Scenarios and Architectures for RRM and Optimization of Heterogenous Networks

Sofia C. Sousa and Fernando J. Velez
Instituto de Telecomunicações, DEM
Universidade da Beira Interior
6201-001 Covilhã, Portugal
sofia.sousa@lx.it.pt, fjv@ubi.pt

Kazi Huq, Shahid Mumtaz and Jonathan Rodriguez
Instituto de Telecomunicações, DETI
Universidade de Aveiro
3810-193, Aveiro, Portugal
kazi.saidul@av.it.pt, smumtaz@av.it.pt, jonathan@av.it.pt

***Abstract*—This work summarizes the state of the art information related to scenarios and architectures from Energy-efficient High-speed Cost Effective Cooperative Backhaul for LTE/LTE-A Small-cells (E-COOP) technologies. One of the proposed architectures exploits infrastructure based on small cell deployment using RRU technology which is connected to the core network using backhaul technology based on fibre optic links. In E-COOP, we go beyond this by addressing four key scenarios in terms of fronthaul deployment strategy (scenario 1) for C-RAN and carrier aggregation (scenario 2). The third scenario exploits the C-RAN architecture to firstly split the control/ data plane where the macro base station improves the signalling service for the whole area. Also, mobile small cells (SCs) are cooperatively specialized towards delivering data services for high-rate transmission with light overhead control and appropriate air interface (mmWave) – scenario 3. This raises significant research challenges in terms of mobile small cell coexistence, and mobility management. In scenario 4, we consider SON in LTE-A for HetNets with ultra-dense small cell deployment with imperfect backhaul. A Primary Network is considered that is overlaid with a cognitive network of Small Cell Networks, performing local sensing and local self-configuration and -optimization algorithms.**

Keywords*—*Backhaul/front haul; LTE; small cell; interference management; cooperative communication, carrier aggregation

I. INTRODUCTION

5G is foreseen as the convergence of internet services with mobile networking, leading to the term “Mobile Internet” over Heterogeneous Networks (HetNets). This applies to the context of personal adaptive, and global networks, expanding the availability of a true broadband connection beyond the home and the office. Small cells (SCs) are becoming a clear solution for an energy efficient high speed wireless internet connection. The goal of using low power nodes is to enhance coverage and throughput, increasing spectral efficiency by the spatial reuse of the spectrum. In this context, the E-COOP project [1] aims to research, design, implement and showcase a new networking topology that delivers ubiquitous small cell access to support future internet services based on exploiting potential disruptive technologies such as cooperative communications and self-organizing networks (SON). E-COOP will extend the notion of femto-like services to outdoor urban scenario. The changing dynamics of wireless networks adds an increased burden on network configuration, introducing the need for mobility management and self-configuration of network solution. The remainder of this paper is organized in four sections. Section II introduces a brief sate of art on interference management, SON and cognitive radio. Section III discusses the scenarios and architectures from ECOOP in detail. Finally, section IV discusses the conclusions.

II. STATE OF THE ART

Unplanned cell deployment of small cells, where mobile operators may or may not have any control over those SCs leads to inter-tier interference. This will require more efficient interference management (IM). In relation to densification, there are limits to increase densification of SCs since interference will be commensurated, and throughput improvements will begin to level off, i.e., further reductions in ISD (Inter Site Distance) providing diminishing returns, as reported in [2] for example. The study from [3] puts the limit (at maximum spectral efficiency) of densification using Long Term Evolution (LTE)-A technology at ISD=100m and at 100-150m for mmWave (e.g., 60 GHz) deployments, corresponding to 115 cells/km^2. Note however, that although there will be losses in spectrum efficiency (SE) at smaller ISDs (50m and below) due to excessive interference levels and levelling-off of SINR in very small cells, the area capacity (despite the losses) will be significantly higher compared to larger ISDs. Several approaches can be considered to limit interference [4].

Thus, interference avoidance at the access layer level will be investigated in the project as a first means to reach significant capacity improvement through ultra-dense networks. Due to the ad hoc nature of the small cell networks’ deployment it is difficult to manage them from a centralized controller. A distributed IM is then preferred to induce intelligence into the small cell AP, and to enable it to self-organize and cope with interference without any (or with limited) assistance by a centralized entity. To cope with the cross-tier interference, spectrum splitting was initially suggested [5]. However, due to the high cost and scarcity of the spectrum, this technique results in reduced efficiency. Power control is another key technique in interference avoidance. Its aim is to limit interference in neighbouring cells in dense deployments, as the efficient control of the small cell transmission power, results in sufficient protection of the outdoor macrocell User Equipments (UEs) [6], [7]. SON [8] is seen as one of the promising areas for an operator to save operational expenditures, by being able to minimize human intervention in networking processes. The main functionality of SON includes: self-configuration, self-optimization and self-healing. 3GPP has defined entities for SON architecture such as its relevant management reference models for the Evolved Universal Terrestrial Radio Access Network (E-UTRAN), including a network manager (NM), domain manager (DM), and network element (NE). The NM manages one or several DMs, while in a DM, one or several NEs are incorporated. SON networks are divided in centralized, distributed or Hybrid. To summarize, As defined in [9], what a SON should accomplish, a system is said to be self-organizing if it is scalable, stable and agile enough to maintain its desired objective(s) in the face of all potential dynamics in its operating environment. Mechanisms of self-organization, specifically the capability to self-adapt to environments and to self-learn, are seen as relevant in cognitive technologies. Local observations can be explored in a scenario where local information cannot be exchanged within cognitive radio networks [17]. A "Cognitive Radio" is a radio that is able to sense the spectral environment over a wide frequency band and exploit this information to opportunistically provide wireless links that best meet the user communications requirements [19]. The development of dynamic spectrum access techniques, allows the assignment of the underutilized spectrum resources. Here secondary users (SU) are allowed to use the temporarily unused licensed spectrum, without interfering the primary users (PU). When PU appears, immediately performs spectrum handover. Spectrum sensing can be performed in time, frequency and spatial domains. As defined in [22] a wealth of literature on spectrum sensing, focuses on primary transmitter detection based on the local measurements of secondary users. Spectrum opportunity (SO) [18] can be found in licensed spectrum with exclusive use or shared use and unlicensed spectrum. SO is defined by location, time, and frequency band as well as transmission power. When SO appears in licensed radio system, the concept of spectrum sharing is known as vertical spectrum sharing. If spectrum availability is on unlicensed radio system, spectrum sharing is known as horizontal spectrum sharing. Here cognitive users and unlicensed users share spectrum, may interfere with each other. This new source of interference may increase noise floor, which will make signal coverage degrade. In order to respond to this phenomenon FCC has present a new metric called the interference temperature (IT). This specification establish an IT limit. IT measured at a receiving antenna, defines the acceptable level of RF in the frequency band of interest. Indeed in a particular frequency band, when the interference temperature is above the limit, that band can be used by un-serviced user.

III. SCENARIOS AND ARCHITECTURES

In designing and planning small-cell deployments over Hetnets, mobile operators come across two significant problems [16]: i) How to transport traffic from the SCs at the edge to the core of a mobile network? ii) How to manage the radio access network (RAN)? specifically, interference and resource management. In this paper, we summarize four advanced scenarios from E-COOP project and discuss the architecture for scenario 2 and 4.

Scenario 1: C-RAN for Interference Management in Multi-tier Infrastructure Networks

Future emerging scenarios in small cell deployment are heading towards the notion of cloud radio. Cloud radio access networks (C-RAN) are a novel mobile technology that separates baseband processing units (BBUs) from radio front-ends such as remote radio units (RRU). In this technology BBUs of several base stations are positioned into a central entity where the radio front-ends of those BSs are deployed at the cell sites [10]-[12]. Therefore, this new framework unfolds a new paradigm for algorithms/ techniques that need centralized and co-operative processing. The general architecture of the C-RAN using fronthaul technology, consists of three main components, namely centralized BBU pool, RRUs with antennas, and Transport link, i.e., fronthaul network which connects the RRUs to the BBU pool. The RRUs transmit the RF signals to UEs in the downlink or forward the baseband signals from UEs to the BBU pool for further processing in the uplink. The BBU pool is composed of BBUs which operate as virtual base stations to process baseband signals and optimize the network resource allocation for a set of RRUs. The fronthaul links can be made upof different technologies, namely, the ideal fiber wired and nonideal wireless mmWave. Challenges in terms of IM fronthaul design, and mobility include coordinating scheduling between SCs and the macro-cell network; exploring the fronthaul design through energy efficient mmWave technology; characterizing energy efficiency in the centralization of the baseband processing; understanding the trade-off between having many SCs or fewer macrocells given their very different power consumptions and dealing with the interference of random deployment of small cells.

Scenario 2: Carrier Aggregation in LTE-A for HetNets with Ultra Dense Small Cell Deployment

Figure 1 shows the general architecture of the C-RAN. Usually, operators have spectrum allocations of less than 20 MHz contiguous spectrum (or multiple bands or non-contiguous spectrum blocks) and carrier aggregation (CA) delivers gains in spectrum usage. This scenario corresponds to a C-RAN architecture, as addressed in 3GPP scenario 4 [14]. Here the macro base station (PCell), operating in a low frequency (for example 800 MHz), will provide full coverage. Thus, it provides system information, control information and functions such as Radio Resource Control (RRC) signalling, connection maintenance and bandwidth limited data transmission. Meanwhile the small base station (SCell), operating in a higher frequency (e.g., 2.6 GHz), will provide local high data rate requirements. A UE CA-capable performs cell attachment on PCell, additional component carries (CC) as SCells can be configured via dedicated RRC, as well as any addition, reconfiguration or removal of SCells. Events that trigger SCell modifications have been defined in [8]. The research challenges include the investigation of the impact of inter-cell interference among SCs when multiple SCs are overlaid onto a sector of macrocells; the studying of optimal CC management, i.e., changing the parameter values of SCell addition/removal; evaluating cell-edge user throughput and fairness of the user throughput among UEs, as well as, evaluating different metrics of the threshold for adding/removing SCells, and overall system performance. CA is done at the MAC Layer, as shown in Figures 2 and 3. In this architecture each CC is treated independently. Transmission parameters such as adaptive modulation and coding scheme, MIMO or link adaptation are selected individually per CC, and HARQ retransmissions are performed independently. RRM and IM are implemented in a centralized way at the BBU pool which manages resource scheduling/interference coordination.

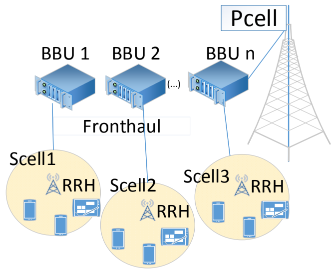

Fig. 1 - C- RAN architecture

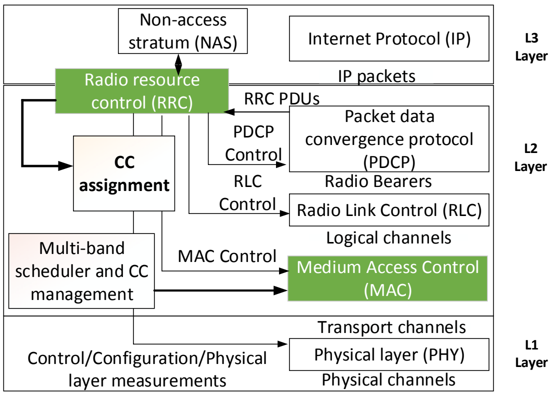

Fig. 2 –LTE Protocol Stack Layer with Multi-band scheduler and CC management performed at MAC Layer

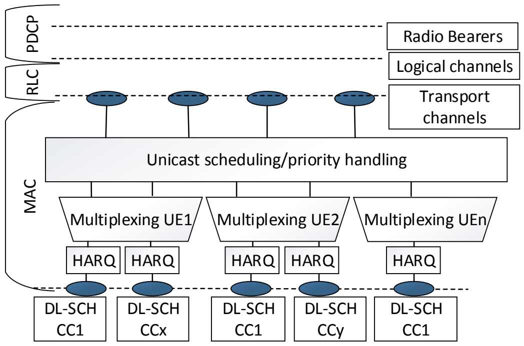

Fig. 3 –Layer 2 structure with downlink CA configuration [15]

Scenario 3: Mobile Small Cells for Ubiquitous High Speed Data Services on Demand

Scenario 3 is an evolution of scenario 1 and introduces the notion of mobile SCs, where the mobile handset adopts the role of the access point or remote radio unit. This new paradigm gives way to research challenges in terms of incentives for cooperation.

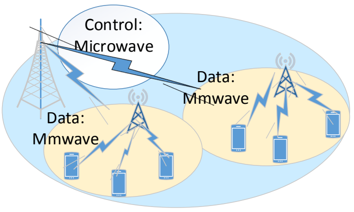

Fig. 4 - Device-centric scenario for on demand small-cells

The control/ data plane are split, does macro base station provides the signalling service for the whole area, and mobile SCs delivers data services for high-rate transmission with a light control overhead and appropriate air interface (mmWave could be the best option), as shown in Figure 4.

Scenario 4: SON in LTE-A for HetNets with Ultra Dense Small Cell Deployment with imperfect backhaul

In an environment where macro layer is overlaid with small cells networks with constrained backhaul, where the required data exchanged between eNBs is not feasible, one needs to consider stand-alone femtocells (HeNB) that have self-configuration, -optimization and -healing capabilities. In this work, as shown in Figure 5 a two tier network is considered. The macrocell layer is the primary network, as it has higher priorities or legacy rights for utilizing a specific part of the spectrum. The HeNB's network is considered the secondary network which will use opportunistic access of the spectrum. The two tiers do not interact, nor does the HeNB network between them. HeNB are installed in public places providing open access to Femto Users (FU). HeNB's receive spectrum information from FU and provide an efficient resource allocation of free parts of the spectrum, among FU. HeNB only use local sensing information, and do not have information about the neighbours. HeNB will decide which RBs are used as well as their power transmission. When a RB changes the state from unused to used, SU will have to change the operating frequency bands. Spectrum handover provides a robust algorithm.

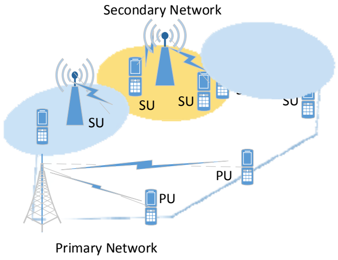

Fig. 5 – Cognitive network, where the Primary Network, the MeNB is overlaid with Small Cells, the Secondary Network.

The dynamic of cognitive network as shown in Figure 6 and 7 is modelled through game theory approach. HeNB are players or Decision makers, and have an Action Space, and local utility functions. Here, MAC layer performs the vital functions of spectrum mobility, channel sensing, resource allocation and spectrum sharing. MAC layer defines the how and when unlicensed users should sense the channels. Sensing may be performed in a reactive or proactive way. Optimizing the sensing periods is vital to reduce unexplored opportunities and sensing overhead.

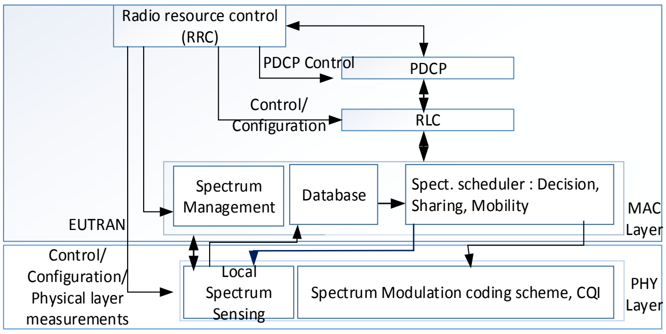

Fig. 6 – Framework of cognitive based spectrum sharing in HeNB (adapted from [20], [21]).

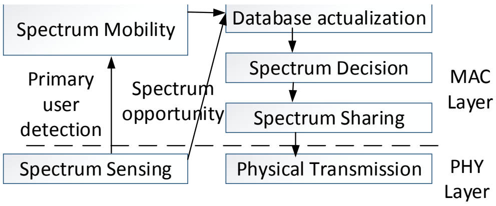

Fig. 7 – Cognitive radio and network iterations

IV. CONCLUSION

E-COOP goes beyond an architecture that exploits infrastructure based small cell deployment. C-RAN has the potential to reduce multi-tier interference and aims to harness all the baseband processing within a common unit. Therefore, the operator has complete control over network, besides alleviating interference-aware transceivers. This in fact, is part of the 3GPPP technology roadmap that still has several research challenges to solve in terms of fronthaul deployment strategy (scenario 1) and carrier aggregation (scenario 2). Scenario 3 exploits the C-RAN architecture to firstly split the control/ data plane. Here, macro base station provides the signalling service for the whole area, and the cooperative mobile SCs deliver data services for high-rate transmission with a light control overhead and appropriate air interface (mmWave). In order to enhance the capacity of small cell users, a SON with small cells, with sensing capabilities, in a non-cooperative environment provides fair scheduling for unused resource blocks through a reinforcement learning algorithm game. Future work includes proposing interference aware implementation of energy-efficient self-organized small cells, as well as RRM improvements through CA within C-RAN.

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REFERENCES

[1] http://ecoop.av.it.pt

[2] M. Abouelseoud and G. Charlton, “System Level Performance of Millimetre-wave Access Link for Outdoor Coverage", InterDigital, WCNC 2013.

[3] “Mobile Data Traffic: Analysis of Demand vs Capacity”, 5GIC internal report, 2014.

[4] T. Zahir, K. Arshad, A. Nakata, K. Moessner, “Interference Management in Femtocells”, *IEEE Communications Surveys & Tutorials*, vol.15, no.1, First Quarter 2013, pp.293,311.

[5] H. Su, L. Kuang, Lu, “Interference avoidance in OFDMA based femtocell network”, in *Proc. of IEEE Youth Conference on Information, Computing and Telecommunication*, September 2009, pp. 126–129.

[6] T. Zahir, K. Arshad, Y. Ko, K. Moessner, “A downlink power control scheme for interference avoidance in femtocells”, in *Proc. of 7th International wireless Communications and Mobile Computing Conference (IWCMC)*, July 2011, pp. 1222–1226.

[7] H.S. Jo, C. Mun, J. Moon, J.G. Yook, “Interference mitigation using uplink power control for two-tier femtocell networks”, *IEEE Transactions on Wireless Communications*, vol.8, no.10, pp.4906-4910, October 2009.

[8] 3GPP, “Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Self-configuring and self-optimizing network (SON) use cases and solutions” TR 36.902, V9.3.1, March, 2011

[9] O.G. Aliu, A. Imran, M.A. Imran, B. Evans, “A Survey of Self Organisation in Future Cellular Networks”, *IEEE Communications Surveys & Tutorials*, vol.15, no.1, pp.336,361, First Quarter 2013

[10] A.Checko, H.L.Christiansen, Yan Ying, L. Scolari, G.Kardaras,M.S. Berger,L.Dittmann, “Cloud RAN for Mobile Networks—A Technology Overview”, *IEEE Communications Surveys & Tutorials*, vol.17, no.1, pp.405,426, Firstquarter 2015

[11] Y.D. Beyene, R. Jantti, K. Ruttik, “Cloud-RAN Architecture for Indoor DAS”, *IEEE Access*, vol.2, no., pp.1205,1212, 2014

[12] Rui Wang; Honglin Hu; Xiumei Yang, “Potentials and Challenges of C-RAN Supporting Multi-RATs Toward 5G Mobile Networks”, *IEEE Access*, vol.2, no., pp.1187,1195, 2014

[13] Shen Zukang, A. Papasakellariou, J. Montojo, D. Gerstenberger, Xu Fangli, “Overview of 3GPP LTE-advanced carrier aggregation for 4G wireless communications”, *IEEE Communications Magazine*, vol.50, no.2, pp.122,130, February 2012

[14] 3GPP TS 36.331 Evolved Universial Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol Specification (Release 11), December 2012

[15] 3GPP TS 36.300, Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network Eutran Overall Description, Stage 2 (Release 1), December 2012.

[16] Nazmus SAQUIB, et al., “Interference management in OFDMA femtocell networks: Issues and approaches”, *IEEE Wireless Communications*, 2012, 19.3: 86-95.

[17] Xiaoyuan Liu; Yanling Zhang; Yang Li; Zhongshan Zhang; Keping Long, "A survey of cognitive radio technologies and their optimization approaches," *8th International ICST Conference on Communications and Networking in China (CHINACOM)*, 2013, pp.973,978, 14-16 Aug. 2013 doi: 10.1109/ChinaCom.2013.6694736

[18] M. Hamid, “Dynamic spectrum access in cognitive radio networks: aspects of mac layer sensing” Blekinge Institute of Technology, 2008.

[19] D. Cabric, S.M. Mishra, R.W. Brodersen, "Implementation issues in spectrum sensing for cognitive radios," *Conference Record of the Thirty-Eighth Asilomar Conference on Signals, Systems and Computers, 2004*, vol.1, pp.772,776, vol.1, 7-10 Nov. 2004

[20] Zhao Xinsheng, Guo Zhiyi; Guo Qiang, “A cognitive based spectrum sharing scheme for LTE advanced systems”, *2010 International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT)*, pp.965,969, 18-20 Oct. 2010

[21] G. Alnwaimi, S. Vahid, K. Moessner, “Dynamic Heterogeneous Learning Games for Opportunistic Access in LTE-Based Macro/Femtocell Deployments”, *IEEE Transactions on Wireless Communications*, vol.14, no.4, pp.2294,2308, April 2015

[22] Beibei Wang; Liu, K.J.R., “Advances in cognitive radio networks: A survey”, *IEEE Journal of Selected Topics in Signal Processing*, vol.5, no.1, pp.5,23, Feb. 2011 doi: 10.1109/JSTSP.2010.2093210