As introduced in this paper, the urban environment represents a perfect ecosystem to start a new common approach in the design and deployment of ICT infrastructures and services. If specific agreements based on innovative regulations are made among main public and private players, it will be possible to deploy a new generation of platforms where environment, citizens and business will benefit.

The path towards fully integrated and automated Smart Cities is long and challenging. However, following the guidelines of a specific research and innovation agenda (see e.g. EU Horizon 2020 digital agenda), these goals can be met.

The cloud infrastructure will need to evolve and improve in order to empower future networks and next generation radio interconnecting the future Internet made by people, content and things.

In this paper, we highlighted the role of small cell technology in future Smart Cities. Small cells will provide Smart Cities with increased broadband...
capabilities, improved flexibility and easy deployment of scalable multi-service network architectures. Moreover, small cells can reduce the environmental impact of the communication infrastructure.

However, some challenges need to be addressed. We think that the forthcoming LTE-A standardisation process should update the concept of small cells. This should become the true broadband last mile segment of the wireless network and not be limited to an ancillary network segment. In order to make this technological shift, novel paradigms targeted at improving security, flexibility and cognitivity of the radio segment should be considered.

In our opinion, the integration of broadband personal communications with M2M and device-to-device communications will represent a key challenge to be addressed by future 4G standards.

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