Digital Communications and Networks 2 (2016) 167–174

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Digital Communications and Networks

journal homepage: www.elsevier.com/locate/dcan

Universal Intelligent Small Cell (UnISCell) for next generation cellular networks☆,☆☆

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ARTICLE INFO

Keywords:
Next Generation Wireless Small Cell
Public Infrastructure Re-engineering
5G Deployment

ABSTRACT

Exploring innovative cellular architectures to achieve enhanced system capacity and good coverage has become a critical issue towards realizing the next generation of wireless communications. In this context, this paper proposes a novel concept of Universal Intelligent Small Cell (UnISCell) for enabling the densification of the next generation of cellular networks. The proposed novel concept envisions an integrated platform of providing a strong linkage between different stakeholders such as street lighting networks, landline telephone networks and future wireless networks, and is universal in nature being independent of the operating frequency bands and traffic types. The main motivating factors for the proposed small cell concept are the need of public infrastructure re-engineering, and the recent advances in several enabling technologies. First, we highlight the main concepts of the proposed UnISCell platform. Subsequently, we present two deployment scenarios for the proposed UnISCell concept considering infrastructure sharing and service sharing as important aspects. We then describe the key future technologies for enabling the proposed UnISCell concept and present a use case example with the help of numerical results. Finally, we conclude this article by providing some interesting future recommendations.

1. Introduction

Cellular technology has evolved from the first generation (1G) to the fourth generation (4G) to keep up with the ever-increasing demand for high-rate information flow in the recent globalization era. However, the current 4G technology cannot meet the data rate demands due to the exponentially increasing number of bandwidth-hungry devices and the scarcity of the available spectrum. Furthermore, the issues of providing broadband access to the remote areas for bridging the digital divide and the integration of different legacy networks in a unified platform still remain unsolved. In this context, the current research trend is towards the conceptualization of the fifth generation (5G) of cellular technology [2–4].

The most important concept applied in the cellular networks is the frequency reuse that enhances spectrum utilization. There has been a significant progress in cellular wireless systems over the past two decades [2]. The earliest commercial cellular system was analog communication system, i.e., 1G, based on Frequency Division Multiple Access (FDMA) technology. The remarkable transition from analog to digital technologies facilitated several advanced processing such as compression, encryption, receiver signal processing, and channel coding, which eventually made the concept of Time Division Multiple Access (TDMA) feasible in the second generation (2G) wireless systems. In parallel to the TDMA, Code Division Multiple Access (CDMA) based systems were developed and due to its superior performance over TDMA, all third generation (3G) cellular systems eventually adopted the CDMA technology [2].

Towards addressing interference mitigation and resource manage-

Peer review under responsibility of Chongqing University of Posts and Telecommunication.
☆ The partial contents of this paper were presented at IEEE International Conference on Communications (ICC), London, United Kingdom, June 2015 [1].
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http://dx.doi.org/10.1016/j.dcan.2016.09.003
Received 28 April 2016; Accepted 2 September 2016
Available online 17 October 2016

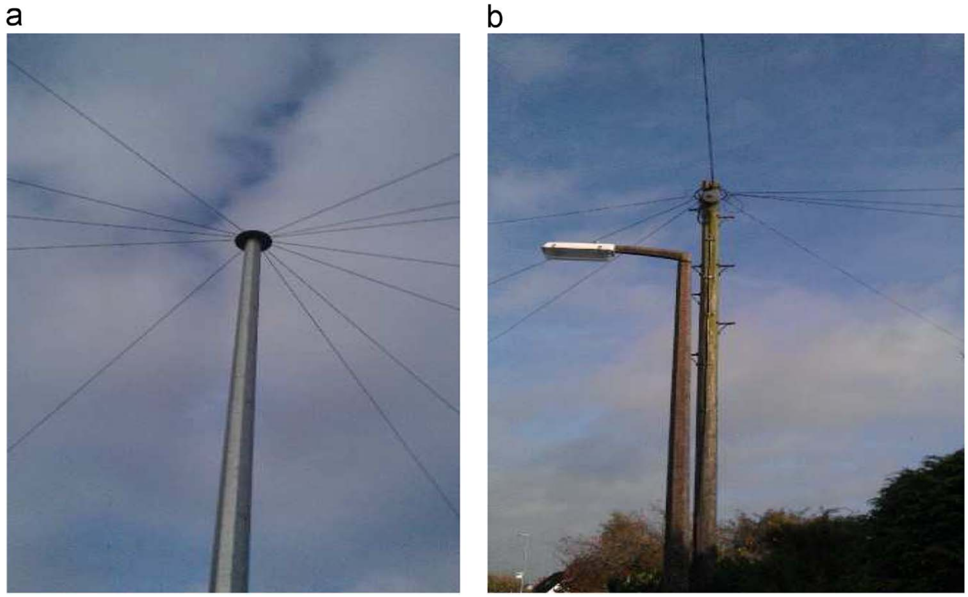

Fig. 1. (a) Existing landline end user connectivity (UK) and (b) Co-existence of both landline and streetlight infrastructure (UK).

ment issues in 3G wireless systems, Orthogonal Frequency Division Multiplexing (OFDM) caught the attention of many cellular researchers/operators/industries and was selected for 4G. Besides the simplicity of OFDM-based receiver compared to CDMA, OFDM provides the advantages of spatial diversity and spatial multiplexing in multiple antenna-based systems due to its intrinsic orthogonality. The current technology, i.e., 4G, also called LTE (Long Term Evolution), is now evolving towards LTE-Advanced with the inclusion of carrier aggregation and coordinated multipoint transmission techniques [2].

To further enhance current 4G technologies towards the next generation, i.e., fifth generation (5G), several researchers, industries, and cellular operators are recently making significant efforts [4–6]. The main industrial players, forums and projects active in 5G wireless research include Ericsson, Qualcomm, Huawei, Nokia Solution Networks, Samsung Electronics, Docomo 5G, 5GPP, METIS 2020 project, 5GNOW, 5GForum, 5G Training, etc. [6]. The main emerging requirements of 5G networks are high data rate, low latency, low energy consumption, and the support of a large number of heterogeneous devices. The key techniques to meet these requirements are ultra-high densification, bandwidth extension beyond 6 GHz, i.e., millimeter wave (mm-wave) and the increased spectral efficiency utilizing Massive Multiple Input Multiple Output (MIMO) techniques [3].

Besides several aforementioned aspects related to 5G wireless, we are also motivated by the immediate need of public infrastructure re-engineering. The existing public infrastructure is of diverse type and can be broadly categorized into (i) street lighting systems, (ii) Public Switched Telephone Network (PSTN), (iii) terrestrial cellular network, (iv) power line communications, and (v) satellite networks. One of the main aims of 5G networks should be how to efficiently utilize the current infrastructures in a cost efficient manner. To this end, the selection of the appropriate physical infrastructure of small cells is a crucial aspect to be considered in 5G networks, and hence is considered in this article. The main contributions of this article are summarized below.

1. We propose a novel concept of Universal Intelligent Small Cell (UnISCell) as an important candidate for the unified 5G wireless platform. The main drivers for the proposed UnISCell platform are savings in infrastructure Capital Expenditure for wireless network operators, availability of the power supply connectivity, and higher revenue generation for the local government authorities.
2. We propose two deployment scenarios for the proposed UnISCell platform considering infrastructure sharing and service sharing as important aspects.
3. We present a use case study considering spectrum sensing intelligence capability of a small cell in the UnISCell platform.
4. We briefly describe the key technology enablers for the proposed UnISCell platform and provide some recommendations for future research.

The remainder of this paper is organized as follows: Section 2 provides motivation and the main aspects of the proposed UnISCell platform. Section 3 proposes two deployment scenarios while Section 4 discusses several emerging techniques for enabling the realization of the proposed universal platform. Subsequently, Section 5 evaluates the performance of one of the proposed deployment scenarios considering a use case. Section 6 recommends some future research topics and Section 7 concludes the paper.

2. Universal Intelligent Small Cell (UnISCell)

2.1. Motivation

The main motivational aspects behind the proposed UnISCell concept are public infrastructure re-engineering and the recent advances in wireless technologies as described below.

2.1.1. Public infrastructure re-engineering

For many years now, there exist a significant number of outdated street lamps in many countries around the world and they need replacement in the near future. For example, in the UK, there are around 7.4 million street lamps, of which 2.32 million are over 30 years old and 1.17 million are over 40 years old, with the need of immediate replacement in the near future [7]. Fig. 1(a) depicts the existing landline end user connectivity in UK while Fig. 1(b) presents the coexistence scenario of both landline and streetlight infrastructures. Besides, the traditional lighting systems are very inefficient in terms of cost and energy consumption and due to advances in solid state light technology, it has been possible to control several properties of the light such as spectral, temporal, spatial polarization and color as compared to the traditional light sources [8].

Furthermore, it is possible to send commands to luminary poles using power line communications [8] in contrast to the radio frequency communication protocol used in the conventional lighting systems [9]. Such an intelligent lighting system may utilize solar energy and widen energy in order to reduce the energy consumption demands. Besides the intelligent control of the light, future intelligent control lighting systems can be considered to be equipped with various sensors and street poles can provide different information such as weather information (temperature and humidity), and road status (traffic intensity, maintenance operations and road barriers).

In addition to the aforementioned advantages, lighting systems can be merged with other communication systems to have an integrated platform for providing various services at the user end. For example, street lighting infrastructure can act as a common infrastructure for small cells while considering each street luminary post as a small cell Base Station (BS) for the coverage underneath it. The distance between two luminary street poles can be designed in order to fit the cellular traffic as well as to guarantee sufficient illumination in the street between them. Furthermore, another aspect is to incorporate terrestrial PSTN in this integrated platform.

Instead of having a separate platform for the terrestrial PSTN, a luminary pole can also act as a distribution point for providing telephone lines to user premises. Nowadays, a significant amount of traditional PSTN business is increasingly being replaced by mobile industries. However, due to the job security as well as the reliability of landline telephony as compared to the mobile telephony in many developing parts of the world, it is expected that this business will continue to exist in the future. In this context, future terrestrial fixed telephone systems should be integrated with the wireless infrastructure, leading to a common network platform for both wired and wireless services. One possible future solution would be to replace the wired end user connections in Fig. 1(a) with the dedicated wireless beams to the end users using Space Division Multiple Access (SDMA).

2.1.2. Advances in wireless technologies

Another main motivation behind the UnISCell concept is the recent advances in various wireless technologies, leading to its practical feasibility. The 5G technology is targeting towards the realization of various technologies which enable higher capacity, wider coverage and high-quality user experience. Furthermore, several spectrum awareness technologies such as spectrum sensing, and signal-to-noise ratio can be utilized in order to make the small cell aware of the surrounding radio environment [10,11]. Subsequently, small cells can exploit this awareness in order to utilize the available radio resources effectively. Besides, due to current developments in antenna technologies and Digital Signal Processing (DSP), it has been feasible to put many antennas (on the order of hundreds) on a single BS, hence bringing the concept of Massive MIMO closer to reality.

The SDMA technology has been considered as one of the promising solutions in order to enhance the cellular capacity in urban environments. The latest innovations in array processing techniques and DSP techniques have made the concept of SDMA feasible in future wireless networks. In addition to current methods for enhancing the cellular capacity such as frequency reuse, cell sectorization/sectoring, SDMA allows denser frequency reuse over the geographical space dimension effectively. Additionally, three dimensional (3D) beamforming exploits the elevation dimension to enhance the cellular capacity and coverage in contrast to the currently used azimuth only dimension [12,13]. With these various technologies and signal processing techniques at hand, the time has come to start looking at the integration of various technologies in order to realize the proposed UnISCell concept.

2.2. Main aspects

Future wireless networks should not rely on the operating frequency band and the traffic. The proposed platform is universal in nature and facilitates the multi-tenancy of the public infrastructure. This platform further leads to a new set of micro-contractual business at the second tier in collaboration with network operators. The integrated infrastructure requires to be powered either locally or centrally, and the existing street lighting network, owned by the local government, is already connected to the national grid. In this regard, local government authorities will handle the deployment of the integrated infrastructures, and then they can lease these infrastructures to the network operators. More importantly, from the business perspective, the proposed platform provides the following advantages: (i) local government authorities will be able to generate much higher revenue, and (ii) network operators will be able to save their capital expenditure by renting these public infrastructures.

The existence of such an integrated platform will encourage the second tier of future wireless network operators, by enabling businesses to develop with the minimum capital expenditure. In the near future, there will be several other stakeholders of this network with the interests in smart vehicle, smart-grid and Tele-health services. This will further stimulate more Information and Communication Technology (ICT) related Small-to-Medium Enterprises (SMEs). As an example, the distributed power requirements could be an opportunity for SMEs in the area of commercially viable renewable energy based micro-grid power generation and distribution.

One of the main features of the UnISCell is its hardware and software capability to implement dynamic SDMA schemes with global spectrum handling. As highlighted in Section 2.1.1, there occurs the frequent co-existence of both land-line telephone and street light infrastructures in the UK, and in many other countries. Implementing the proposed UnISCell platform in the aforementioned coexistence while facilitating the sharing of the existing infrastructure is an important research challenge.

The proposed platform would further facilitate the possible business sustainability of the distributed micro/pico scale energy generation/supply from renewable energy sources to the cellular network infrastructures as well as the street lights, thus leading the cellular network and street lighting network to be “greener”. Subsequently, such a platform will create an intermediate layer of telecom network operators (small cell operator, possibly on a contractual basis with a single or multiple cellular network operators or internet service provider) and small scale renewable fuel based energy generating firms.

Our vision on UnISCell is to have a universal platform of small cells which are capable of providing wireless access from street luminary posts and are capable of integrating with the infrastructures for electricity and the fixed telephone service. Furthermore, it can be integrated with other infrastructures such as bus stops, and e-car charging stations where the power is already available. In this way, a broad vision of integration towards 5G systems can be realized. From the management viewpoint, future wireless networks are considered to be two tier networks with separate link budgets in each tier. Furthermore, there should be the involvement of a third party which can lease the capacity of the integrated infrastructure to the operators based on their demands.

The multi-tier network in the proposed universal platform would also benefit from the service sharing function. Different networks in the tier may have unique capabilities in terms of serving the traffic demands. In one network, there may be an overflow of the traffic at a certain time instant and another network resource may be idle at that time instant. In this context, service sharing mechanisms can result in the following advantages: (i) better spectrum utilization, (ii) reduction in the overall blocking probability, and (iii) significant improvement in the quality of experience. With the help of proper spectrum awareness functionalities at the network, service sharing can be realized using the following schemes: (i) unidirectional in which the traffic flows only in one direction depending on which network is less congested, (ii) bidirectional in which traffic flows in both directions, and (iii) hybrid in which both networks are saturated and new resources need to be

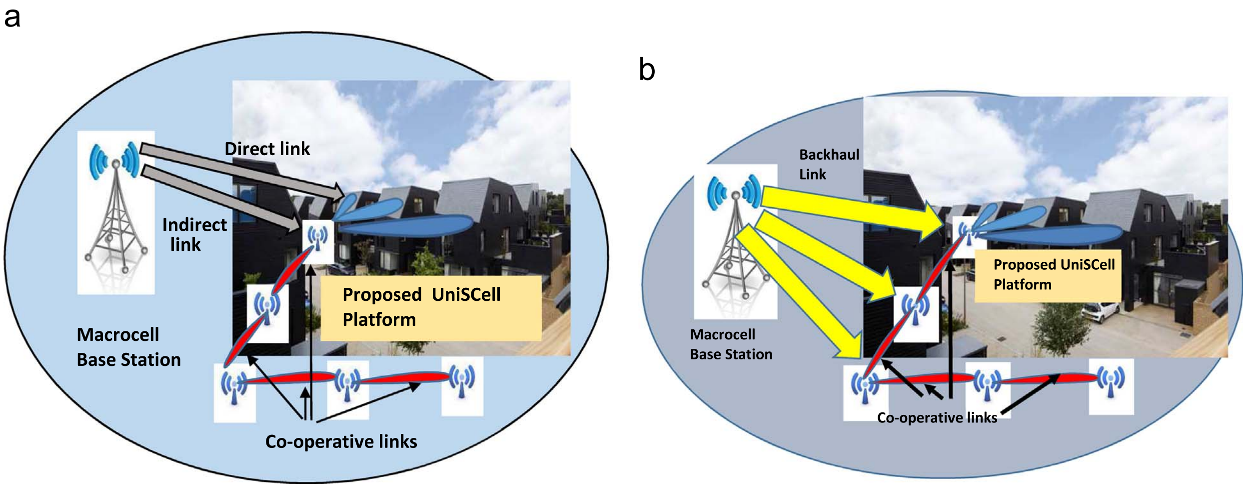

Fig. 2. (a) Deployment model for universal/fixed coverage assignment and (b) deployment model for on-demand/dynamic coverage assignment.

seeked in order to make the overflow traffic get through the network.

3. Proposed UnISCell deployment scenarios

In this section, we present two deployment scenarios for the proposed UnISCell platform as depicted in Fig. 2(a), defined as Scenario A, and Fig. 2(b), defined as Scenario B. These scenarios have different features as highlighted in Table 1 and are briefly described in the following subsections.

3.1. Scenario A

The scenario in Fig. 2(a) is useful for *universal/fixed coverage assignment* and considers an omnidirectional antenna at the macrocell BS, thus providing both direct and indirect links to the user terminals. In this scenario, UnISCell platform can be considered to be supplied with its own local power. Therefore, the macrocell BS does not need to transmit more power than in the conventional macrocell only scenario. For the practical deployment, the UnISCell platform is supposed to have the energy harvesting capability. On the one hand, the energy harvesting capability of the UnISCell helps to enhance the energy efficiency while on the other hand, the macrocell BS is equipped with an omnidirectional antenna and transmits signals in the conventional manner, which may result in the waste of the scarce power resource.

Another main advantage of this scenario is low outage probability. In the case of the failure of the UnISCell platform, the user service will not be disturbed due to the presence of a direct link between the macrocell BS and the User Terminal (UT). Furthermore, a high degree of spatial diversity can be achieved considering energy harvesting capability at the macrocell BS.

Table 1
Features of the proposed deployment scenarios.

Parameters	Scenario A (Fig. 2(a))	Scenario B (Fig. 2(b))
Coverage assignment	Universal/fixed	On-demand/dynamic
Macrocell BS antenna	Omnidirectional	Directional
Layers of smart beamforming	1	2
Spatial diversity	Relatively high	Relatively low
Application area	Rural/suburban	Urban
User partitioning reliability	Moderate	Relatively high
Energy efficiency	Moderate	Relatively high

3.2. Scenario B

The scenario in Fig. 2(b) is useful for *on-demand/dynamic coverage assignment* and consists of a directional BS and the signal to the user terminal is provided with the help of indirect link via UnISCell platform. This can be considered as a two tier network with the first tier being the backhaul network and the second tier being the access network. The main advantage of this scenario is that it may employ two layers of smart beamforming in order to provide higher throughput to the desired user/user group. As compared to Scenario A, a significant amount of BS transmitting power can be saved since the transmitting power is not wasted in unwanted directions due to beamforming implementation at the macrocell BS.

One of the main requirements of 5G networks is to be able to serve more users in a densed location. This scenario can be considered as a promising solution in order to enhance the data rate in densely populated urban areas. Furthermore, the application of SDMA in this scenario becomes more efficient as compared to the first scenario due to the possibility of having two layers of smart beamforming, and hence a more reliable SDMA can be implemented. Moreover, user partitioning becomes more reliable in Scenario B than in Scenario A.

4. Potential future technologies for enabling the proposed UnISCell

In this section, we briefly discuss the potential enabling technologies for the proposed UnISCell concept.

4.1. Spectrum awareness intelligence

Cognitive Radio (CR) technology has received more attention towards addressing the problem of spectrum scarcity [14,10]. Recent technical developments such as Software Defined Radio (SDR), wideband transceivers, and DSP techniques have made it possible to employ intelligent transceivers, hence leading to the possibility of utilizing the available spectrum in a very dynamic and adaptive manner. Furthermore, there has been a significant progress in terms of spectrum awareness techniques such as spectrum sensing, and Signal to Noise Ratio (SNR) estimation and their practical realizations in the context of CR networks [14–16]. Similar to the CR approach considered in the literature, our proposition is to employ the spectrum awareness intelligence at the small cell BSs in order to have better interference management.

The proposed UnISCell platform is considered to be intelligent enough regardless of frequency bands and traffic types. For example, an Amplify and Forward (AF) repeater is less complex from implementation perspectives and provides several advantages for future 5G communications but its main drawback is that it amplifies interference as well as noise in unnecessary bands. In this context, we propose to have this intelligence at the small cell so that only active channels will get amplified and a significant capacity improvement can be achieved. This has been demonstrated with the help of analysis and numerical results in Section 5 as an example.

4.2. Source localization and 3D beamforming

In many spectral coexistence scenarios, the interference occurs between two coexisting links and the application of blind source separation techniques can be considered as an important future topic for interference management. Active source/transmitter localization is an important aspect for implementing adaptive beamforming and resource allocation schemes. The effective localization of the active sources helps to enhance the energy efficiency of the networks by concentrating energy only in certain localized areas of the network. Ranging and localization are two main phases for source localization. The ranging phase basically determines the distance among sensor nodes and the most common techniques used for ranging are angle of arrival, time difference of arrival, received signal strength indication and hop count [17]. After ranging, the function of the positioning phase is to determine the absolute or relative coordinates of sensor nodes. The most commonly methods used for positioning are minimum–maximum algorithm, lateration, ring overlapping algorithm, convex optimization, multi-dimensional scaling, global position system, lighthouse location system, ad hoc positioning, and self-positioning mechanism [17]. In the proposed deployment scenarios specified in Section 3, the localization of the desired user/user group significantly helps the UnISCell platform to employ adaptive 3D beamforming approach which is briefly described in the following [12,18].

Most of the existing beamforming schemes employed in wireless cellular networks control the radiation pattern in the horizontal plane. The main drawback of this conventional beamforming approach is that it does not consider the elevation dimension in designing the beamformer and hence the beampattern is not adapted in the elevation plane. In this regard, the concept of 3D beamforming has recently received important attention in the recent wireless literature [12,18]. The recent technological advancements in adaptive and flexible antenna structures/technologies have led to the possibility of designing a fully dynamic antenna pattern which can be specified as per resource block and as per user equipment, thus making 3D beamforming practically feasible [18]. In contrast to 2D beamforming, 3D beamforming approach controls the radiation beam pattern in both elevation and azimuth planes, thus providing additional degrees of freedom in the elevation plane while designing a wireless system. This significantly helps to boost the capacity of future wireless networks in comparison to the current networks.

4.3. Massive MIMO

MIMO technology provides a significant capacity benefit in wireless systems by exploiting the reuse of the spatial dimension [19]. The concept of multi-user MIMO relies on the concept that multiplexing streams for different users on different antennas can achieve large gains promised by multiple antennas, even if each device only has a few antennas. Multi-user MIMO provides several advantages such as cheap single-antenna terminals, no requirement of scattering environment, and simple resource allocation mechanism. In order to further enhance the capacity gains of MIMO wireless systems, the concept of Massive MIMO, also known as very large MIMO, hyper MIMO, full-dimension MIMO, is being widely investigated in the literature [20,21]. This technology uses a large number of service antennas over active terminals and is considered as a promising candidate for the next generation wireless networks. The main benefits of this technology are [21]: (i) system throughput improvement, (ii) higher energy efficiency, (iii) reduced latency, (iv) simplification of MAC layer, and (v) robustness against jamming. In the proposed UnISCell framework, the macro base station is considered to be equipped with massive number of antennas which will be capable of generating very directive beams towards small cells or users/user groups.

4.4. Multicell coordination

The mitigation of intercell interference is an important challenge to be addressed in order to allow the aggressive reuse of frequencies in the considered heterogeneous deployment scenarios. One of the promising approaches to address this problem is the use of coordinated transmission strategies and resource allocation schemes across multiple BSs. In the proposed UnISCell platform, this coordination can be made with the help of coordinated links between the UnISCell BSs as shown in Fig. 2. The coordination among different base stations can be in the form of data signals, transmission strategies and resource allocation strategies. In contrast to the signal-level coordination, the coordination of transmission strategies requires much less overhead in terms of the backhaul capacity. Furthermore, by employing the user scheduling, power allocation, and beamforming strategies of multiple BSs and multiple User Terminals (UTs), intercell interference can be mitigated, hence enhancing the overall performance of the network. Furthermore, in the context of multicell scenarios, the use of scheduling, beamforming and power allocation for intercell interference mitigation has been already considered in LTE-advanced standardization activities [22].

4.5. Millimeter wave communication

Another promising way of solving spectrum scarcity problem in future wireless systems is to enable mobile communications using millimeter wave (mm-wave) frequencies. With the help of extensive propagation measurement campaigns at 28 GHz and 38 GHz bands, authors in [23] have shown that these frequencies can be used for wireless communications when employing steerable directional antennas at the base stations and mobile devices. Although mm-wave technologies have been already standardized for short-range services in IEEE 802.11ad, the exploration of these technologies for cellular communications is still in its infancy [24]. There occur several issues such as propagation loss, blockage, rain fading, and low efficiency of radio frequency components towards the realization of mm-wave technologies. However, recent advances in CMOS technology, very high gain and steerable antenna arrays, adaptive beamforming techniques have strengthened the realizability of mm-wave wireless communications.

Millimeter wave communication technologies mainly provide the following advantages [23]: (i) increased data rate due to the extension of channel bandwidths significantly far beyond the present 20 MHz channels, (ii) decreased latency for digital traffic, thus supporting much faster internet-based access and applications with minimal latency, and (iii) relatively closer spectral allocations, resulting in more comparable and homogeneous propagation characteristics for different mm-wave bands. Besides the aforementioned advantages, the combination of mm-wave communication with the Massive MIMO technology allows to create very sharp beams from one base station to multiple small cell base stations in the considered UnISCell platform.

4.6. New multiplexing and modulation schemes

In addition to commonly used time, and frequency division multiplexing/multiple access schemes, several emerging multiple access schemes such as SDMA, orbital angular momentum multiplexing, polarization division multiple access, interweave division multiple access, and sparse code multiple access are being investigated in the literature [25]. SDMA technology has been considered as an important candidate for future networks and it provides the possibility to serve multiple users simultaneously in the same channel, and thus allows to increase the system capacity [26]. Besides its multiple access capability, it also allows channel reuse within a particular cell, i.e., reduction in the reuse factor resulting in significant increase in the spectral efficiency.

Recently, orbital angular momentum multiplexing has been shown as an important candidate for high capacity mm-wave communications. It has been demonstrated that this multiplexing scheme can enhance the system capacity as well as the spectral efficiency of mm-wave links by transmitting multiple coaxial data streams with a single aperture transmit/receive pair [27]. Moreover, the concepts of polarization division multiplexing and phase division multiplexing widely used in the optical communications can be regarded as other promising approaches in order to enhance the multiplexing gain of 5G wireless systems. Furthermore, there is an emerging concept of polarization modulation technique for carrying information bearing signals [28]. This approach uses circular polarization of the propagating electromagnetic carrier as a modulation attribute in contrast to the conventional approaches of using amplitude, frequency and/or phase as modulation characteristics and this has the capability of providing inherent benefits of circular polarization as well as diversity gain in wireless fading channels.

In summary, the proposed UnISCell concept envisions the implementation of the deployment scenarios presented in Section 3 using a Massive antenna system, very possibly at millimeter wave frequencies, equipped with 3D beamforming and source localization capabilities. Furthermore, multicell coordination, spectrum awareness as well as new multiplexing and modulation schemes can be considered as the important enablers of the proposed concept.

5. System level evaluation

In this section, we carry out a system level evaluation considering a use case under the framework of Scenario A[1] proposed in Section 3 based on [1]. For this evaluation, we consider a small cell to act as an AF repeater with spectrum sensing intelligence. In contrast to the traditional AF repeaters which amplify the entire downlink/uplink system bandwidth, the proposed small cells amplify only the active channels at a certain time.

The conventional belief about the amplifying and forward repeaters is that they are responsible for amplifying the unnecessary frequency bands, hence injecting additional interference to the received signal. In order to address this issue, our proposition here is to employ an intelligent small cell which is capable of performing dynamic spectrum sensing. The employed spectrum sensing technique can vary from a simple energy detection to more complicated feature detection depending on the level of allowable complexity and the performance requirement [10]. For the sake of simplicity, we consider an energy detector in this study. By comparing the received energy levels with a predefined threshold, a simple energy detection based spectrum sensing technique can find the dynamic spectrum energy peaks (active channels) as well as regular non-zero energy occupancy within the spectrum of interest. Based on the knowledge of active channels, the proposed small cell performs the selective amplification of the channels instead of the whole assigned bandwidth. The fundamental assumptions considered in the realization of the proposed small cell are detailed in [1]. For the sake of completeness, we briefly highlight the main assumptions below.

1. The small cell is a passive network entity although being a part of the network.
2. The small cells are to be assigned with predefined coverage areas.
3. The small cells can sense active occupancy of the spectrum within the assigned spectrum within a predefined area of interest.
4. Moreover, at least three neighboring small cells can serve or negotiate the serving area (space) in a co-operative manner for implementing SDMA.
5. The proposed small cells are expected to be intelligent enough regardless of frequency bands and traffic types.

For this evaluation, we consider a frequency division multiple access-based dual-hop cellular network with a BS-repeater link and the repeater-user link with respect to Fig. 2(a). The cellular network is represented with hexagonal cells, each of radius R and the frequency reuse factor is τ. We assume that repeaters are placed at a certain distance from the BS to the cell border and N_R number of repeaters per cell are considered. In the considered set up, the desired signal is sent from the serving BS to the user and the interference signal comes from other cochannel BSs to the user. The received signal at the repeater is amplified along with the thermal noise and is forwarded to the user. Finally, the received signals at the UT are summed together as multipath signals.

Fig. 3(a) depicts the system throughput versus transmit power for two different values of repeater gain, i.e., $R_G = 80$ dB and $R_G = 100$ dB considering 20% active channels over the considered spectrum. From the figure, it can be noted that system throughput increases with the BS transmitting power for all the cases. Another important observation from the figure is that the system throughput with the proposed SS intelligence is higher than in the conventional case without SS intelligence (up to 13% improvement for $R_G = 100$ dB).

In order to analyze the effect of dynamic occupancy of the channels, we present the system throughput versus percentage of active channels in Fig. 3(b). The system throughput decreases with the increase in the percentage of active channels. This is due to the fact that as the number of active channels increases, the amplification bandwidth of the repeater increases, and hence increasing the overall noise power at the UT. Another observation is that the rate of decrease is higher for the lower percentage of active channels than for the higher percentage of active channels.

6. Future recommendations

In this section, we provide future recommendations for enabling the proposed UnISCell deployment scenarios.

- *Public infrastructure re-engineering*: How to implement the proposed UnISCell platform in the coexistence scenarios of different wired and wireless networks while facilitating the sharing of the existing infrastructure is an important research challenge to be considered. In this context, a suitable cost-effective business model should be investigated based on the public private partnership and private finance initiative.
- *Investigation and selection of key techniques*: As highlighted in Section 4, there are several promising techniques which help to enable the proposed UnISCell concept. Selection of the most promising techniques among them, considering spectral efficiency, energy efficiency and the complexity of implementation as the main concerns, is foreseen as an important future step.
- *Interference analysis and mitigation*: One of the main problems in the deployment scenarios presented in Section 3 is how to mitigate intrasystem and intersystem interference in the densed networks. In this context, interference analysis of the considered scenarios utilizing realistic channel models is another future task. Subsequently, suitable interference mitigation techniques are to be investigated.
- *Awareness mechanisms and adoption*: How to acquire the awareness intelligence, how to make reliable decision, and how to exploit the acquired intelligence in the proposed deployment scenarios are

[1] The evaluation of a use case under the framework of Scenario B is considered as our future work.

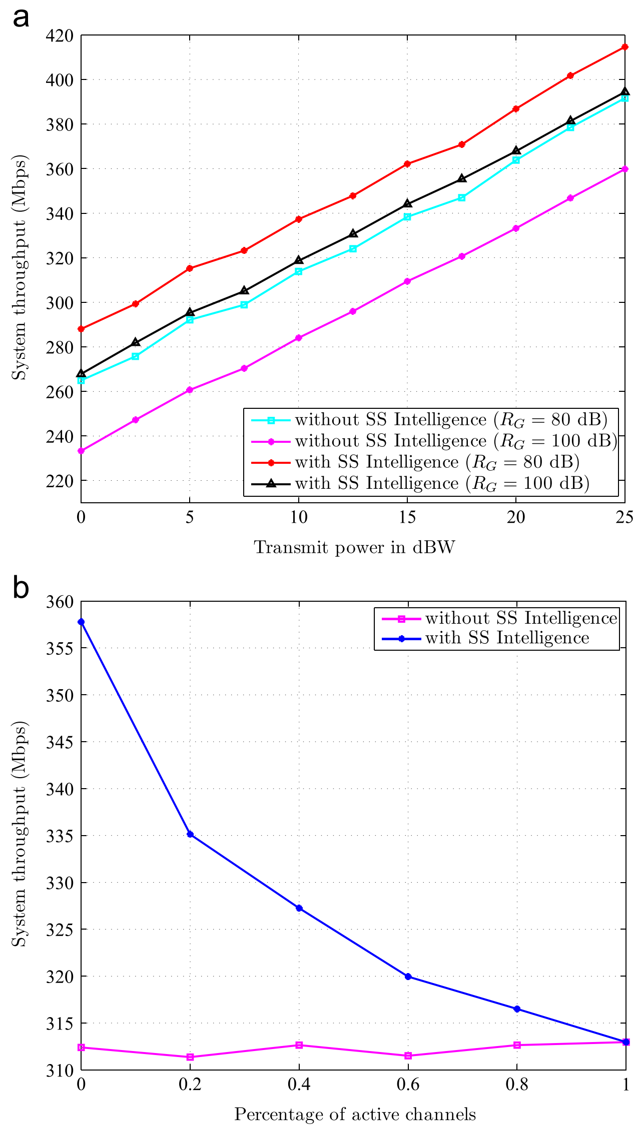

Fig. 3. (a) System throughput versus BS transmit power and (b) system throughput versus percentage of the active channels (BS transmit power $P_{t,BS}$ = 10 dBW, R_G = 100 dB).

interesting topics to be investigated in future research. Investigation of suitable signal processing techniques required for intelligence awareness and exploitation require further investigation. Several intelligence mechanisms which can be employed in the proposed intelligent small cell transceiver such as dynamic SDMA, adaptive source localization and tracking, cognitive resource allocation, smart antenna design, dynamic SS should be investigated in detail referring to the proposed deployment scenarios.

- *Cooperation and synchronization issues*: The assessment of backhaul link requirement for the cooperative communication among different small cells is another important future step. Furthermore, the issues of channel acquisition and synchronization require future investigation.
- *Optimum resource allocation and cost-efficient strategies*: A large number of emerging new smart devices, Internet of Things (IoT) and applications demand high power consumption, thus leading to the need of investigating renewable energy sources. The main applications of IoT are smart grid, smart vehicle, tele-healthcare and smart cities, and they all compete strongly for the available wireless resources such as power and bandwidth. Besides, since future wireless networks will use macro cells complemented with variable dimension micro or pico cells and relays, the network models for the future wireless generation will need significant capital expenditure in order to implement the required dense infrastructure. Therefore, there arises a strong need of investigating cost-efficient strategies to utilize the available resources optimally in the proposed UnISCell platform.

7. Conclusions

Motivated by the need of public infrastructure re-engineering and the recent advances in wireless technologies, this article has proposed a novel concept of UnISCell as an intelligent small cell architecture for future cellular networks. The proposed concept envisions an integrated infrastructure platform of the existing public infrastructures such as street lighting network, PSTN network and future wireless networks. The existence of such an infrastructure will foster the second-tier business for cellular network operators, the development of more ICT related SMEs and more stainable energy businesses, leading to a greener wireless network. In future work, several challenges and recommendations highlighted in this article will be investigated in detail in order to enable the proposed UnISCell concept.

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