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Review

Interrelationship between energy efficiency and spectral efficiency in cognitive femtocell networks: A survey

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ABSTRACT

In this paper, initially the issues of spectrum allocation among macro (or "licensed") and Femto (or "unlicensed") users in an Orthogonal Frequency Division Multiple Access (OFDMA) based dual-layer femtocell networks have dealt with. This research contribution leads to basic coin in the design of next generation (5G) wireless networks. This manuscript exemplifies the trade-off issues of energy efficiency (EE) and spectral efficiency (SE) with both cooperative and non-cooperative architecture in cognitive femtocell networks. The pivotal concepts for each technology are described along with their potential impact on 5G and the research challenges that remain. Further, the trade-off between EE and SE is reposed with respect to the state of the art. The obtained insightful observations from the trade-off analysis of EE ans SE can lead to provide design guideline for 5G wireless Networks.

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1. Introduction

A forward movement of research will demand basic modifications in the design of fourth generation (4G) cellular architecture. Scarcity of spectrum resources is a significant challenging issue in present military, commercial and civil applications. Therefore, it is quite obvious that communication equipments will need more spectral resources [1]. By utilizing the cognitive radio (CR) technology, unused spectrum named as cognitive spectrum hole can be detected. Meanwhile, implantation of the femtocell, small power renovation, which comes up with better quality of service (QoS) in terms of coverage of the mobile user through Femto Access Point (FAP), gives QoS by maintaining better connectivity for the metrics like voice, data or video services to military personnel in hostile environment [2]. The action of using the resource of mobile data is exploited by video streaming, smartphones and tablets for all time high speed connectivity maintaining QoS that associated with capacity, end-to-end (E2E) latency and reliability. Besides, ultra-dense femtocell deployments and latest technologies such as massive multiple-input multiple-output (mMIMO), software defined networks (SDN) and network function virtualization (NFV) yield an impetus to reassess the basic prototype concepts towards 5G [3].

Wireless networks traffic needs promising QoS to provide defendable performance and experience levels for the edge users. For example, latency is a major QoS parameter in voice over LTE (VoLTE), Videotelephony and streaming-media applications in wireless communications. A review of cooperative network model working under QoS limitations is presented in [4]. In [5], authors probed the EE in accordance with QoS limitations by evaluating the SE in the small-power and wide band of frequencies practice along with the discussion of varying rate/varying power, and varying rate/constant power transmission techniques based on the knowledge of channel state information either at transmitter or receiver. In accordance with this condition, SE is stated as effectual capacity per-unit spectrum BW and likewise EE is also stated as energy absorbed per effectual capacity bit. Power absorption by the circuit and power loss during the transmission are assumed, respectively, in their energy model based on which they also formulate the quasi-convex generalized EE expressions [5]. To explore a tradeoff between EE and SE under QoS limitations, authors introduce a generic close-form estimation for EE–SE expressions by applying a curve fitting scheme. The conclusion draws from the investigation on impacts of QoS for EE–SE tradeoff is that QoS requirement infects the EE–SE tradeoff differently in low-SINR and high-SINR regime, respectively. The impact of QoS is found to be more in high-SINR regime and less in low-SINR regime [6].

This research work introduces cooperative [7,8] and non-cooperative architecture which consists of a small cell, large number of mobile terminals (MTs), multiple radio access technology, cognitive relay and virtual antenna array. The paper initially draws attention to trends in end-user activity, and devices developed from scientific knowledge to encourage the challenges of heterogeneous network that belong to the next generation [9,10]. The CR technology is an inventive software explicated radio technique contemplated to be one of the encouraging technologies to revamp the utilization of the spectrum scarcity [11,12]. In general, embracing CR is stimulated by the fact that a substantial part of the whole radio frequency (RF) spectrum is underused. In this system type, a secondary network can use a large portion of the spectrum with the licensed primary network, either on the basis of an interference-mitigation or on the basis of an acceptable interference level [13].

The cognitive technology should be familiar with the neighboring radio scenario and control its transmission correspondingly. In interference-mitigated system, secondary users (SUs) are permitted to utilize the spectrum only when the primary users (PUs) are not using it. The CR receiver observes, checks through spectrum sensing at the beginning and then allocate the underutilized bandwidth and provide this intelligence back to the CR transmitter. In interference-mitigated system, SUs can rake off the spectrum resource with a licensed spectrum while maintaining the interference below a given threshold. In contrast to interference-mitigated system, acceptable interference-level based system can get better spectrum efficiency by opportunistically using the spectrum resources jointly with PUs, at the same time we can achieve better SE and EE. The femtocell proposal is a novel concept, presently identified as a key technology in 5G [14–16].

1.1. Definition & types of femtocells

A Femtocell is a low power, small cellular base station. This can operate in both licensed and unlicensed band and it provides network service from 10 m to 100 m [17]. It can shift its position and an effectual change in its connection possible to the backbone which can be a part of a computer network that interlinks various pieces of networks. It allows a path for the exchange of information among the different subnetworks. Deployment of Femtocells can improve the heterogeneous networks (HetNets) in various ways [18]. First of all, femtocells can provide better SE of the total network. We notice that enhancing the number of PUs that communicate with the macro base station (MBS) via the Femto base station (FBS) results in an improvement of SE, and this is better in contrast to the case in which PUs communicate directly with the MBS [19]. Besides, it is possible to decrease the consumption of energy of a user located in the FBS network because of short distance communication and small signaling overhead. In this paper, 5G dual layer network architecture can be followed by addressing a few basic technology enablers, design selections and different challenging cases [20].

Femtocell makes various openings to meet the goal that regulators set out to obtain [21], such as:

- Revamped Access: Femtocells yield a price effective matters of enhancing consumer access to mobile services. They enhance coverage in a difficult to reach indoors without the large deployment of outdoor base stations (BSs) [22]. They provide broadband mobile services within existing spectrum [23]. In rural and remote areas, femtocells permit a user to access services that would otherwise be difficult for operators to deliver economically.

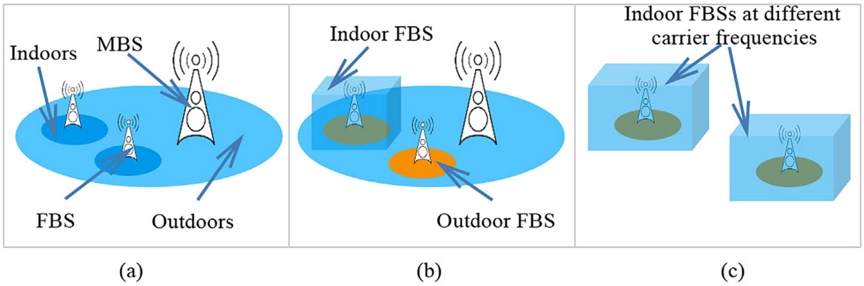

Fig. 1. Possible femtocell scenarios: macrocell (outdoors) and femtocell (indoors) at same carrier frequency (a), macrocell (outdoors) and femtocell (outdoors/indoors) at different carrier frequencies (b), femtocell (indoors) at different carrier frequencies (c).

- Spectrum efficiency: Femtocell can utilize available mobile operator spectrum or operation, taking both presently unutilized and already utilized spectrum by outdoor sites. They also open up the utilization of upper spectrums whose span might be unnecessarily restricted to large-area performance, expanding the comprehensive available frequencies [24].
- Renovations and openings: By decreasing the deployment and operating price of mobile broadband services, the femtocells can enhance the value of services for both consumers and service suppliers. Most importantly, they create a broadband link more fascinating to consumers by simply activating the utilization of an operator-compatible portable handset at home. They enhance the span of service frameworks accessible to operators, stimulate contest, and productivity [25,26].

If the femtocell and macrocell tiers utilize the same carrier frequency, the obtained down link (DL) power on femto user equipment (FUE) from the macrocell is considered as an interference. When there is no separation between the indoors and outdoors, they are strongly coupled and the inter-tier interference is at its maximum, particularly, if the buildings are situated near to the middle of the macrocell. In this matter including femtocells to the building (with the same carrier frequency) is like including cells to the middle of another cell (Fig. 1(a)). This is the worst-case scenario. For example, it is good practice to neglect installing femtocells with the same carrier frequency in positions where the DL power from outdoor macrocells is very large. Interference issues in the scenarios depicted in Fig. 1(b) can be reduced through different carrier frequency domain solutions such as fractional frequency reuse (FFR). Because the worst interference is from the user equipment (UE) positioned close to the cell edge that should transmit higher power, but because of the UL budget constraints, the users located at cell edge cannot utilize the entire bandwidth. As a result, it is becoming ease for the FFR algorithm [27] to limit the assigned UL bandwidth to the cell-edge users and adjust the neighbor cell-edge user's transmit frequencies to neglect UL interference; i.e, users located at macrocell cell-edge and femtocell cell-edge can utilize different carrier frequencies, respectively.

For large office buildings, only those femtocells and femto users (FUs) positioned close to the windows or outer walls (i.e., with small penetration losses) will suffer from large inter-tier interference. Those positioned deep inside the building will have too large separations, hence their transmit power will not create much interference to the outdoors. Besides, the transmit power from outdoors cannot reach them. These femtocells and FUs with large separation does not require to limit the resource allocations and can therefore have a large capacity [28,29]. Fig. 1(c) illustrates a scenario where interference among neighboring femtocells within the building is a major concern. Particularly, the randomness of femtocell locations in residential environments causes major interference concern among neighboring cells because some femtocells may be located too close to each other, as shown in Fig. 1(c).

The interference in wireless networks is one of the basic concerns which makes a difference to the performance of the networks. The operator targets is to enhance the capacity of the system model by exploiting the frequency BW among the FBSs even though every task of transmission performs under an allocated spectrum. Now, deployment of FBSs helps to improve the SE, although this leads to produce intra-tier and inter-tier interference issues respectively. Hence, the major challenge is to develop an efficient network model attenuating possible interferences. The possible scenarios responsible for producing interferences can figure out as: 1. MBS UE to FBS, 2. MBS to FBS user, 3. FBS user to MBS 4. FBS to MBS user, 5. Femtocell 'X' user to FBS 'Y', 6. FBS 'X' to Femtocell 'Y' user. The following first four types of links belong to inter-tier interference and rest two types of links belong to intra-tier. Although, these challenges may grow to another level in the above possible scenarios as unwanted interference signal may a problem in the environment of static and portable users. It is due to vehicular users are more exaggerated by path-loss exponent, building penetration loss, radio link failure and signal fluctuation factors. Besides, invoking vehicular network coverage to provide service to the vehicular users may enhance the intra-tier interference concern between the macro users and the vehicular users. The discussed concerns are the paramount metric, particularly in the vehicular environment, to enhance the vehicular users' SE and throughput.

The UEs located in this scenario with poor SINR need extra help from interference mitigation techniques like inter-cell interference coordination (ICIC) or enhanced inter-cell interference coordination (eICIC). In this regard, high capacity

Table 1
A general comparison of Femtocell, Picocell and Wi-Fi for various parameters [30].

Parameter	Femtocell	Picocell	Wi-Fi
Site rental	Customer	Operator	Customer
Installation	Customer	Operator	Customer
Electricity bill	Locally organized	Prior and global	No
Radio planning	Customer	Dedicated	Customer
Backhaul connection	Customer	Dedicated	Customer
Macrocell interaction	No interaction	Yes	Not applicable
Transmission power	< 23 dBm	$23 - -30$ dBm	20 dBm
Access rights	Restricted	Public	Restricted
Handover	Possible	Yes	Vertical

Table 2
Femtocell design challenges [31].

Parameter	Benefits
Lower device price	Efficient, less-price power amplifiers, Largely delicate receivers, dynamic channel spectrum, authenticate radio frequency filters; less price and less power implementation; etc
Network interference management	Minimization of interference from FBS to MBS (and vice versa); minimization of interference from adjacent FBS.
Femtocell capacity optimization	Connections and access policies (hand off, admission control strategy, utilization of resource, traffic and data control), flexible bandwidth allocation and sharing, etc.
Backhaul bottleneck	Wired or wireless backhaul, reducing signaling burden, prioritization policy based on quality of experience provisioning and traffic, joint access and backhaul design; etc
Variable system architecture	Control & data planes, access policy, the action of verifying the identity of a user, local breakout, methodical forwarding, smooth and continuous mobility etc.

indoor wireless solutions are compared as in Table 1. The Fujitsu small cell product has a potential property known as LTE/Wi-Fi Switching mode. This property is applied to mitigate the cross-tier interference in a co-channel HetNet deployment. If interference from the macro-tier is very large then the network coverage of femtocells reduce dramatically, in such situation the femtocell will control femtocell users to move to Wi-Fi. Furthermore, Femtocell design challenges for various performance metrics and their benefits are discussed in Table 2.

1.2. Network features in femtocell based 5G system

The following points are the network features:

- Role of Self Organizing Network (SON)
- Cell Identity Management
- Mobility Management
- Power Saving features

The essential discussion on advantages and disadvantages have been addressed for different types of network features as an overall description of the 5G systems in Table 3. Femtocell devices need to be plug and play with self-configuration abilities. Another substantial issue is to provide seamless mobility within the semi-planned network to stop any service interruption or deterioration in user experience. Adjacent findings and rapid handover reductions are substantial to optimize handover efficiency and decrease signaling load. Besides, an adjustment in transmitting power of femtocells is required to perform better capacity offloading whilst reducing pilot pollution (i.e., areas with large interference) over the heavily deployed femtocells. Moreover, to optimize network capacity and user experience, radio resource management (RRM) techniques (e.g., interference co-ordination and load balancing) take substantial role. Transmit power and RRM techniques take backhaul restrictions into account due to the fact that femtocell backhaul can be shared by other devices. In this subsection, quite a few SON techniques have been discussed to address the above mentioned issues [32–35].

Mobility management has to be an effective parameter for the viability of dense femtocell to achieve the massive capacity target. Fig. 2 illustrates the entire different possible transitions that a mobile has to travel across a femtocell network in both idle mode mobility and connected mode mobility. The connected mode femtocell can be macrocell to femtocell, femtocell to femtocell, and femtocell to macrocell. Fig. 2 shows different mobility management constraints specific to femtocell deployment. For femtocell to femtocell and femtocell to macrocell mobility, the discovery is not an issue as it can happen automatically due to channel deterioration of the serving cell (considering in the latter case that the macrocell ID would have been supplied by the network management on femtocell). For macrocell to femtocell mobility, a mobile device requires a track down femtocells whilst it is on the overlay macrocell network, even in favorable channel conditions. This constraint can be resolved in various ways. One of the approaches is to configure a larger threshold on the

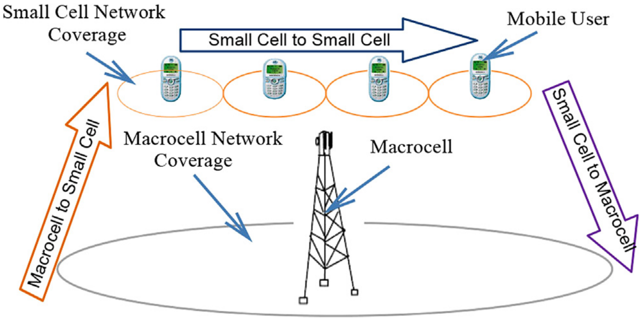

Fig. 2. Mobility management scenario of an adjacent femtocell network.

Table 3
Benefits and shortcomings of different network features in femtocell based 5G system [36].

	Benefits	Shortcomings
SON	SON features addressing this challenge, especially in the areas of interference, mobility, and resource management that provides a powerful solution for meeting the exploding data demand.	As the femtocell backhaul may be shared by other devices, transmit power and radio resource management methods to take into account backhaul constraints with difficulties.
Cell identity management	To avoid physical cell identity (PCI) collision/confusion, a small cell can use a UE like receiver/sniffer, a.k.a. a Network Listening Module (NLM) to detect physical layer identifiers of the neighboring cells and hence, avoid selecting the ones that are already being used in its neighborhood.	Since cell identity of each cell is unique, two neighboring cells with different cell identities, but same PCI can indicate collision/confusion.
Mobility management	Effective mobility management is important for the viability of the dense femtocell approach to reach the massive capacity goal.	The mobility management issue fundamentally boils down to ensuring all mobiles, including legacy, are supported in idle and connected nodes in the femtocell network.
Power saving features	With the increase in the number of femtocells, power consumption increases. One viable way out to save the power is to opportunistically scale down the number of femtocells depending upon the network load. The 5G network design should consider viable solutions to permit opportunistic support of femtocells to limit the power consumption	This brings up a number of constraints taking user's discovery, idle camping, interference burstiness due to cells suddenly appearing/disappearing, and others.

femtocells. This ensures that the UE searches the femtocell frequency even under quality macro signal. The downside of this approach is the least impact on the handset's battery life as the handset requires to perform a search in every instant as it wakes up regardless of the quality macrocell signal. An alternative method for prioritizing the femtocell frequency in case of committed carrier deployment for the approaches is to configure a larger threshold on the femtocells. This can make sure that the UE searches the femtocell frequency even under quality macro signal.

The downside of this approach is the little impact on the handset's battery life as the handset requires to perform a search in every instant as it wakes up, regardless of the quality of the macrocell signal. An alternative method for prioritizing the femtocell frequency in case of committed carrier deployment for the femtocell layer. An autonomous search of mobile device on the femtocell spectrum is another approach for validating femtocell discovery. By modifying the periodicity of these probes, a trade-off between discovery time and battery life of the handset can be obtained. The utilization of cell reselection beacons to validate discovery can be considered as an alternative approach. In this method, the considered femtocell transmits narrow beacon bursts on the macrocell channels to decrease the macro signal quality for the time being and activate a search whilst the device is closed to the femtocell. Appropriate beacon design can make sure rapid discovery whilst lessen impact on adjacent voice/data users. In this connection, the key factors that drive the 5G wireless technology are summarized as in Table 4, where "H" , "M", and "L" represent high, moderate, and low, respectively.

1.3. Spectrum extension for 5G using femtocell architecture

Femtocell access nodes, with low transmit power and no specific planning needs, are formed to be densely deployed, leading to HetNets. This method yields better SE by decreasing the gap between transmitters and receivers. In order to provide better macrocell network service by offloading wireless traffic, thus extricating radio resources in the access. Femtocell densification is an approach to enhance the capacity and data rate towards 2020. HetNets is a step further towards low cost, plug and play, self-configuring and self-optimizing HetNets.

Table 4
Native support specifications for different types of communications [37,38].

	Latency 1 ms	Mobility 500 km/h	Peak data rate 20 Gb/s	User-experienced data rate 100 Mb/s	Area traffic capacity 1 Mb/s/m^2	Spectrum efficiency 3xIMT advanced	Network energy efficiency 100xIMT Advanced	Connection density 1,000,000/km^2
Enhanced mobile broadband	M	H	H	H	H	H	H	M
Massive machine-type communication	L	L	L	L	L	L	M	H
Ultra-reliable low latency communication	H	H	L	L	L	L	L	L

5G will require and to deal with even more BSs, deployed dynamically and in a heterogeneous manner, combining different radio technologies that require to be flexibly integrated. Moreover, a massive deployment of Femto access nodes produces several constraints such as an adverse interference scenario or extra backhaul and mobility management needs that 5G requires to address [39]. Various levels of coordination/cooperation among Femto cells are key to increase the network capacity and keep interference at a sufficient level in order to manage mobility and spectrum, to make sure service availability and response to non-uniform traffic distribution between adjacent access points. With the growing density of networks, the backhaul will become more heterogeneous and possibly also scenario dependent (i.e., fiber, wireless backhaul or other non-ideal types of backhaul might be utilized based on their availability). Additionally, the connectivity among the network nodes may alter in order to permit for fast direct exchange of data between them. This will be challenging in ultra-dense deployments. The heterogeneous backhaul structure will also influence the mechanism of the RANs, e.g. latency differences on backhaul links will impact inter-cell coordination and cooperative communications. Thus, both RAN and backhaul network require to be aware of the constraints and abilities of each other. The large user data traffic demand in conventional wireless communication systems tends to enhance the number of needed access points or BSs per area in a network, producing an adverse scenario where communications are severely affected by interference. One way of enhancing the SE of the network is the utilization of advanced coordination or cooperative approaches among transmitters in order to combat the produced interference. In the LTE Advanced and its evolutions these approaches are known as coordinated multi-point (CoMP). The wide deployment of optical communications networks, with fiber connections closer to the end users, makes sense also for wide band links between Femto-cells, changing the present fundamental idea of traffic scaled cellular deployment to a modern view of opportunistic spectrum access based cooperative networking. In conjunction with the cooperative femto-cells scenario [40], the terminal will be acting as a local access enabler, managing radio communications not only from the user but also from surrounding smart objects. Radio network architectures can then consider the roaming user device (on the bus, in the street, inside the car, at home, etc.) as an Internet of Things (IoT) relay node capable to facilitate the coverage extension and to act as a gateway to the Internet for the IP enabled smart objects. Note that, in Table 5, we outline the importance and differences of our paper to the reference [41].

1.4. Contributions and key results

We summarize the major contributions and key results below.

- With the installation of the cognitive relay under both cooperative and non-cooperative mode of communications, for coverage optimization and higher throughput, we derive analytical expressions of SINR for an MU and an FU to find total network capacity.
- We investigated the outage probability at network stage in non-cooperative CR femtocell based architecture. It signifies that the EE is proportional to N^2 where N indicates the deployment of base station density. It can also be seen for EE and SE that both of theme rapidly grew with enhancing probability of outage.
- The numerical results show that, if unlicensed radio resource remain maintain to grow, the capacity, convenience of VAA is changed to the maximum, and both EE and SE experience hardship from the over purveying of unlicensed radio resources. Over purveying of unlicensed radio resources occurs while the capacity does not grow in proportion to the enhancement of power or bandwidth.

1.5. Organization of the paper

The rest of this paper is structured as follows. In Section 2, the architectural view for both cooperative and non-cooperative communications in a cognitive femtocell network for 5G is discussed. In Section 3, utilizing down-link (DL) spectrum sharing as a useful way of transmission, the analytical expressions of MU's SINR and FU's SINR for DL capacity is

Table 5
The importance and differences of our paper to the reference [41].

Features	Reference [41]	Contributions
Technology	CDMA	OFDMA
Infrastructure	Comparison among femtocells, distributed antennas, microcells	Comparison among femtocell, picocell, Wi-Fi
Performance metrics	CDF, Outage Probability	Normalized EE, SE
Entire matter	In this article authors overview the technical and business aspects for femtocells and describe the state of the art on each front.	In this article we overview the technical aspects for femtocells only and describe the state of the art.
Challenges	The technical challenges focused on femtocell networks- • broadband femtocells: resource allocation, timing/synchronization, and backhaul • voice femtocells: interference management in femtocells, allowing access to femtocells, handoffs, mobility, and providing Emergency-911 services • network infrastructure: securely bridging the femtocells with the operator network over IP	The following technical challenges focused on femtocell design and 5G network- • low device cost • network interference management • femtocell capacity maximization • backhaul issues • variable system architecture • tactile internet latency • peak data rate: 100x that of currently deployed 4G
Architecture	Authors have not considered any specific architecture in details; rather they have contributed various technical and business aspects.	Here, we have precisely worked on co-operative and non-cooperative architecture of cognitive-femtocell networks in 5G
Salient properties	Physical and Medium Access Layer for broadband femtocells and voice femtocells	The following network features in femtocell based 5G system can be found- • Role of Self Organizing Network (SON) • Cell Identity Management • Load Balancing & Mobility Robustness • Power Saving features
Femtocell deployment	Predictive return on investment (ROI) from femtocell deployments have been discussed in this article	Femtocell deployment options and issues have been discussed in licensed spectrum and unlicensed spectrum for the operator-setup and user-setup
The interference mitigation issue	Interference can be avoided by employing adaptive power control strategies, CDMA time hopping and antenna sectoring	We have discussed a cognitive radio approach based on distributed spectrum sensing can be the solution for interference mitigation in femtocell networks.

presented. The numerical results is presented in Section 4 where explanation of different case studies on the cooperative and non-cooperative communications has been performed and achieve design insights. Finally, this work end up in Section 5 with conclusions.

2. Architecture of cognitive-femtocell network in 5G

To resolve the above challenging issues and fulfill the 5G network needs, we require a rapid modification in the design of architecture of cognitive femtocell network. The architecture of cognitive femtocell networks can be classified as non-cooperative architecture and cooperative architecture [42–44].

2.1. Non-cooperative architecture

As depicted in Fig. 3a, two different radio interfaces operate over the licensed radio resources provided by CR technology in a non-cooperative architecture [45]. The non-cooperative CR based architecture operates in a multi-radio access technologies (m-RATs), where the two radio interfaces function at the licensed channel (LC) and momentarily unused channels by the UEs, known cognitive channels. Cognitive radio resource is utilized to develop a separate network, which overlays with the existing macrocell network. The dual layer of the network is partitioned in the physical layer, and to be unified in the upper layers to conduct collaborative scheduling. Many dual-tier architecture have been introduced so far for 5G networks. A macrocell belongs to the upper layer and FBSs perform under the supervision of the macrocell in the lower layer.

There are several utilization cases for a dual layer network in non-cooperative communication mode as depicted in Fig. 3a. The non-cooperative architecture can be utilized in many ways, as: (i) the cognitive and LC are utilized by UEs close to the MBS and also far apart from the MBS, respectively, (ii) the cognitive and LC are utilized for relaxed QoE and

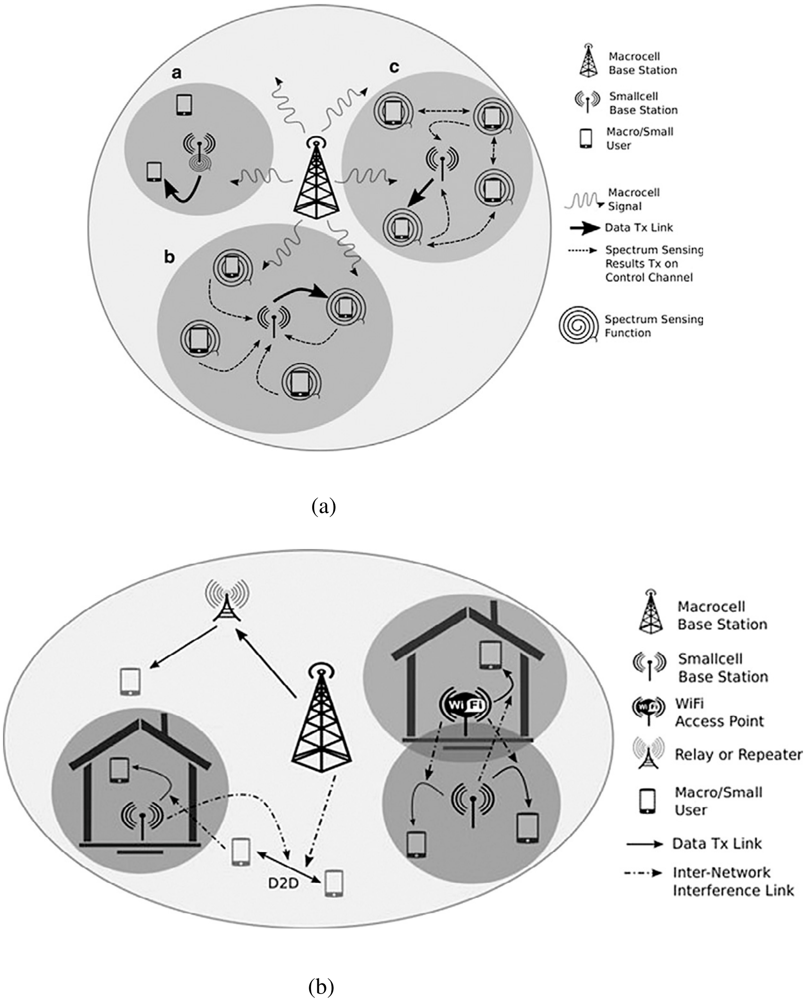

Fig. 3. Non-cooperative architecture (Fig. 3a) and Cooperative architecture (Fig. 3b).

strict QoE, respectively. For instance, services with inflexible QoS needs can be programmed to licensed radio interface with the compensation of higher expenditure, but not much reliable, whereas services with flexible QoS needs can be produced over the CR interface with lower expenditure. Alternative promising technology is to deploy CR-femtocells that utilized cognitive radio resource to overcome from the coverage gap issue. In contrast to licensed spectrum based femtocell network, the CR-femtocell network can provide more throughput and higher interference shelter to the MBS. Eventually, this can be noted that non-cooperative CR-femtocells network is being strongly followed by the corporate sector, with many white research articles presently published by prime corporate players to recommend the collaborative deployment of femtocell in a CR environment [39,46].

2.2. Cooperative architecture

Cooperative architecture (introduced in [45,47]) utilizes both licensed and unlicensed radio resources to develop a physical layer by the concept of cooperative communications. Cooperative communications permit distributed user equipments (UEs) to perform and pass on intelligence in a coordinated way to get notable performance gains. It can split a point to point (P2P) transmission into several phases between two entities. The principle of cooperative architecture is to meticulously complement the heterogeneous radio resource to different types of channels. Therefore, licensed radio resources are superior for long-distance transmissions, whereas unlicensed radio resources are superior for short-distance transmissions as they facilitate local cooperation. The cooperative architecture can be utilized in many ways [48], as: (i) a FBS exchanges information with a MBS utilizing the LC and facilitates service to its users through an opportunistic access to the licensed radio spectrum, (ii) a LC is utilized to serve users by a FBS and the opportunistic access of LC is utilized to shift backhaul traffic to the MBS. The network capacity of a cooperative architecture has been investigated in [49–51].

It has been noticed that cooperative networks are having significant merits to increase the capacity of longer-distance communications in contrast to non-cooperative networks. The capacity gains are much steadier over the instability of the unlicensed radio resources. Two representative cases of cooperative architecture are depicted in Fig. 3b. A cognitive relay is installed for coverage optimization or higher throughput in one case.

Alternatively, unlicensed radio resources can be utilized for backhaul and primary or macrocell radio resources for local coverage. This another choice of settings is encouraging when the secondary spectrum lies in the frequency band 3.5 GHz to 35 GHz range and it can be worthy for static microwave access. One distinctive advantage of another choice of configuration is that no alteration is required for conventional UEs which only work in the licensed band. In the second case, neighboring portable UEs can utilize secondary or unlicensed radio resources to construct a virtual antenna array [52]. The virtual antenna array can again construct a virtual MIMO linkage in the spectrum which is licensed to macrocell to bring in operation yield in contrast to a multiple-input multiple-output network [53–56]. In short, the cooperative architecture facilitates an actual instinct of incorporating cognitive-femtocell networks in future generation networks, where a FBS performs as a secondary network, (SN) which monitors pursuits of a primary network (PN) and performs on momentarily unoccupied radio spectrums by a PN to facilitate services to its users with negligibly interrupting MBS pursuits.

3. Total system capacity in 5G network

In this section, based on the above introduced non-cooperative and cooperative architecture, we explore few encouraging key wireless parameters which can aid 5G heterogeneous network to satisfy operation needs. The motivation of advancing these technologies is to enable a rapid capacity enhance in the system with the methodical use of every feasible resources. If the entire bandwidth consists of N_{SC} sub-channels indexed by $n = \{1, 2, 3, \ldots, N_{SC}\}$ and the number of users (MUs and FUs) supported by a macrocell is N_{mu}, then the total network capacity according to Shannon–Hartley theorem $\mathrm{C}_{\mathrm{sum}}$ can be written by [57]:

$$C_{sum} = \sum_{i=1}^{N_{mu}} \sum_{n=1}^{N_{SC}} B_n log_2(1 + \frac{P_i}{N_0 + I_i}), \tag{1}$$

where B_n is the allocated bandwidth (BW) to nth channel, P_i is the adaptive signal power to nth channel, N_0 indicates the noise level, and I_n indicates interference on nth channel.

Ergodic capacity with receiver channel state information (CSI) can be defined as $E[C_{sum}]$ where E is the expectation operator illustrating ensemble average of a random variable.

A performance metric P_{out} is considered to indicate the probability that the network cannot successfully decode the transmitted symbols. Now, corresponding to a SINR threshold γ_0, the outage probability can be expressed as: $P_{out} = p(\gamma < \gamma_0)$, For the received SINRs less than γ_0, the received symbols cannot be successfully decoded with probability 1, and the network declares an outage. Since the instantaneous CSI is not known at the transmitter, this transmits using a constant data rate $C_{out} = B_n \log_2(1 + \gamma_0)$ which can be successfully decoded with probability $(1 - P_{out})$. Hence the average outage rate R_{out} correctly received over many transmission bursts can be expressed as: $R_{out} = (1 - P_{out})B_n \log_2(1 + \gamma_0)$.

3.1. Interference analysis of an macro user (MU)

As there is no interference within the cell, we let consider that the received interference for the reference macro MU utilizing sub-channel n is from adjacent MBSs and nearby FBSs. Here, nearby interfering FBS refers to the FBS whose position is less than a certain distance between MUs.

Therefore, the SINR of MU k located at the edge of the serving area (i.e., R_m) using sub-channel n can be expressed as:

$$SINR_k^n = \frac{p_k^n |h_k^n|^2 R_m^{-\alpha}}{\sum_{l=1 \neq k}^{M} p_l^n |h_{l,k}^n|^2 d_{l,k}^{-\alpha} + \sum_{i=1}^{F} \rho_i^n p_i^n |h_{i,k}^n|^2 d_{i,k}^{-\alpha} + N_0}, \tag{2}$$

where ρ_i^n indicates that nth sub-channel has been selected by ith femtocell for transmission and $\rho_i^n = \{1, 0\}$ based on availability of the channel; α indicates pathloss exponent. Here, $|h_k^n|^2$, $|h_{l,k}^n|^2$, $|h_{i,k}^n|^2$ denote the generated channel gain from the serving MBS, the adjacent MBS l and the FBS i to the MU k, respectively; p_k^n, p_l^n, p_i^n denote transmit power by the corresponding base station entity that facilitates service over the nth sub-channel, respectively; $d_{l,k}^{-\alpha}$ is the distance between the adjacent MBS l and the kth MU, $d_{i,k}^{-\alpha}$ is the distance between the FBS i and the kth MU; $R_m^{-\alpha}$ indicates Large Scale Path Loss (LSPL) between a referenced MU and its serving MBS.

3.2. Interference analysis of an femto user (FU)

The received interference for the reference FU is large due to adjacent MBSs and other FBSs positioned within the same macrocell. Therefore, the SINR of FU i located at the edge of the serving area (i.e., R_f) using sub-channel n can be expressed as:

$$SINR_i^n = \frac{p_i^n |h_i^n|^2 R_f^{-\alpha}}{\sum_{k=1}^{M} p_k^n |h_{k,i}^n|^2 d_{k,i}^{-\alpha} + \sum_{j=1 \neq i}^{F} \rho_j^n p_j^n |h_{j,i}^n|^2 d_{j,i}^{-\alpha} + N_0}, \tag{3}$$

where ρ_j^n indicates that nth sub-channel has been selected by jth femtocell for transmission and $\rho_j^n = \{1, 0\}$ based on availability of the channel; α indicates pathloss exponent. Here, $|h_i^n|^2$, $|h_{k,i}^n|^2$, $|h_{j,i}^n|^2$ denote the generated channel gain from the serving FBS, the MBS k and the adjacent FBS i to the FU i, respectively; p_i^n, p_k^n, p_j^n denote transmit power by the corresponding base station entity that facilitates service over the nth sub-channel, respectively; $d_{k,i}^{-\alpha}$ is the distance between the MBS k and the ith FU, $d_{j,i}^{-\alpha}$ is the distance between the adjacent FBS j and the ith FU; $R_f^{-\alpha}$ indicates Large Scale Path Loss (LSPL) between a referenced FU and its serving FBS.

Suppose a set of F FBSs is there in the network coverage of MBS. For any FBS $j(\forall j \in F)$, there is a set of i FUs. In this paper, we consider notation j to represent the femtocell to identify the target FBS. We make use of a set of N_{SC} channels that have been made available for femtocell j.

The DL capacity of ith FU in an jth femtocell can be expressed by Shannon's capacity formula as presented in [46]:

$$C_{ij} = \sum_{c \in N_{SC}} B \log_2(1 + \beta_{ijc} SINR_j^n), \tag{4}$$

where β_{ijc} is a binary indicator. If $\beta_{ijc} = 1$, user i in femtocell j works on channel c, zero otherwise.

Therefore, we can express the DL capacity of a femtocell that is supported by N_{fu} FUs as the sum total of users' capacity.

$$C_j = \sum_{i \in N_{fu}} \sum_{c \in N_{SC}} B \log_2(1 + \beta_{ijc} SINR_i^n), \forall j \in F. \tag{5}$$

3.3. DL spectrum sharing

In this paper, we contemplate the DL spectrum sharing issue, where FBSs use the licensed channels keeping in mind that the licensed channels are not being used by macrocell user. Hence, cross-channel interference between macrocells and femtocells has been removed. Besides, co-tier interference among the FBSs can also be minimized at large. Let us consider that each FU in a femtocell needs one channel. We articulate the worst case where all nearby FBSs are in DL transmission. Here, we analyze the DL capacity and then prepare methodically the spectrum sharing issue. The spectrum allocation in CR-femtocell can be used in DL communication to maximize the DL capacity of the FBSs keeping the parameters such as channel allocation [58], SINR, and power constraints at the desired value [46].

$$P: max \sum_{j \in F} C_i, \qquad \text{Subject to: } \beta_{ijc} \in \{0, 1\}, \quad \forall j \in F,\ i \in N_{fu},\ c \in N_{SC}$$

$$\sum_{c \in N_{SC}} \beta_{ijc} = 1, \qquad \forall j \in F,\ i \in N_{fu} \tag{6}$$

$$\sum_{i \in N_{fu}} \sum_{c \in N_{SC}} \beta_{ijc} = 1, \qquad \forall i \in F \tag{7}$$

$$\beta_{ijc} \geq \psi,\ if\ \beta_{ijc} = 1, \qquad \forall j \in F,\ i \in N_{fu},\ c \in N_{SC} \tag{8}$$

$$p_{ijc} = 0,\ if\ \beta_{ijc} = 0, \qquad \forall j \in F,\ i \in N_{fu},\ c \in N_{SC} \tag{9}$$

$$p_{ijc} > 0, \qquad \forall j \in F,\ i \in N_{fu},\ c \in N_{SC} \tag{10}$$

$$\sum_{i \in N_{fu}} \sum_{c \in N_{SC}} p_{ijc} \leq P_i^{max}, \qquad \forall j \in F \tag{11}$$

where ψ indicates the minimum desired SINR for FUs and p_{ijc} indicates power transmitted by femtocell j for FU i on channel c. A limitation in (6) signifies every user in this cognitive femtocell scenario can only use one channel. A limitation in (7) signifies the maximum channels to be utilized in a femtocell is equal to the total femto users within the network of FBS. A limitation in (8) indicates that if cth channel is assigned to the jth FU located in the network of ith FBS for DL communication, the achieved SINR of jth FU has to be larger than the cut-off value to establish ψ in advance. A limitation in (9) signifies that if cth channel is not assigned to ith FBS, then no power shall be assigned to cth channel by ith FBS. A limitation in (10) indicates that ith FBS's transmit power not to be smaller than zero, whereas a limitation in (11) signifies that ith FBS's transmit power to its FUs should not be more than the maximum power limit, P_i^{max}. The MATLAB simulation parameters are listed in Table 6.

4. A trade-off between EE and SE

As discussed before, CR networks might include several architectures. In every architecture, the study of capacity can be reviewed at three different levels. At every stage, both ergodic capacity and outage capacity have been employed to take measures on the matter. Hence, a number of case studies on a trade off between EE and SE can be made in respect to the

Table 6
Simulation parameters [59].

Parameters	Value
Macrocell coverage radius	1000 m
Femtocell coverage radius	20 m
MBS transmit power	50 dBm
FBS transmit power	15 dBm
Maximum number of FUs per femtocell	6
The noise power	1.4×10^{-14} W
Carrier frequency	2.5 GHz
Channel bandwidth	200 kHz
Sub-carrier bandwidth	20 kHz
Number of sub-carriers per channel	15
Channel type	Rayleigh fading channel

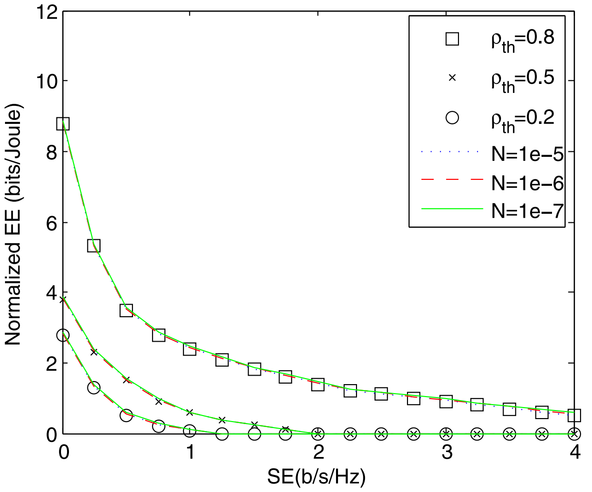

Fig. 4. The trade-off between EE and SE in CR femtocells at the network stage.

architectures, stages, and different types of capacity. In this connection, three scenarios have been presented to illustrate insights of different kinds of architectures based on a trade off studies of EE and SE. These scenarios are conscientiously selected as they not only illustrate insights of different kinds of architectures, stages, and different kinds of capacity, but also cogitate the recent research development and which we can take as the most encouraging schemes [60]. Three case studies have been chosen for discussion:

- Case study 1: Non-cooperative CR femtocells + network stage + outage capacity,
- Case study 2: Cooperative cognitive resources VAA network + femtocell stage + ergodic capacity,
- Case study 3: Cooperative CR relay + connection stage + ergodic capacity.

In general, CR resources fluctuate rapidly in different frequency spectrum. Due to that it is proficient to take an analysis on cognitive radio resource behavior by three variables: unlicensed spectrum B_s, secondary power P_s, and fidelity parameter a. Here $0 \leq a \leq 1$ represents the probability that the unlicensed spectrum is available at a given time instant. Let B_p and P_p indicate the licensed spectrum and primary power; it is normally proficient to take the bandwidth (BW) ratio $\Theta = B_s/B_p$ and power ratio $\psi = P_s/P_p$.

Case study 1: In this case study, we investigate the outage capacity at network stage in non-cooperative CR femtocells as shown in Fig. 3a. We contemplate a scenario of largely deployed CR femtocells in a two-dimensional plane. In the middle of every femtocell, there is a secondary base station (also known as FAP) communicating with uniform power. The FAPs have been uniformly distributed. Entire communicative channels have been conditional upon the Rayleigh faded propagation channel. Considering the capacity in the DL for a random user; the expression of the outage capacity in a closed-form is to be achieved by the analytical scheme [61]. In Fig. 4, we illustrate the trade-off between EE and SE obtained from the outage capacity. The EE can be normalized on π^2N^2 to achieve superior insight. Three parameters are identified that can impact on the trade-off issue of EE and SE such as deployment of base station density N, outage probability ρ_{th}, and fidelity factor a. For the sake of intelligibility, $a = 1$ is considered in Fig. 4. The following compelling inspections are composed. It signifies that the energy efficiency is proportionate to N^2. Next, both spectral efficiency and energy efficiency become greater in amount with growing response. Fourth, for a provided outage probability, there is an extreme point for both metrics (i.e., spectral efficiency and energy efficiency). It has a distinct capacity outcome obtain from the Shannon–Hartley theorem, in which spectral efficiency can reach to immensity. The cause is that cross-tier interference is chosen at the network stage, and thus the operation is interference-limited. In the end, it can be noticed that both metrics (i.e., energy efficiency and spectral efficiency) rapidly grow with enhancing the outage probability. An easy mapping finds between a and ρ_{th} as they are both measures of fidelity. Precisely, for any CR network with an outage need ρ_{th}, its trade-off between EE and SE is parallel to other network keeping $a = 1$, and fixing up outage need $1 + (\rho_{th} - 1)/\text{a}$. For instance, for the values of a and ρ_{th} as 0.6 and 0.8, respectively, the trade-off between EE and SE is the similar response as $a = 1$ and $\rho_{th} = 0.5$. The influence of a can be seen in Fig. 4. Provided $\rho_{th} = 0.8$ and a varying from 1 to 0.6, the trade-off between energy efficiency and spectral efficiency will deteriorate from the top most curve to the central one. When the SE is fixed, the normalized EE decreases with the decrease of outage probability. When the outage probability is fixed, the normalized EE decreases with the increase of SE. However, it can be noticed that the outage probability has more impact in contrast to the deployment of base stations. That is due to the fact that the number of available channels reduces with the increase of SINR. As a result, the service state of being otherwise unoccupied in wireless networks is decreased and then the EE in CR femtocells is decreased. Fig. 4 also shows that the response of the network for normalized EE in accordance with the consideration of SINR, where the normalized EE decreases less rapidly with the increase of SE compared to the work presented in [45]

Case study 2: In this case study, ergodic capacity has contemplated at a femtocell stage in a virtual antenna array (VAA) based cooperative cognitive networks [45,62] as shown in Fig. 3b. The consequences of the fidelity metric a become insignificant due to the fact that it can only produce a linear scaling response over the ergodic capacity. Hence, we eventually consider $a = 1$ for the sake of intelligibility. Here, the work of interest is the up link (UL) data communication in a cognitive virtual MIMO mode with many FBSs and portable UEs. A tiny part of the users are active users (particularly, source users) that are having information to communicate with the BS. The rest of the users, belong to the category of cooperative users which are interested to construct VAAs with vigorous users to help transmission in a virtual MIMO network. The data transmission through virtual MIMO communication comprises of two levels: a local simulcast transmission (level I), and disseminated access of MIMO (Level II). Let us consider that Level I, and II function over the unlicensed and licensed spectrum, respectively, by a spectrum-split manner. Every base station is fitted with a number of antennas, whereas every portable user is having single antenna. Let us assume that the spatial distributions of FBSs, portable users, and active users are homogeneous PPP with densities $\mathrm{N_b}$, $\mathrm{N_u}$, and $\mathrm{N_v}$, respectively. We also consider that data transmission of an active user possible only with the neighbor base station (BS). Likewise, a cooperative UE only collaborates with the neighbor active UEs. In the initial level, every active user equipment simulcast transmission of its contain information with an adaptation of transmit power P, which is normalized over the unlike noise power. A cooperative user can be a member of the VAA if and only if it has the ability to potentially decode the information communicated with the nearby active mobile user. Let Θ be the BW ratio. The trade-off between EE and SE can be assessed mathematically by the steps followed in [63]. It can be noticed that this mathematical analysis does not include cross-tier interference at the base station into account; thus, this is assessed as a femtocell stage study. Fig. 5 illustrates the trade-off between EE and SE of the cooperative cognitive VAA networks with corresponding MIMO and SIMO networks. The EE is normalized over $\pi^2 N_b^2$ for superior response. The following comprehensions are possible to achieve from Fig. 5. Initially, in contrast to the single-input multiple-output network (i.e., without virtual antenna array), the virtual antenna array is only advantageous for large SE values. It is to put additional resources in Level I associated with few multiplexing gains in Level II due to the conviction of VAA. The advantages of multiplexing gains can be worthy of attention only at large spectral efficiency values. Next, the trade-off relationship between EE and SE is not mandatory to be maintained. It is feasible to increase both EE and SE curves simultaneously when the value of both of them is relatively low. Third, possession of the cognitive radio resource (i.e., enhance either P or Θ) can provide a better response in the upper SE values region at the price of the operation degradation in the smaller SE values region. Although, if unlicensed radio resource remain maintained to grow, the capacity convenience of VAA is changed to the maximum, and both the energy efficiency and spectral efficiency experience hardship from the over purveying of unlicensed radio resources. Over purveying of unlicensed radio resources occurs while the capacity does not grow in proportion to the enhancement of power or bandwidth. Such an over purveying occurrence is feasible to see with clarity in Fig. 5. The comparison of the three curves, keeping transmit power, P = 100 dB, an inceptive grows of BW ratio, Θ typically from 0.2 to 2 can provide better energy efficiency in the upper spectral efficiency system (precisely, spectral efficiency > 5 b/s), in that case higher value of Θ from 2 to 15 can only help to deteriorate the trade-off performance between EE and SE. When the adaptation of transmit power is fixed, the normalized EE decreases with the increase of BW ratio for a reference value of SE in the lower SE region and upper SE region illustrates unstable oscillating response compared to that of the presented work in [45] is because of the incorporation of intra-tier and inter-tier interference. When the BW ratio is fixed, the normalized EE increases with the decrease of the adaptation of transmit power for a reference value of SE in the lower SE region. Numerical results of the presented wireless networks invariably confirm that there exist the optimum SE values for the consideration of different SINR values. In general, the path loss exponent deteriorates wanted signals as well as unwanted interference signals. However, SIMO and MIMO curves imply that the path loss exponent has a more attenuation impact on the interference, results in better response with respect to the existing results given in [45]

Case Study 3: In this case study, we introduce ergodic capacity at link stage in the cooperative CR relay network. Precisely, we include an easy relay network keeping three points in which a source telecasts to a relay. The relay transfers

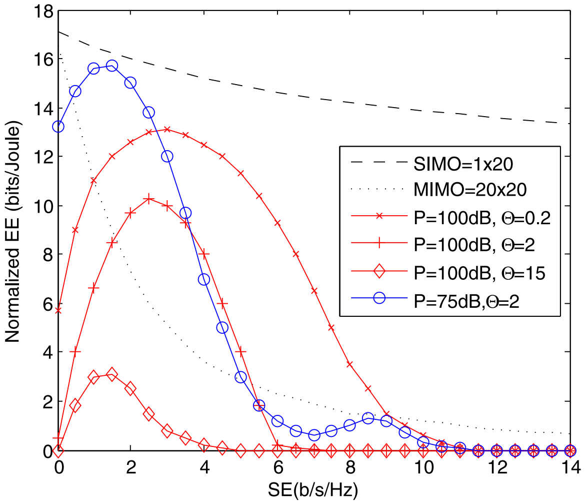

Fig. 5. Trade-off between EE and SE in cooperative virtual antenna array at the femtocell stage ($N_b = 2/\text{km}$, $N_u = 30/\text{km}$, $N_v = 300/\text{km}$).

information to the destination utilizing unlicensed radio resources in such a manner that the simultaneous transmission of two signals executed in opposite directions. The unlicensed relay based channel is radically dissimilar as compared to the traditional relay based channel where the relay and origin are topic of different resource restraints. Here, channel type is Rayleigh faded propagation channel and path loss exponent equals to 4. Followed by the mathematical analysis in [63], the bottom and top bounds of the capacity of the link-stage of the unlicensed relay base channel are to be computed. The smaller bound capacity can be utilized for the assessments of energy efficiency and spectral efficiency as because of bottom and top bounds are low. Without any loss of extrapolation, the BW ratio and power ratio of the macrocell band can be fixed to one, and the relay can be positioned in the middle between the place of origin and the place to which information being sent. We are concerned with how the trade-off between EE–SE changes with dissimilar values of unlicensed BW ratio Θ and power ratio. Fig. 6 illustrates trade-off curve between EE and SE on the unlicensed relay channel of Rayleigh fading type. Individual curve is computed by setting up either Θ or ψ and changing the other. Two significant findings are made in Fig. 6. Initially, for a provided Θ and ψ, there is a high spectral efficiency and energy efficiency. The cause is that the relay channel's capacity can eventually restrict by the preset macrocell radio resource depending upon boundary limits, which asserts that the network channel capacity is minimum of two capacities corresponding to the macrocell and femtocell radio resources, respectively [64]. Secondly, the trade-off relationship between EE and SE is not mandatory to be maintained; there are instances in which both energy efficiency and spectral efficiency are to be grown simultaneously. It occurs while the channel capacity is very badly bounded by the unlicensed radio resources (i.e., particularly, while both Θ and ψ are low valued), so that licensed and unlicensed radio resources are extremely disproportion. In a CR based relay channel, the following issues are precisely articulated: provided cognitive radio resource, subject matter of the utilization of unlicensed radio resource by the cognitive relay to obtain the most favorable response for the parameter either capacity, spectral efficiency, or energy efficiency. Here in Fig. 6 the normalized EE reaches to the optimal value smoothly and again decreases gradually with the increase of SE for the fixed BW ratio, whereas rapid transition can be seen to reach to optimal value and after crossing the peak level, respectively, as given in [45]. Hence relay based channel with interference consideration produces better EE response in terms of stability compared to the EE response presented in [45] in presence of relay based channel without interference. For fixed power ratio, the non-varying normalize EE response with the increase of SE to a certain limit has been extended up to some extend with respect to the existing results given in [45].

Followed by the contribution in [64], the optimum trade-off curve between power and bandwidth in terms of each parameter are to be expressed. Three plots in Fig. 7 separate the power and the BW approach into five domains. Each of the five domains are having significant observations as follows:

- Domain M: Resource redundant domain, where power and bandwidth are over flexible and result in non-responsive influence on SE and EE
- Domain N: Power bounded domain, where growing power develops all three parameters, while enhancing bandwidth develops capacity and energy efficiency but deteriorates spectral efficiency
- Domain O: Power and BW bounded domain, in which enhancing either power or BW develops each of the three parameters
- Domain P: BW bounded scheme, in which enhancing bandwidth develops each of three parameters, whereas growing power develops capacity and SE but deteriorates EE

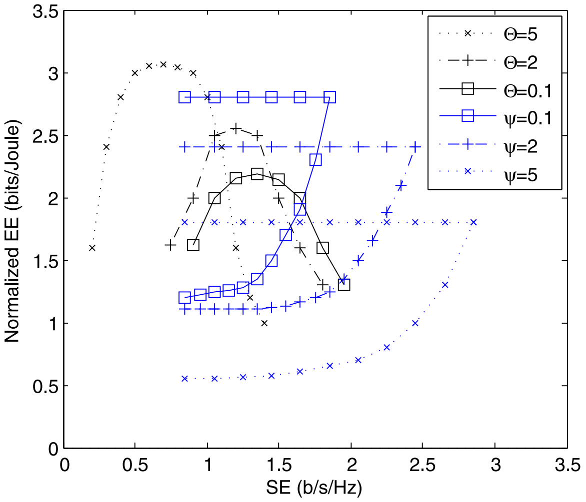

Fig. 6. Trade-off between EE and SE in Rayleigh based relay channel at the connection stage.

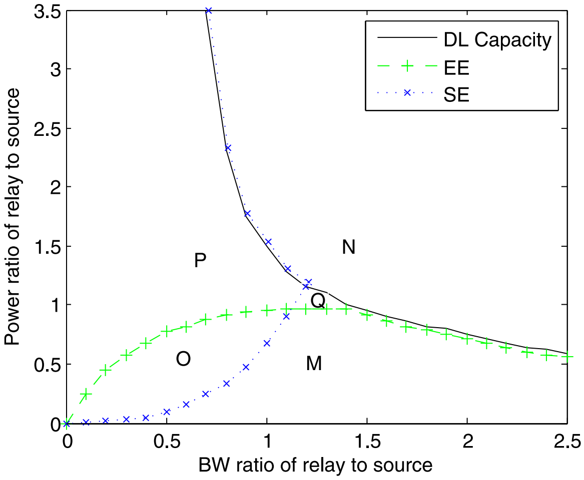

Fig. 7. The power ratio performance with respect to the bandwidth ratio in relay-source channel.

- Domain Q: Trade-off domain, in which enhancing power develops capacity and spectral efficiency but deteriorates energy efficiency, whereas enhancing BW develops capacity and energy efficiency but deteriorates spectral efficiency.

In this paper, the curve of EE belongs to domain M with the adjacent to domain N and the curve of DL capacity belongs to domain N with the adjacent to domain M are not in-line as interference taken into account. Likewise, it can be seen that the curve of SE belongs to domain N with the adjacent to domain P and the curve of DL capacity belongs to domain P with the adjacent to domain N are also not in-line in contrast to the results given in [45]. However, both the results in this paper and the results in [45] have shown much stable response irrespective of interference.

As discussed before, cognitive femtocell networks have many architectures. For all architectures, the capacity can be reviewed at three different stages. For all stages, two different types of capacity analysis possible to establish : ergodic capacity and outage capacity. Simultaneously, number of EE–SE trade-off investigation can be established with respect to each specific type of architecture, stages, and capacity types.

5. Conclusion

The trade-off between EE and SE has been investigated for the cognitive femtocell networks. These are very important analytical metrics which not only yield compelling theoretical insights into the basic constraints of CR networks, but also produces helpful outlines for radio resource management. Even though the precise evaluation objectives of the future generation networks (i.e., next to 4G) have not been officially announced yet, there is a growing consensus that next

generation network 5G will obtain a thousand times the network capacity, ten times the SE, EE, and bit rate, and around thirty times in contrast to the average macrocell throughput of 4G networks. Eventually, it can be visualized that non-cooperative CR femtocell networks would useful to enhance the bit rate and macrocell capacity, whereas cooperative CR femtocell networks would have produced alike kinds of developments in SE and EE. From the above discussion and from the architectural consideration earlier, it is concluded that native support of femtocell in 5G requires radical changes at both different edge network topologies and architectural level. The interesting areas for future directions of research are:
(1) Analyzing the effect of channel state information errors induced by co-channel interference on MIMO femtocell performance.
(2) The complexity limitations of MIMO femtocell receivers, which may be significant vs. macrocell receivers due to cost considerations.
(3) Channel models for MIMO femtocells, since the diversity characteristics may be very different from macrocells.
(4) Providing a scalable architecture to transport data over IP backhaul and upgrading femtocells to newer standards to reduce Operating expenditure.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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