Radio resource management: approaches and implementations from 4G to 5G and beyond

Tafseer Akhtar, Christos Tselios & Ilias Politis

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Radio resource management: approaches and implementations from 4G to 5G and beyond

Tafseer Akhtar[1] · **Christos Tselios**[1] · **Ilias Politis**[1]

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Abstract

Radio resource and its management is one of the key areas of research where technologies, infrastructure and challenges are rapidly changing as 5G system architecture demands a paradigm shift. The previous generation communication technologies require customizations and upgrades as 5G will remain inclusive for significantly long duration. Radio resource management (RRM) schemes that are evolved during LTE/LTE-A network environment period will remain relevant for 5G, however, these schemes must become more intelligent and adaptive for future as features and requirements of network and users will be diverse and highly demanding. In this paper, a comprehensive view is provided upon various aspects of RRM, its challenges and existing schemes. The existing RRM schemes are presented with their respective architecture which has significant impact on the approaches. The problem of RRM is multi-dimensional and different dimensions are presented with their respective solutions such as interference or energy management. In this paper study of legacy and state of the art RRM schemes is presented with their features and inefficiencies in the modern telecommunication era of heterogeneous, ultra-dense, very low latency and highly reliable mobile network. In addition to this various comparison among approaches and schemes are presented for analyzing the solutions. The need of RRM solution is critical and this paper aim is to outline the challenges, existing solutions and directions for research to find and develop smarter and more adaptive schemes for future.

Keywords Radio resource management · Heterogeneous mobile small cells · 5G architecture

1 Introduction

Recent technological advancements (i.e., IoT, cloud, big-data, smart city, ultra-high definition video, online gaming, multimedia applications, etc.,) have transformed the requirements of telecommunication and conventional cellular systems, (e.g., 3rd Generation (3G) Universal Mobile Telecommunication System and Long-Term Evolution) [1]. Fourth Generation (4G) mobile telecommunication system which is also known as advanced LTE (LTE-A), requires futuristic technological leap to work in synchronization with next generation. The advancement towards 5th Generation (5G) cellular system is inevitable, however 5G will be an inclusive evolution which will include the existing systems and technologies with compatibility changes. The previous generation cellular system will not be completely replaced but evolve towards the 5G environment.

Radio resource management is key for satisfying the standard requirements of 5G environment, as it demands efficient management of interference and spectrum while considering fairness and Quality of Service (QoS) requirements as well. RRM is more challenging in hyper dense HetNets environment due to sheer number of devices and presence of various levels, as both co-tier and cross-tier interference affect this environment [2]. Energy and spectrum management are other key aspects of RRM and more efficient approaches are required to handle these challenging issues in 5G environment. Fairness among users

✉ Tafseer Akhtar
akhtar@upatras.gr

Christos Tselios
tselios@ece.upatras.gr

Ilias Politis
ipolitis@ece.upatras.gr

[1] Wireless Communications Laboratory, University of Patras, Patras, Greece

which are randomly distributed in the coverage area of hyper dense heterogeneous network, in terms of resource allocation is another critical task of RRM. The QoS requirements of users in 5G environment will be diverse in nature and demands of resources will change according to the applications running on the user's equipment. Ultra-high definition video, online live gaming, time critical applications will require efficient RRM approach for satisfying their resource demands [3].

Heterogeneous Networks (HetNets) are typically composed of various small cells and macro cell which create a hyper dense environment that can help in satisfying the diverse Quality of Experience (QoE) requirements of 5G system [4]. However, dense HetNets environment has its inherent challenges like interference, spectrum and energy management. Highly dense HetNets will become key network in 5G environment and small cells which are essential part of HetNets will play key role in efficient implementation and realization of 5G environment. Small cell (i.e., micro, pico and femto cell) is typically a low transmission base station with limited coverage area. Small cells are mainly used to handle the traffic congestion and coverage extension, however, small cells are expandable and their usability will only increase in 5G system and beyond.

The existing RRM schemes will not work with evolving 5G environment, as the challenges of next generation communication technologies are different and more complex in nature. However, intelligent RRM schemes which are proposed for LTE/LTE-A environment may work with 5G environment after re-examination and further analysis. The architecture of 5G is very different from previous generations and its design has many challenging issues to handle, also the performance requirements of 5G is more diverse and demanding than before. The architectural implementation of 5G introduces many components such software defined network (SDN), network function virtualization (NFV), Mobile Edge Cloud (MEC), etc., as its inherent part with slicing at Radio Access Network (RAN) level. The implementation of RRM scheme can be distributed or centralized in nature which will take advantage of 5G native architecture. This paper extensively surveys legacy RRM schemes (i.e., Frequency Scheduling, Frequency Reuse, Priority-Based Spectrum Allocation, etc.) and recent RRM schemes (i.e., Game theory based, Cognitive radio, Distributed learning, etc.). A systematic comparison is presented based on various parameters focusing complexity, fairness and energy efficiency and conclusion are drawn for suitability of these schemes in 5G small cell environment. Hybrid RRM approaches that incorporate distributed learning and game theory-based algorithms seem to be more suitable candidates for emerging 5G networks due to their highly distributed implementation and efficiency which are essential for the highly dense and heterogeneous 5G paradigm. Table 1 lists the key technological evolution for 5G realization.

In the rest of the paper, Sect. 2 provides an overview of 5G challenges and why resource management is critical for upcoming future, Sect. 3 describes the basic functions and task of RRM. Sect. 4 provides a study of the major evolutionary steps included in the standards over the recent years that defined the utilization of small cells and femto cells. Section 5 disusses about the key issues and challenges RRM in HetNets involving small cells. Sections 6 and 7 RRM schemes which are particularly developed for LTE/LTE-A small cells, with and without relay nodes are discussed. Various schemes related to Radio interference management, spectrum efficiency management and energy efficient management are explained and compared in Sects. 8 to 10. While in Sect. 11 hybrid resource management schemes are described and compared against various QoS parameters. Section 12 describes the design features of 5G wireless network regarding mm-wave wireless channel implementation, massive MIMO systems, full duplex radio technology, etc. In Sect. 13 RRM as part of the 5G architecture and slicing is discussed. Finally, Sect. 14 concludes the paper.

2 Overview of 5G system performance challenges

2.1 Explosive growth in the traffic volumes

There will be explosive traffic volume growth in near future as information access and sharing will happen from anywhere at anytime through anything, which will require improvement in performance at every level compare to last generations [18]. The technological requirements are massive where network should be scalable and self-sustainable, also 5G system will include the existing RATs (i.e., WLAN, Bluetooth, 3G, 4G, etc.) for mm Wave backhaul operations [17]. New network architecture and communication schemes, complexity of multiple access, air interfacing, duplexing approach [8, 19–21] are few of the reason to design efficient and futuristic RRM approaches. Enlarging the spectrum, using smart antennas (Massive MIMOs [5]), cooperation among BSs are some of the research outputs that can help in realization of the future 5G systems. Evolved radio access technologies (RATs) backbone with ultra dense networks (UDNs) and futuristic applications with elaborate use cases require far more sophisticated RRM schemes for 5G with massive traffic volume [14, 15].

Table 1 Key technologies of 5G system

Technologies	Advantages	Disadvantages
Massive MIMO [5, 6]	Massive traffic management Diverse QoS support Massive number of device support Better EEM and SEM tradeoff performance Fading and noise elimination	High computation complexity High CSI overhead High manufacturing cost High requirements of signal processing
Full Duplex [7, 8]	Massive traffic management Multiple technology cooperation and convergence Diverse use cases	Suffer from self-interference Multiple radio requirement
Energy harvest based [9–11]	CAPEX and OPEX cost reduction Diverse use cases Better waste recycling	High RF emission requirement High requirement of energy transfer Depend upon various energy resources
Multi-tier communication [7, 12]	Seamless mobility support QoS issues resolution for cell-edge users SDNs support RAN architecture simplification Better traffic offloading	Asymmetrical power control in downlink User exacerbation for upstream association
Ultra-dense networks [13, 14]	Better EEM and SEM trade-off performance Diverse use cases support Mm-Wave support Frequency reuse support in multi band Clustering and cooperation of BS	Better power control technique needs Scrambling in scarce resource Better RIM technique requirement User association restriction
mm-Wave [15–17]	Wider bandwidth and energy harvesting support Inter BS cooperative support SDNs applications support	Multi-hop support with throughput degradation Compatibility issue in inter band with UHF

2.2 Unprecedented increase in connected wireless devices

The increase in wireless connected devices will be unprecedented, it is expected to be 100 times more connected devices in 5G compare to present scenario [13]. Smart cities, smart power grids, surveillance devices, smart home systems will result in massive increase of wireless sensors and devices [22]. This challenge will require smart extensions from traditional cellular technology, where humongous number of machine type communications (MTCs) will also become the extended part of cellular network, which will need seamless integration with existing cellular RATs. The newly explored mm-Wave technology will surely come handy while dealing with massive MTCs, but issues such as spectrum management for backward compatible devices, scalability, battery constrains, and interference management will require much better RRM approaches [15].

2.3 Wide range of QoS requirements and characteristics

The QoS requirements for 5G system is immensely demanding and challenging. Seamless mobility, high reliability and resilience, very low latency, extremely high data rate, higher lifetime of devices, lower cost are few of the essential QoS features of 5G [13]. Short range communication (i.e., 10 to 100 m) can be used to achieve the demands of UDNs operating in very wide transmission band such as 100MHz with higher working frequency (i.e., 10 to 100 GHz) [17]. In UDNs environment, the transmission power is low by default and BSs need to offload the traffic to user equipment (UEs) or D2D network. The offloading of traffic must be efficient and timely, which means efficient release of resources as well as the access of these released resources [22, 23]. Therefore, D2D communication and linking requires better approaches in 5G system. Smart city, e-Health, traffic management requires ultra-low latency and very high reliability as human lives will depend upon the decision made through these systems [24]. The RRM schemes design must consider the factors such as control-channel design, link adaptation, coding and modulation to strike a balance between low latency and high reliability trade-off. In UDNs environment, smart functionality such as minimization of signaling, synchronization, node sleep mode, low link distance can help in bringing down the energy consumption, which is very critical for 5G and future network [25]. Figure 1 describes the overall 5G RAN system architecture with various tiers, spectrum, gateways, core with different internal and external interactions.

The performance challenges of 5G wireless network are discussed in the last section, the next sections describe the radio resource management with its main functions, small cells and issues of radio resource management in heterogeneous LTE-A network with small cells and relay nodes.

3 Radio resource management

There are few main functions of RRM in LTE/LTE-A cellular technologies such as packet scheduling, resource allocation, link adaptation and control, radio admission and removal and handover management.

3.1 Resource allocation among macro cell and small cells

Resource allocation between small cells and macro cells is very crucial, in HetNets where relay nodes are also part of the network, resource allocation is done among access, backhaul and direct links between UEs and eNB on the operating band mode basis. There are many factors that play the key role during resource allocation such as number of users, available resources, buffer size, interference, etc., which are mainly managed at eNB level [2].

3.2 Packet scheduling

Packet scheduling is done at MAC layer in LTE/LTE-A, at each transmission time interval (TTI) where physical resource blocks (PRBs) are allocated to UEs. Cell throughput and spectral efficiency maximization is key objective behind dynamic packet scheduling [26]. The scheduling decisions depend upon various parameters such as channel state information (CSI), QoS requirements of UEs, channel quality indicator (CQI), interference, etc.

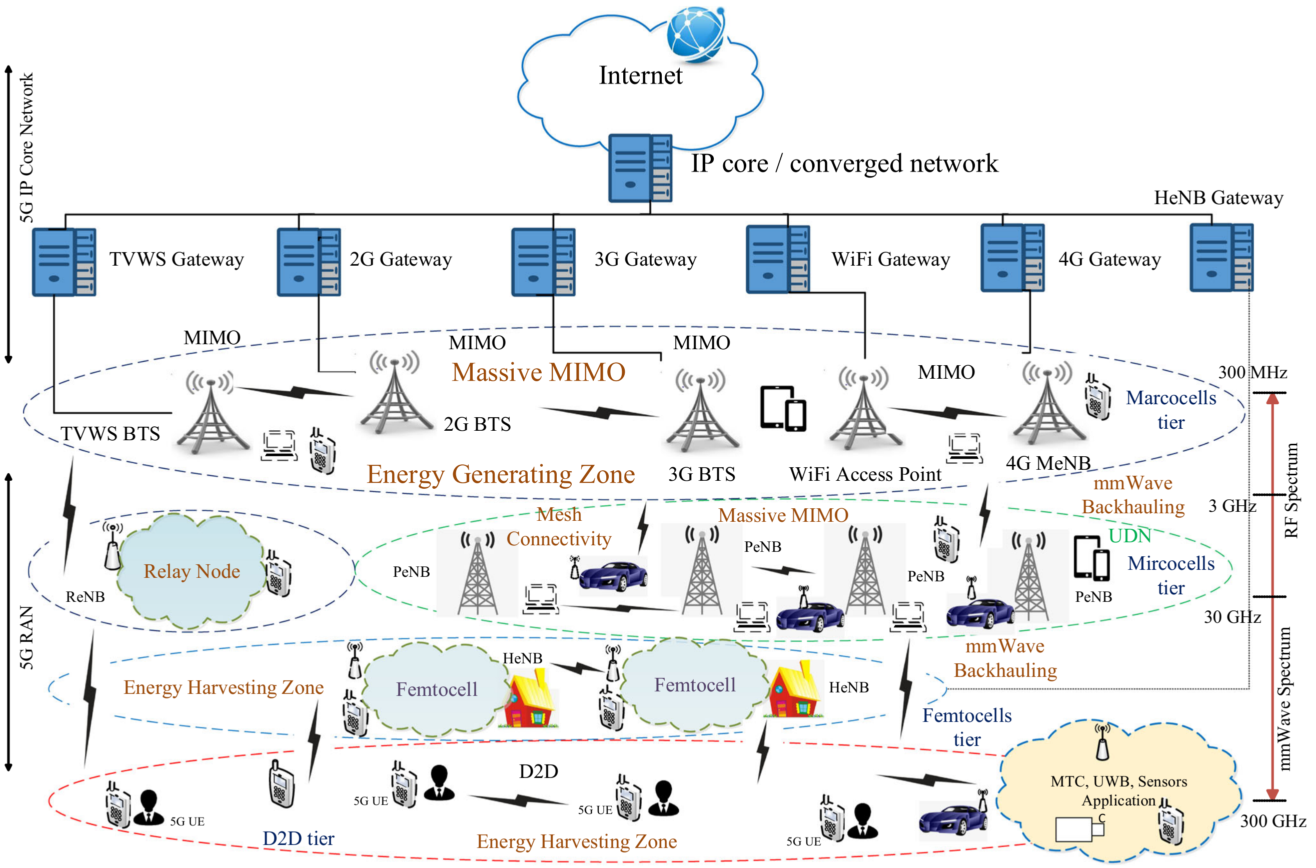


Fig. 1 5G RAN system architecture

3.3 Link adaptation

Another important RRM function is link adaptation which is managed at MAC layer for improving user throughput at targeted block error rate (BER) [26]. Link adaptation includes transmission power control and adaptive modulation coding (AMC) as two major functions, with a higher modulation and coding order a user can achieve high CQI. Transmission power control can help in better management of interference, as well as in cell throughput improvement.

3.4 Radio admission control and handover management

Radio admission control entity belongs to layer-3 in LTE/LTE-A, that decides if a radio bearer will become part of the network or not, this decision depends upon the radio bearer requirement of resources and availability. Radio admission entity work towards achieving the maximum resource utilization and satisfaction of new UE's QoS requirements, decision also check if this UE is new or a handover from neighboring cell. User handover and mobility management is done at radio resource control (RRC) layer, in LTE/LTE-A the decision of handover is made at eNB level and signal measurement happens at UE level with only hard handover support [2]. In LTE/LTE-A system, contention and non-contention based random-access procedure can be executed for handover of UEs to its target eNBs.

As main functions of radio resource management is discussed in the next section we described the small cell with the focus on femto cell as they are critical part of heterogeneous network for 5G and will remain a key component while designing the RRM schemes for future.

4 Evolution from small cells to femtocells

Femtocells are mainly developed for indoor environments [27]. It is a low transmission, short range base station with coverage area of 10 to 30m and power range of 10 to 100 mW [28]. Femtocells are considered as 'plug and play' devices which can be installed in 'Ad hoc' manner. Mobile operators use this ability of femtocell to manage backhaul cost and traffic, as it can help in offloading of data traffic from eNB to femtocell for congestion control. Femtocells can operate in various access modes [29] (i.e., open, close and hybrid) and can be assigned to any distinct spectrum [30]. Around 70% of all data and 50% phone calls are expected to be generated from indoor environment in future [31], however, indoor environment suffers from high penetration losses due to building walls. Femtocells in the indoor environment can significantly reduce the power consumption with better QoS and improve the coverage due to proximity with users.

Femtocell is different from a typical microcell as they are more autonomous and adaptive. The backhaul interface is IP-based, and it supports high latency and low rates compare to picocell. The need of coverage fills in residential environment due humongous increase in traffic leads to new architectural design in cellular environment [32]. A possible way to handle traffic growth situation is reduction in size of cell and reuse of spatial frequency by using small cells [33]. Technological evolution such as availability of wired broadband internet at low cost, standard IP-based and OFDMA deployment in 4G, circuit switched networks, efficient software and hardware integration enabled the economic feasibility of small cell deployment. Self-optimization, auto-configuration capabilities of femtocell with existing small cell environment make them highly efficient plug and play device, also automatic integration ability of femtocell with end users enable them for high scale deployment [34].

Femtocell is efficient for short range communication and high throughout demanding networks, but there are many other abilities such as interference management, authentication, hand offs, etc., which further enhance the usability of femtocell. Femtocell has major impact on various standardizations to bodies like 3GPP and ETSI, for regulation, interoperability standardization, promotion and marketing of femtocell solutions in the industry, regulators, standard bodies.

4.1 Femtocells standardizations

3GPP and 3GPP2 have put forward architectures of femtocells similar to cdma2000 and other three embodiments of UTMS which are CDMA based, its data transmission capability is higher than GMS however, it is highly load dependent. Unlike centralization of power control in CDMA, femtocell power control is distributed with different magnitude at various points and this issue can be handled either by open access control or closed access depending on the interference and availability of band [34].

The focus of 3GPP was shifted towards Long Term Evolution Advanced (LTE-A) technologies [35], where femtocell MAC and physical layer was defined similar to WiMAX, due to the OFDMA design. However, the difference between the two technologies exists in the dynamic allocation of time and frequency slot quantity [36]. Resource allocation in femtocells can be orthogonal with existing macrocells or picocells, which requires efficient interference management and coordination. Semi-static partition is needed between femtocell and macrocell for better throughput in a densely populated environment where large number of physical resource blocks (PRBs) are allocated to macrocells and small number of PRBs to femtocells [37].

4.2 Femtocell modeling

There are many factors involve in modeling channel such as frequency, antenna, propagation model, range, etc., and these factors are theoretically abstracted into more accurate form like path losses, fading effect, shadowing, etc., which are empirical models used in 3GPP [38]. Femtocells are different from typical cellular system, except use of carrier frequency and its channel characteristics behavior that is similar to WiFi channel [39].

Multiple users working simultaneously can be much more complex environment in cellular system. Although many sophisticated modeling techniques are present for broadcast (downlink) as well for multi cast (uplink) channel, but various factors are not considered while modeling [40, 41]. Hexagonal grid model is accepted by most of the research communities due to its analytical traceability, whereas random placing of base station is also considered for signal to interference and noise ratio (SINR) distribution through precise expressions in cellular environment [42].

Femtocell network modeling requires evolution in traditional cellular model, a simple scenario involves one base station which is connected to mobile users and other small cells (downlink), also users (uplink) will act as interferer [43, 44]. Interference is bound to strong in this scenario due to proximity of cells and users which is main limitation of this environment as downlink users suffer from high interference leading to inaccurate characterization. Another modeling approach can be random distribution of macrocell, femtocell and mobile users, which significantly improve SINR distribution and tractability. This model also allows the evaluation of model's impact on MAC and PHY design [45, 46]. Many high-level formulation models, such as game theory can be used for better resource allocation, distribution of channel gain and power control to improve the efficiency of overall cellular model scenario [47].

4.3 Femtocell access control

There are three main subscriber groups for femtocell access control, closed subscriber group (CSG) which includes only registered mobile users that will access linked femtocells, in open subscriber group (OSG) any mobile can access available femtocell [43]. Hybrid subscriber group combines the advantages of both while ignoring the limitations of CSG and OSG access control models. Selection of suitable access control model can be key for any cellular model involving femtocell.

In the previous section we described the femto cell and its evolution and in the next sections issues and challenges of RRH in the HetNets.

5 Issues and challenges of RRM in HetNets

In LTE/LTE-A, small cell HetNets deployment provides many benefits however, many inherent RRM challenges also exist in this environment.

5.1 Interference management

There are mainly two types of interference exist in small cell network, namely co-tier and cross-tier interference [28], in co-tier interference, co-channel interference between similar cells are considered (i.e., between two femtocells), whereas in cross-tier interference co-channel interference between dissimilar cells (i.e., between femtocell and macrocell) are analyzed. Femtocells are mainly used for handling coverage holes in indoor environment, therefore cross-tier interference are mostly less, but deployment of femtocells in highly dense environment leads to high co-tier interference in both downlink and uplink scenario. In multi-hop network where relay nodes (RNs) are also involved, two types interference exist namely intracell and inter-RN interference. Intracell interference occurs when all the links (i.e., backhaul, access and direct link) share the PRBs of same set [48]. Inter-RN interference happen when two RNs share the PRBs of same set, which can be adjacent [49]. Interference occurred between two adjacent RN which belong to two different macrocell is also belong to inter-RN interference.

5.2 Radio resource utilization

Another crucial RRM challenge is to achieve peak data rate by efficient resource utilization when the availability of spectrum is mostly limited [50]. The RRM approach should maximize the spectral efficiency and control the interference simultaneously. Frequency reuse can be an effective way to approach this problem if trade-off is managed well. The HetNets environment is more challenging due to dense deployment of small cells as RRM approach should be adaptive and scalable.

5.3 Fairness

Fairness is another important issue, which need to be tackled by the RRM that requires fair scheduling of packets among connects UEs. In multi-hop network this issue is more complicated as fair resource partitioning is required between backhaul, direct and access links. Fairness is mainly categorized into local and global fairness [51], local fairness is linked with the scheduling of packets among various UEs and global fairness is associated with the fairness of resource allocation between backhaul, access and direct links in multi-hop network. In small cell environment, if the resource requirement at cell level is satisfied, the allocation is called 'globally fair', whereas if the minimum required data rate of every UE is ensured with maximization of resource allocation is called 'max-min fair'. Max-min fair ensure that poor channel quality UEs will receive more resource and better channel quality UEs will receive less resource. Jain's fairness index [52] is used for evaluating fairness as performance metric. Table 2 indicates energy efficient resource management techniques for heterogeneous networks.

5.4 QoS management

Management of QoS is another challenging task in LTE/LTE-A HetNets, where the deployment of small cells is dense and availability of radio resource is scarce. The number of UEs are high and co-tier interference can hamper the QoS experience at UEs level [52]. A sophisticated RRM approach is essential in demanding environment such as airports and shopping malls where number of UEs may increase suddenly with limited resource availability.

5.5 Implementation and computational complexity

Complexity consideration is essential part for deciding the RRM approach in terms of both computation and implementation. Signaling overhead and exchange of data that is required for RRM implementation at base-station is considered as implementation complexity. The time requirement for algorithm execution that is linked with RRM approach is known as computation complexity [51]. Huge signaling overhead which is linked to RRM schemes are not suitable for LTE/LTE-A environment. The allocation of resources to UEs are done for each TTI, if computation time required for executing RRM algorithm is more that single TTI (i.e., permissible computation time) then this approach is not feasible to use in LTE/LTE-A system.

In the next sections we described the existing radio resource management schemes for heterogeneous LTE/LTE-A network with small cells.

6 RRM schemes in heterogeneous LTE/LTE-A networks with small cells

In centralized approach for RRM, a central unit is used for every user association with macro-cell or femtocell. This approach can provide optimal resource allocation with heavy signaling overhead and single point of failure, which is inefficient for highly dense heterogeneous network. A decentralized approach can be more suitable for highly dense network with low signaling overhead and complexity, but optimal resource allocation is difficult in this approach. A hybrid, semi-centralized or partially-decentralized approach for RRM is more practical.

6.1 Frequency scheduling and reuse approaches

It is one of the simplest approaches to allocate the resources (PRBs) to UEs, on the basis of CSI and interference information. In HetNets this approach can be implemented by using orthogonal channel deployment or with co-channel implementation. The eNB decides PRBs allocation to femtocell UEs based on the CSI with interference control of any kind, also its eNB's job to determine which PRBs are the best for each femtocell UE. Considering some other critical factors like power constraints of cell and QoS can enhance the performance of the approach [57]. In another approach more PRBs can be

Table 2 Energy efficient resource management techniques in heterogeneous networks

Description	Technique of computation	Convergence
Energy efficient allocation of resources in HetNets [53]	Optimal LDD with allocation of sub channel and power	Fast convergence towards sub optimal solution with degradation in performance
Intra cell interference management for EE performance improvement [54]	MSC adaptation with scheduling of sub channel	Faster convergence towards suboptimal solution
Joint operating BS with distribution of load [18]	Greedy Hungarian algorithm	Faster convergence towards suboptimal solution
Optimal switching among BS and sharing of resources [55]	Greedy algorithm	Slow convergence with better scalability for users, BSs
Energy efficient allocation of resources with backhaul capacity limitation [56]	Dinkelbach technique	Sub linear convergence towards optimal allocation of power

assigned to UE for satisfying the target outage probability [58]. Fairness in scheduling can be assured by implementing blind round-robin scheme as simple round robin scheduling is inefficient. Matrix-based chunk method of allocation is also suggested, where eNBs are aware of their surrounding and neighborhood to enhance spectrum usage. Matrix chunk scheme also improved the fairness as spectral efficiency and interference trade-off is balanced. The issue of co-tier interference is still a major concern and it is addressed by designing centralized scheme for two tier femtocell network using proportion fair scheduling [59], where UEs are aware of their surrounding interfering eNBs with their respective signal power. In this scheme PRBs are allocated to UEs by central entity (resource manager) based on the CQI and interference information of every UE channel. Resource manager work to reduce the interference by using power control of eNB with minimization of transmission power received by UEs. Proportional fair scheme is better than frequency scheduling approach, although it suffers from the issue of QoS management. As it guarantees QoS requirement per UE, and a UE can have multiple radio bearers which results in different QoS constraints. Resource manager has high signaling overhead which only increases when it is used in densely heterogeneous environment [60].

In multi-cellular HetNets environment, frequency reuse has been a suitable approach to improve overall utilization and interference mitigation at every level. Frequency reuse requires division of channel bandwidth into various frequency band with a defined reuse factor, then these bands are divided and assignment to the femtocell in a manner where reuse of same frequency band is possible between any two non-adjacent femtocells. In this scheme scheduler is used [61] at different levels, an upper level scheduler can be used to find the data flow transmission requirements for every real time connection in predefined frame interval. Lower level scheduler uses proportional fair scheme to allocate PRBs to transmit data, which is already defined by the upper level scheduler. This scheme is efficient for real-time connection due its priority preference, which results in guaranteed low packet losses in data transmission [62]. In this approach QoS requirements are also satisfied as resource utilization is optimized, scheduling is also fair and QoS aware, however, ensuring fairness in highly dense environment is challenging and requires adaptive, intelligent technique. In hyper dense HetNets demand of fairness standard is very different from traditional cellular network, global fairness requires attention as the dynamic frequency reuse technique which only can be tested extensively. Similar way the cross-tier interference needs more attention as femtocells and macro-cell work on co-channel spectrum with limited frequency bands. In another approach scheduling schemes reuses the same PRBs instead of frequency bands [63], also UEs of any non-adjacent eNBs can reuse the same PRBs [64]. In these schemes the allocated PRBs of UEs can again be reallocated and reuse in other non-adjacent femtocells. These approaches can ensure proportional fairness, better resource utilization and efficient handling of both interference. The soft frequency reuse (SFR) technique is applied on macro-cells, eNB distance from cell-center is calculated to achieve maximum throughput on cell-edges with UE defined threshold [65]. In this technique cell-edge UEs exploit total available bandwidth, although cell center UEs can interfere with other UEs at center. This scheme handles the cross-tier interference effectively with optimized resource utilization and less implementation complexity, however, other factor such as fairness, co-tier interference and QoS requirements need further analysis [66].

6.2 Cooperative approaches

Cooperative approach involves exchange of information among base stations to optimize the overall throughput of RRM, it is a suitable approach for HetNets environment where eNBs cooperate with other to minimize cross-tier interference [67]. In down-link communication UEs find the PRBs with the poor-quality signal and determine the interfering HeNB based on reference signal received power (RSRP) [68]. Then these PRBs are excluded from the HeNB with the help of eNBs. In up-link scenario UEs determine the poor PRBs from the set of PRBs based on signal-to-noise-ration (SINR) of eNB signal with the defined threshold value, then HeNB restrict eNBs to use these poor PRBs in future communications. This scheme works better than fixed and non-shared spectrum allocation and for mitigating cross-tier interference, however, co-tier interference, QoS requirements and fairness are not addressed. Also HeNB requires dedicated channel via X2 interface for connection with other HeNBs to exchange various information related to interference gain and traffic loads. To optimize the resource allocation solution, a maximization problem is required with limited information (a NP hard problem) [69]. Water filling algorithm with few modifications and iterations is used for solving this problem [70] which requires two steps. In first step, PRBs are allocated to UEs using proportional fair technique [71] and in second step, power is allocated with respect to each PRBs on HeNB level [72]. Cooperative approach is another effective RRM solution, where problem of interference of both kinds can be addressed, however, it has some weakness in terms of signaling overheads. The cooperation always needs the information exchange at multiple level that increases the implementation complexity, also maintaining QoS requirements is another cause of concern that need proper attention [73].

6.3 Femtocell aware spectrum allocation approach

In this approach the bandwidth is divided into two different spectrum, one is dedicated to macrocell and other to femtocell, it's another important component is femtocell-interference pool which has the list of UEs that can interfere nearby femtocell. PRBs are allocated from macrocell spectrum to the member of femtocell-interference pool, while at the same time PRBs can be allocated to other UEs from the dedicated macrocell or femtocell spectrum. The UEs with high CQI and low speed are considered as interferer in macrocell dedicated spectrum [74]. Co-tier interference is handled using two strategies, first one is orthogonal allocation of spectrum where spectrum is divided into different portions and allocated to groups of UEs and other strategy is co-channel allocation of spectrum where all UEs can share the allocated spectrum.

6.4 Hybrid and priority-based spectrum allocation approaches

The orthogonal spectrum allocation needs division of spectrum into different portion which can serve various groups of UEs, it is efficient technique for interference management but not for resource utilization. Another approach is co-channel allocation where every UE share the same spectrum which leads to better resource utilization, but it suffers from high interference. A hybrid approach can use the strong aspect of both these allocations while minimizing the weaknesses, the spectrum bandwidth can be assigned to macro-cell user equipment (MUE) and a portion of it is given to femto-cell user equipment (FUE) [75]. A semi-static spectrum management scheme is designed for two-tier LTE network, which divide the spectrum and serves on the basis of inner and outer UEs based on their distance from the eNB [76]. For the reduction of cross-tier interference in downlink mode, fractional power control (FPC) scheme is proposed [77]. Hybrid spectrum allocation approaches essentially focus on spectrum sharing among various UEs, therefore interference management is always a challenge and most of these approaches ignores the QoS requirement issues which are also very critical for future communication requirements.

Several divisions of bandwidth are done in same sized chunks which are then assigned to a specific femtocell, these chunks are prioritized for every respective femtocell. The PRBs are allocated from these chunks to the FUEs of a femtocell and if additional PRBs are needed, chunks of low priority are selected based of the average SINR from neighboring femtocell [78]. Global fairness is achieved by using this scheme but whenever low priority chunks are used, it always leads to co-tier interference as the same chunks can be assigned to other FUE. A power control technique is used for minimization of co-tier interference, but cross-tier interference is not addressed in this approach.

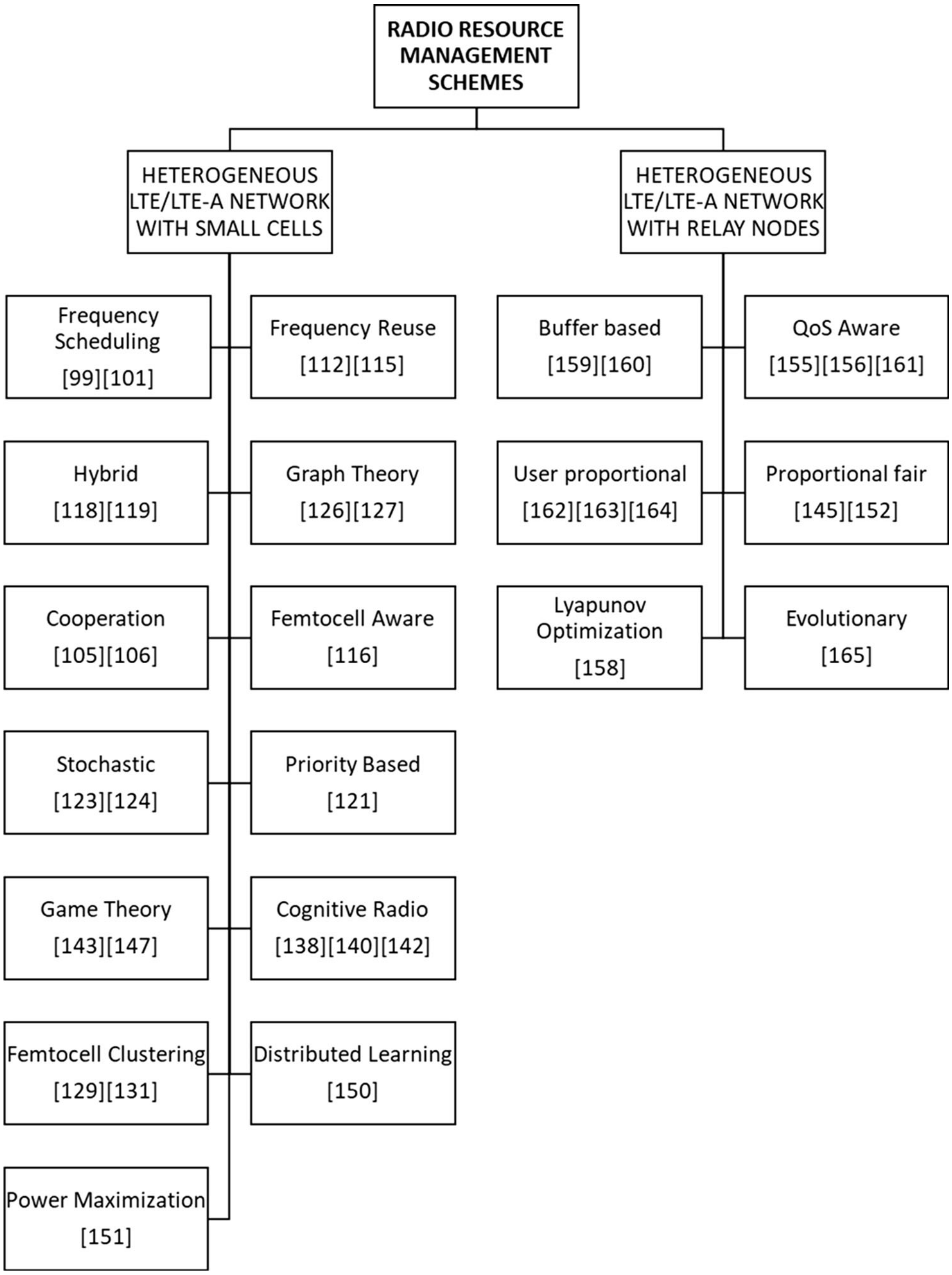
6.5 Stochastic resource allocation approaches

Resource allocation based on the probabilistic likelihood characterization with respect to interference among BSs or other FUEs is known as ’Stochastic’ allocation of resource. Bandwidth can be divided into same sized chunks and the allocation PRBs of these chunks is done based on probabilities. A FUE with high selection probability is chosen for PRBs allocation and less probabilistic chunk's PRBs is allocated to MEUs. The MUEs are further classified in indoor and outdoor to handle cross-tier interference [79], also different size of chunks is created for high and low probability selection. A decentralized approach is considered for stochastic allocation of resource in both uplink and downlink LTE femtocell network, where the bandwidth is divided into two different sets of PRBs and one is chosen for indoor and other for outdoor MUEs [80]. Based on the probability, PRBs from any set can be allocated to FUEs, one bias parameter is also included with PRBs for probability calculation. The scheme's complexity is low, but interference issues increases and efficiency decreases with the growth of femtocell size. For handling cross-tier interference, shadow chasing approach is introduced which uses the obsolete downlink control information (DCI) [81]. Allocation of PRBs is known to the eNB which uses acknowledgement (ACK) and negative-ACK (NAK) signal with obsolete DCI to determine the probability of PRBs used by indoor or outdoor MEUs. Allocation of PRBs with the likelihood and FUEs association help in managing cross-tier interference. Various stochastic resource allocation is effective in interference management and resource utilization as well as in low complexity implementation, however, QoS requirements considerations are missing in these approaches. In Fig. 2 we classify the Radio Resource Management schemes applied on HetNets. The classification is based on the relay nodes presence in small networks.

6.6 Graph theory approaches

Interference is one of the complex and challenging problem in the dense heterogeneous LTE/LTE-A network, graph theory can help in resolving this problem where interference relationships can be represented as graphs. A hierarchical RRM approach is introduced where various phases are defined, firstly number of PRBs for every eNB are decided for maintaining minimum data rate using channel

Fig. 2 Classification of radio resource management schemes in HetNets



gain by every FUE. In the next phase a central entity creates an interference relationship graph for every pair of eNBs based on the distance, then each eNB is represented by collection of nodes (vertices) where number of nodes is equal to required PRBs and links (edges) are created if two nodes belong to same eNB [82], otherwise these nodes create interference for each other. In next phase resource allocation is done using graph coloring method where a color is assigned to each node after PRB allocation, if two different color is given to two linked nodes then these two do not share the same PRBs. This approach is efficient for interference management and resource utilization however, graph coloring is NP hard problem and heuristic approach [83] is needed to solve this problem in dense network. In the final phase power allocation is independently done by eNB for every PRB. Global and local fairness problem are handled by PRBs assignment which is based on channel quality and achievable rates. Signaling overhead and implementation complexity are also low due to decentralized nature of packet scheduling which is linked with every eNB. A minimum transmission power can be linked to eNBs for minimization of interference received by UEs to a certain level. However, QoS requirements such as high data rate, low packet loss rate, latency and delay need further analysis. QoS constraints can be taken into consideration by including QoS class identifier (QCI) and Guaranteed Bit Rate (GBR). The QCI of connection is identified and if it belongs to non-GRB category, at least one PRB is allocated to this connection otherwise, it indicates low connection satisfaction with allocated PRBs. Graph theory approach also enhance the spectral efficiency with interference management, however, the complexity of implementation is higher and centralized server suffer with high signaling overheads.

6.7 Cognitive radio approaches

Spectrum scarcity is a major problem of modern communication evolution and cognitive radio can provide a potential solution for this issue. It is based on the exploitation of unused or under-utilized spectrum in available frequency band [84, 85]. Spectrum sensing, mobility, sharing and intelligent decision-making help cognitive radio technique to exploit the otherwise wasted spectrum. Two types of network are defined for cognitive radio technique, primary network which owns few frequency bands known as licensed bands and secondary network which does not own any frequency band. Primary network is used by primary user which can access the bands all the time, whereas secondary users detects the spectrum holes [86] in licensed bands and then transmit without interference with primary users. Cognitive radio frequency scheduling is proposed, where eNB receive information related to scheduling and PRB allocation to MUEs through backhaul [87]. The eNB uses cognitive radio technique for spectrum-sensing to find the nearby MUEs occupied PRBs, then compare it with scheduling information for avoiding co-tier interference. This approach is a cooperative technique where eNBs share the information regarding scheduling with other eNBs. Another approach uses the proportional fair frequency scheduling for better local fairness [88], additional TV bands are used to remove both co-tier and cross tier interference with improved fairness [89], however, implementation complexity is high with no guarantee of QoS. Two different cooperation model are introduced for resource allocation, in first model FUEs are used as relay station for MUEs using opportunistic cooperation where primary band occupancy is less as cooperative relay provides more transmission opportunities for FUEs [90]. The other is interference model, which allow simultaneous transmission for both primary and secondary user by deferring transmission during busy primary user transmission period. Power allocation problem of this approach is solved using Markov decision making [91]. For LTE, femtocell specific scheme uses sensing frames and data frames to create a sensing period, which is linked with single LTE sub frame [92]. Spectrum sensing is done to detect occupied PRBs for every sensing frame, sensed data is processed for information extraction to determine PRBs association with FUEs and eNB and respective data frame uses effective capacity theory [93] to ensure QoS. Better QoS is ensured in another approach where different QoS classes are created namely real-time, non-real-time and best effort, which are determined using various factors like packet loss, delay, bit error rate, etc. Also, an optimization problem is formulated which is solved using multiple stages by assigning different priorities to UEs that guarantees better QoS. However, it suffers from fairness issues and co-tier interference [94]. Cognitive radio schemes mostly ensure better spectral efficiency and resource utilization with low implementation complexity but have high computational complexity.

6.8 Game theory approaches

Game theory is mathematical decision-making technique that can be used in the context of resource allocation, where decisions are taken by BSs for efficient resource management. In the existing cognitive radio approach [92], a strategic game can be formed where every eNB has strategic profile which is linked with set of probabilities, these probabilities indicate the use of fix PRBs out of available PRBs, whenever available PRBs are sensed [95]. The expected pay-off is avoidance of co-tier interference for these fix PRBs. Nash equilibrium [96] is reached at certain iteration of game, if the pay-off of every eNB is same for all fix PRBs corresponding to some probability and no other profile linked with eNB can provide better pay-off than the current one. A utility function is created with three components, first component focuses on data rate demands linked with eNB, second is related with fairness of PRBs consumption by eNBs and the last one corresponds to transmission power control for co-tier interference management, maximization of this utility function locally is the goal of strategy game. Concept of correlated equilibrium is introduced for global and local fairness assurance [97, 98]. A cooperative game approach is also designed with cognitive femtocell network, where coalitions of UEs are created and they are assigned to one BS, these coalitions maximize the throughput of network with guaranteed fairness. A utility function is formed that shows the throughput achieved by the UEs which belong to coalition, pay-off of the game increases in terms of throughput using utility function after joining the coalition. More constraints are added to this utility function, one is ensuring the pay-off sum should remain equal to the total coalition revenue, other is subscription of UE which belongs to closed access femtocell. One more constraint ensures a predefined pay-off for every UE joining any coalition otherwise it remains as singleton without any BS, and last constraint relates to fair allocation of resources which ensures no other coalition for UEs exist with better pay-off than current one. These utility function constraints make the optimization problem more accurate for cooperative coalition game and its solution satisfies most of the requirements needed for efficient resource allocation [99]. Optimal pay-off allocation or solution is referred as core, reaching to core is overall objective of game. Distributed coalition is also suggested for reaching to the core earlier. The implementation complexity of this approach is less, however, reaching to the core is computation extensive problem. Table 3 shows the RRM schemes comparison in LTE/LTE-A femtocells networks. In Fig. 3 three different clusters are shown with respective cluster heads and main base stations.

6.9 Distributed learning approaches

Learning from the environment is another approach investigated by the researchers for making resource management decision in small cell network. A reinforcement learning is used for managing the cross-tier interference in distributed manner, proportional fair method is used for resource scheduling and transmission power to eNBs are assigned with a particular manner [100]. Q-Learning is used in place of decentralized learning in another scheme, where eNBs act as learning agents with fixed set of actions [101]. A cost utility function is created for action evaluation which can increase or decrease cost function value, increase in utility cost indicates power level has crossed predefined threshold. Q-values refer to discounted sum of expected cost in future which are linked to each eNB and when an action is taken, Q-value with a state and an action becomes part of learning. Optimal power allocation in any state means smallest Q-value for this state after taking a particular set of actions. RRM schemes proposed in distributed learning efficiently manages cross-tier interference, local fairness but QoS and global fairness issues need further investigation [102].

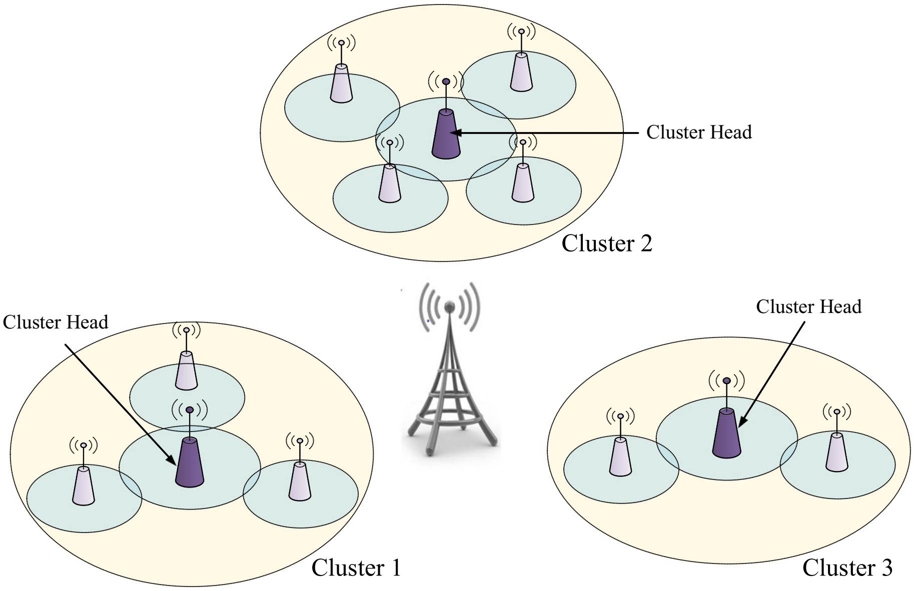
6.10 Femtocell clustering approaches

Femtocell clustering is based on the grouping of the femtocells which are interfering with each other, the grouping creates the cluster which reduces co-tier interference with great scalability. The resource allocation based on femtocell clustering is done in three stages [106], first each eNB generate a list of interfering neighbors at one-hope distance with neighboring femtocells and sent it to its neighbors

Table 3 RRM schemes comparison in LTE/LTE-A femtocells networks

Scheme		Complexity	Interference	Spectral efficiency	Guarantee of QoS
Frequency scheduling	[57]	Low	Low	High	Medium
	[59]	High	Medium	Medium	Low
Frequency reuse	[63]	High	High	High	Low
	[66]	Low	High	High	–
Hybrid	[103]	Low	High	High	Low
	[76]	Low	High	High	Low
Graph theory	[104]	Medium	High	High	Low
	[105]	High	High	High	High
Cooperation	[69]	Medium	High	High	–
	[70]	Medium	High	High	Low
Femtocell aware	[74]	Medium	Medium	Medium	Low
Stochastic	[80]	Low	Medium	High	Low
	[81]	Low	High	High	Low
Priority based	[78]	Low	High	Medium	Low
Game theory	[96]	Medium	High	High	Medium
	[99]	Medium	High	High	Low
Cognitive radio	[91]	Medium	High	High	–
	[93]	Medium	High	High	Medium
	[95]	Medium	Medium	High	High
Femtocell clustering	[106]	Medium	High	Medium	Low
	[84]	Medium	High	High	Medium
Distributed learning	[102]	Medium	High	High	Low
Power maximization	[107]	Medium	High	High	Medium

Fig. 3 Femtocell clustering



which are at one-hop distance. Then eNBs calculate the degree of interference and then cluster heads with highest degree interference is chosen for the one-hop neighborhood. In the next stage PRBs allocation is done by cluster head, where it aims to allocate the PRBs and minimize the highest difference between number of PRBs required and PRBs allocated. This optimization can be solved using ILOG CPLEX solver [108], round robin scheduler is used for packet scheduling to FUEs. In the last stage feedback is available from every FUEs, which is transferred to its connected eNB regarding PRBs collisions, when different clusters share the same PRBs. Orthogonal allocation of spectrum is done to reduce the cross-tier interference and spectral efficiency improvement. Some improvements are made over initial approach for cluster head formation which leads to better overall fairness and QoS, however, implementation complexity still remains high [109].

6.11 Power minimization approaches

Transmission power has a direct relation with interference, therefore power minimization RRM schemes are also investigated where their main objective is to reduce co-tier interference [107]. Joint allocation optimization problem for PRBs is formulated for UEs to minimize total transmission power related to eNBs. A constant has been included in problem which ensures the minimum throughput demand of every UEs through PRBs allocation by eNB that consists various transmission power levels. To maintain a tolerable SINR for every UE another constraint is added and a network-simplex algorithm is considered for solving the optimal power and PRBs allocation problem. The RRM mechanism is executed at every eNB level which reduces the implementation complexity with better utilization of resources and interference management, however, it suffers with high signaling overhead and computation complexity.

In the next sections existing radio resource management schemes for heterogeneous LTE/LTE-A network with relay nodes is described performance comparison.

7 RRM schemes with relay nodes in LTE/LTE-A

Multi-hop network in LTE/LTE-A involves relay nodes (RNs) which relay packet transmitted from eNBs to UEs as mediator to cover larger region where two different transmissions occur, one through backhaul and other by access link.

7.1 Proportional fair approaches

The design objective of this approach is to achieve both local and global fairness using proportional fair scheme, a maximization problem is formulated to achieve total proportional fairness for every UEs through summation of logarithmic rate [51]. Solving this problem results in proportional fairness, but this problem is NP-hard and has high implementation complexity and signaling overhead. These issues are solved using two step approach, in first step resource partitioning is done between accesses, backhaul and direct links. Some assumptions are made related to achievable rate for backhaul and direct link access where Lagrange method is used for solving the maximization problem. In the second step, two different scheduling techniques are used for PRBs allocation, in backhaul sub frame eNB uses buffer-aware scheduling for every RN, then proportional fairness scheduling is used by eNB and RNs for accessing sub frame to allocate PRBs among MUEs and RUEs. This scheme is better in terms of spectral efficiency, local and global fairness. Also, the intracell interference can be reduced using Coordinated multi point (CoMP) transmission in a manner where both eNB and its associated RNs jointly serves the UEs and CoMP can help in traffic load balancing as well. Implementation complexity of these schemes are high as every eNB act as centralize server which is making decisions also QoS guarantee is not assured [110].

7.2 QoS-aware resource allocation approaches

A two-level scheduler is proposed by this scheme which ensures QoS requirements, first level scheduler determines the data requirements for every radio bearer to satisfy delay in LTE-A frame interval level [62, 111]. Scheduler of lower level work on quota determination of data used by proportional fair scheduling scheme for PRBs allocation, static frequency reuse technique is also used in the scheme. Another approach for multi-hop LTE-A network in uplink scenario is considered where concept of intra-cell CoMP [110] is used, eNB and UEs transmission is overheard and regenerate-and-forward technique is used at every time slot for next time slot transmission. Optimization problem is created to maximize the throughput of network while considering the QoS constraints, this problem can be solved by using dual decomposition. First power allocation is optimized using Katush-Kuhn-tucker condition [72], then joint optimal selection of relays and PRBs allocation is done using sub gradient technique. This scheme suffers from signaling overhead, selective fairness and high implementation complexity [112]. Super flow concept is introduced in another approach which is a grouping technique of data flow for a CQI number linked with each backhaul flow at eNB. These super flows are scheduled after QoS metric consideration with links delay and data rate requirements that improve the QoS and global fairness significantly, but overall complexity is still high [113]. Table 4 shows, RRM schemes comparison with Relay Nodes in LTE/LTE-A networks.

7.3 Evolutionary approaches

A genetic algorithm is proposed for resource allocation in LTE-A multi-hop environment where the main goal of scheme is throughput and fairness maximization with load balancing between RNs and their respective eNBs. An optimization problem is formulated where channel gain of UEs and optimal PRBs allocation is considered for throughput maximization. The modeling of this problem is done using weighted bipartite graph where eNBs represent the vertices and edges are channel quality between RNs or UEs, genetic algorithm is executed repeatedly with a certain termination condition [122]. A set of solution is selected and initiated randomly with some mutation, the solution must converge to a single set (i.e., PRBs allocation and channel gain) which is the final solution. Genetic approach can achieve high resource utilization, better interference management and fairness, however, a centralized server always increase the implementation complexities, also convergence to a solution is a known issue of evolutionary approaches.

7.4 Lyapunov optimization approaches

A joint allocation optimization problem is formulated can be solved using Lyapunov function while considering number of constrains. Maximization of logarithmic average rate by every UEs is the problem with many constrains such as guaranteed stability if packets queue is related to RNs and eNB, fix average and instantaneous power threshold, limited number of active packets, one PRB to every UE, no concurrent transmission between access and backhaul link for same sub frame, etc. [120]. An auxiliary variable is added in the constrains and Lyapunov function is defined with packets queue length for eNB and RNs, also with the power and virtual queues for auxiliary constraints. Drift-plus-penalty function of Lyapunov is used for minimization of certain components which results in optimal sub frame which satisfies power and PRBs allocation requirements. Standard differentiation is used for minimization of auxiliary constraints as a convex problem, dual decomposition is used for PRBs and power minimization when joint allocation of sub frame is done. This approach is efficient for multi-hop LTE-A network with high spectral efficiency, local and global fairness, better intracell and inter-RN interference management. However, the QoS requirements are not considered and implementation complexity is high. Figure 4 describes a scenario of joint transmission CoMP where edge users (red rectangle region) are benefited because of neighboring base stations cooperation.

Radio resource management can be divided into few major task such as radio interference management, spectrum management and energy management. The next few sections radio interference management is discussed.

Table 4 RRM schemes comparison with relay nodes in LTE/LTE-A networks

Scheme		Complexity	Interference management	Spectral efficiency	Guarantee of QoS
Buffer based	[114]	Low	Medium	Medium	Low
	[115]	Low	Medium	Low	Low
QoS Aware	[112]	High	High	Low	Medium
	[113]	Low	Medium	Medium	High
	[116]	Low	High	Low	High
User proportional	[117]	Low	Medium	Medium	Low
	[118]	Low	Medium	Medium	Low
	[119]	Low	High	Low	Low
Proportional fair	[98]	Medium	High	Medium	Low
	[110]	High	High	Medium	Low
Lyapunov optimization	[120]	High	High	High	Low
Evolutionary	[121]	High	Medium	Medium	–

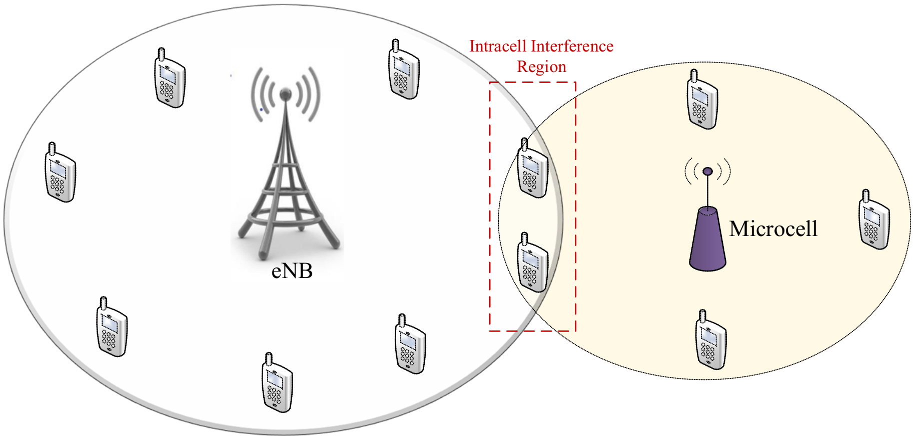


Fig. 4 CoMP joint transmission for edge users

8 Radio interference management (RIM) schemes

Ultra dense network (UDN) deployment in 5G can cause serious co-channel interference if single frequency is used for BSs, it can ultimately leads to bad QoS experience for cell edge users [123, 124]. UDNs can be clustered to embrace multi-frequency system as 5G architecture always has various RATs and tiers that works in non-overlapping spectrum of frequency using coordinated control of transmission power. Few motivations behind the work for RIM in 5G are following (1) hyper dense heterogeneous deployment of devices, (2) traffic load imbalance and coverage issue because of different transmission powers of various BSs, (3) different kinds of access restrictions results in various interference levels, (4) different frequencies priorities for accessing channel and strategies of resource allocation [12]. Table 5 lists RRM schemes comparison with Relay Nodes in LTE/LTE-A networks.

8.1 Coordinated multi-point (CoMP) transmission based

CoMP is suggested by many schemes to counter co-channel interference, where many BS jointly serve receivers with simultaneous data transfer that results in better data rate and cell-edge performance [125]. This scheme highly depends upon CSI and data sharing between transmission points (TPs) which indicates toward high CSI feedback overhead, backhaul latency, low capacity and synchronization issues between TPs [126]. Game theory-based clustering and cooperation in CoMP is suggested where lower signaling overhead and better performance is observed [127–129]. Cluster-wise beam forming is done jointly with coalition game formation in the small cell for BSs cluster. The recursive core is achieved using merge algorithm which has low complexity with better QoS performance in UDNs however, cross-tier interference management in multi RATs environment costs high CSI

Table 5 RRM schemes comparison with relay nodes in LTE/LTE-A networks

Scheme		Complexity	Interference management	Spectral efficiency	Guarantee of QoS
Buffer based	[114]	Low	Medium	Medium	Low
	[115]	Low	Medium	Low	Low
QoS Aware	[112]	High	High	Low	Medium
	[113]	Low	Medium	Medium	High
	[116]	Low	High	Low	High
User proportional	[117]	Low	Medium	Medium	Low
	[118]	Low	Medium	Medium	Low
	[119]	Low	High	Low	Low
Proportional fair	[98]	Medium	High	Medium	Low
	[110]	High	High	Medium	Low
Lyapunov optimization	[120]	High	High	High	Low
Evolutionary	[121]	High	Medium	Medium	–

overheads. Another approach includes the optimization of mutual information in distributed manner for MIMO Gaussian channel where Nash Equilibrium (NE) is achieved by using metrics of transmit covariance. RNs activation probability is suggested as well where the transmission can be jointly cooperative and non-cooperative depending on the condition of the channel which will improve the overall sum rate. A control model for channel is created with cooperative clustering and various architectures of CoMP is used, first is centralized, next is semi-distributed and finally fully distributed [130]. This model improves the reliability of 5G with performance gain, but messaging overhead can be high during heavy traffic condition [131].

8.2 Advanced interference management scheme

Advanced interference management (AIM) is focused on empowering UEs as well as BS, where every UE (i.e., receiver) is capable enough to make interference decisions based on signal characteristic such as coding scheme, modulation, resource allocation scheme, etc., [132]. Every receiver decodes the symbols to distinguish co-channel interference present in neighborhood from physical characteristics and thermal noise, to reconstruct and cancel received signal for managing interference effectively. However, high signaling overhead, complexity of system, lack of practical architecture and CSI are the major issues in this approach. Turbo receiver are suggested to work along with AIM schemes with its coding, modulation and separate MIMO [133]. In the coding part, bit-interleaved coded modulation (BICM), space time, precoding is included which are based on quadrature amplitude modulation (QAM) or low-density parity check (LDPC). However, due to large code block length and modulation order the implementation complexity grow very fast with increase in number of users. Table 6 shows, RIM schemes in 5G with QoS requirement.

8.3 Power control for multi-tier RAN systems

Interference management for co-channel and intercell communications, requires more intelligent power control system. Open loop power control (OLPC) is suggested to vary power levels for tracking variations of fast fading to adjust mechanisms of adaptive modulation and control (AMC) [143, 144]. Feedback messaging is used by BS to correct the power transmission level for UEs to achieve seamless mobility and high data rate [145–147]. In this scheme, intercell interference is managed by uplink power control while co-channel interference is managed by downlink power control. Self-interference of full duplex communications (FDCs) and intercell interference of multi-RATs in 5G leads to various schemes such as hybrid of multiple medium access control (HM-MAC), LAS-CDMA, OFDMA and MC-CDMA. Learning based adaptive power control (LeAP) is also suggested which uses the neighboring cell interference information to reduce multi-tier intercell interference [109], learning algorithm uses the transmission power control variable sets to optimize the overall throughput and latency of the network [134]. Use of fast heuristic technique can help in the convergence of optimal solution for improving QoS. A fully decentralized heuristic approach with self-organization is suggested with interference and power control management where transmission power is dynamically controlled according to QoS requirements of UEs [148]. However, decentralization of power control limited to every tier is not suitable for multi-

Table 6 RIM schemes in 5G with QoS requirement

Scheme	Massive number of devices	Huge traffic	Diverse use cases
Power control in multi-tier [134–137]	Yes	Yes	Yes
CoMP based transmission [125, 126, 129]	No	Yes	Yes
AIM based [132, 133, 138]	Yes	Yes	No
MIMO channels-based [139–142]	Yes	Yes	Yes

tier environment, also asymmetric operating powers of various BSs is a big challenge. A graphical theory-based scheme is introduced to manage interference and QoS requirements in multi-tier RAT architecture [149]. Two phase solution is given to manage intercell interference (ICI) problem first is coarse scale and other is fine scale ICI management with channel-aware resource allocation. Set of various UEs linked with different multi-RATs are represented in the interference graph, BS cooperation is mapped into MAX k-cut problem which affects ICI coordination, also CSI conditions are exploited by the problem formulation. Instantaneous CSI is evaluated to find the solution with downlink multi-cell OFDMA for ICI management with high data rates, however, flood of instantaneous CSI can hamper the QoS experience. A multi-tier joint power control scheme is proposed which can resolve the interference issues of different tiers (i.e., micro, femto, pico, etc.), in a coordinated 5G system multi-layer deployment, the scheme can reduce the interference [150, 151]. A joint multi-tier power control system can help the network to acquire and surrender the resources in coordinated manner which ensures performance improvement of network in terms of power control and interference at cell-edges.

8.4 MIMO channels-based interference mitigation scheme

Current and instantaneous CSI at transmitter (CSIT) is used for MIMO based interference management schemes [139, 152, 153], MIMO Broadcast Channel (BC) which uses multi-antenna can achieve higher degree of freedom (DoF) and low delay with CSI feedback. Antennas deployment in large scale is used in an approach, which provide highly directional vectors with linked channel which can be modeled as random vectors of Gaussian model [154]. In this approach tier-1 BS can be used for directional beam forming [155] to reduce intercell interference from tier-2 cell. Reverse-TDD (R-TDD) and co-channel-TDD (co-TDD) is also introduced, in which downlink of tier-1 is aligned with uplink of tier-2 (and vice-versa) and down-link of tier-1 is aligned with downlink of tier-2 (and vice-versa) respectively. In most of the cases, performance of R-TDD is better than co-TDD however, amount of CSI feedback is huge and computational complexity is high [156]. In another approach massive MU-MIMO downlink interference management is suggested by using pre-beam forming for various group of UEs based on the multiplication of actual matrix of channel and pre-beam forming matrix. Information of channel statistics are used instead of CSI which varies slowly and can be estimated faster. Partial connectivity between small cells and macro cell is suggested in HetNets environment where two step interference alignment is designed for macro cell users and DoF of the system [157], self-interference and interference due to simultaneous transmission is controlled because of partial connections. A semi-distributed MIMO interference management technique is suggested with five different phases: access point discovery, MIMO-weight computation and CSI measurement, synchronization and link-set-advertisement, transmission of data, and acknowledgement [140]. Interference is managed using spatial multiplexing and interference canceling, a MIMO weight is assigned to every participating node depending upon CSI measurement. This scheme successfully handles the MIMO channel interference, but a few assumptions of the scheme are not applicable in the 5G system scenario. Figure 5 describe the classification of radio resource management techniques based on various schemes (i.e., energy efficient management (EEM), Hybrid Resource Management (HRM), Radio Interference Management (RIM) and Spectrum Efficient Management (SEM)).

Spectrum management is discussed in the next few sections which is key part of radio resource management.

9 Spectrum-efficient management (SEM) schemes

The spectrum scarcity is one of the major limitations faced by providers of cellular service in wireless environment, as carrier frequency spectrum of mobile broadband lies between 700 MHz to 2.6 GHz. Every major provider of

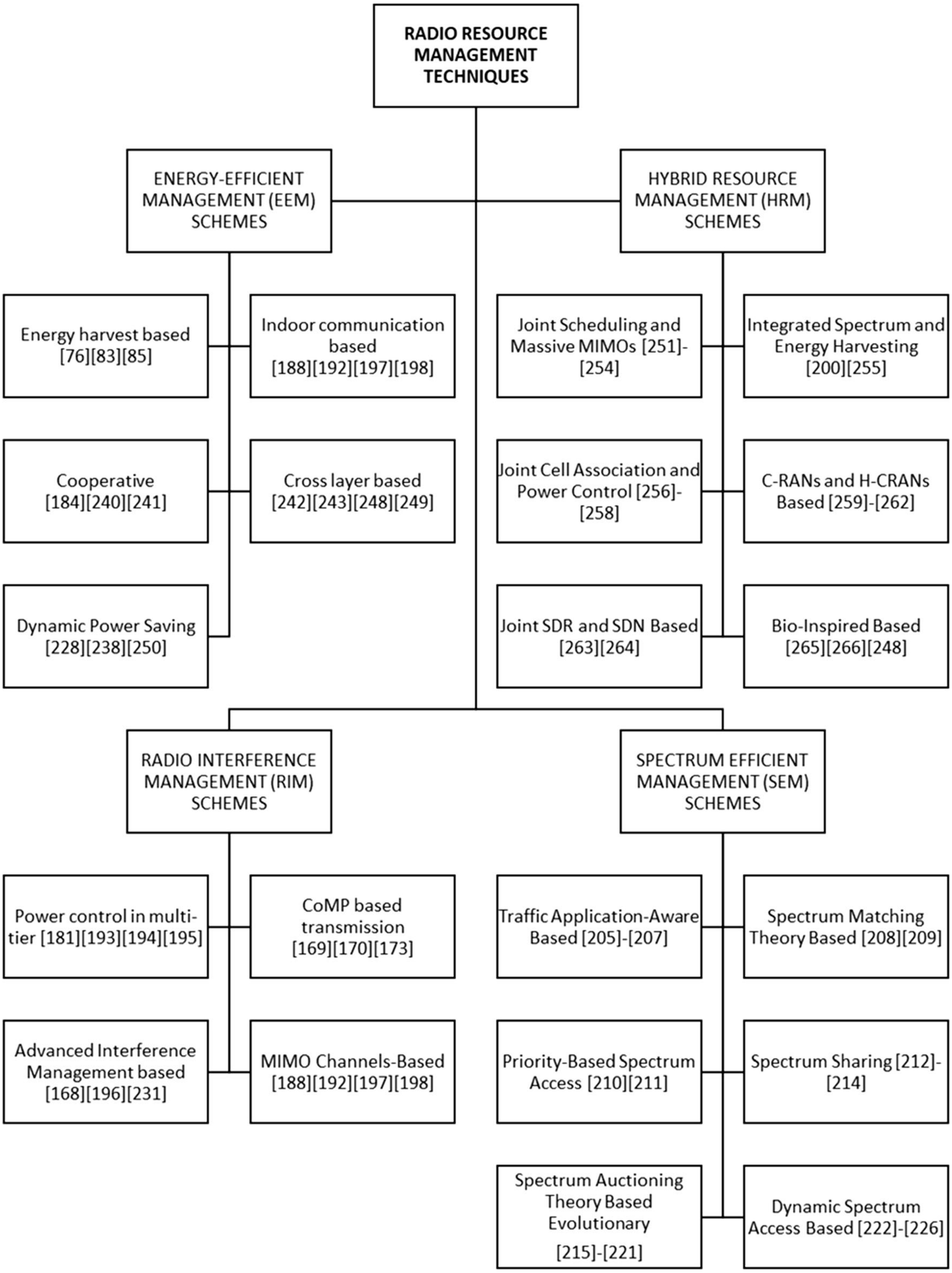


Fig. 5 Classification of radio resource management techniques

cellular services has only 200 MHz bandwidth spectrum across every mobile broadband and broadband mobile application must not exceed 780 MHz bandwidth spectrum [158]. The mobile operators have divided the spectrum allocated to them into various frequency bands, which has different RANs, penetration losses and propagation attributes [159]. 3GPP has explored more spectrum to deal with scarcity, some of the exploited parts are 470 to

694 MHz, 694 to 790 MHz, 3600 to 4200, 4400 to 4990, and some band near to 2GHz as well, they are open for use by International Mobile and Telecommunication (IMT) [157]. For UDNs and D2D network milli-meter Wave (mm-Wave) cellular systems are suggested which offer new frequencies range from 28 to 38 GHz and beyond, also growing spectrum demands has forced 3GPP to introduce spectrum aggregation of carrier components (CCs). This technique can improve user throughput in LTE-A network and future 5G environment as well [156].

Allocation of resource with existing scarcity of spectrum create a bigger challenge for 5G system where multi-tier (i.e., macrocell, picocell, femtocell, D2D) network exist [160]. The new advances in 5G technologies such as UDNs, massive MIMO, full-duplex communication (FDC) has opened the doors for innovative radio spectrum resource scheduling [161–163]. Spectrum resource scheduling uses the available spectrum and assign it to every user efficiently by meeting their QoS requirements such as low latency, high data rates, longer life of battery, reliability, etc. In future, it is expected that a scheduler and RB (i.e., smallest resource radio unit) will be assigned to every UEs in the shared channel of available spectrum where every RB has 12 OFDM sub-carriers at adjacent position with 15 kHz spacing between sub-carriers. QoS requirements, buffer status and CSI will play key role in taking scheduling decision at UEs level [124].

9.1 Traffic application-aware based

Application-aware scheduling approach uses utility function that represent various applications working on different UEs. This function can be sigmoidal and logarithmic, objective of this function is to maximize the overall cellular network utility with efficient resource allocation and proportional fairness among every utility [164]. In another approach time, location and content awareness is included in optimization problem to allocate resource effectively by eNB to various UEs with multiple applications [165]. Different priority is given to inelastic and real-life traffic for delay tolerable algorithms which help scheme to perform better in terms of QoS requirements than proportional fair approach [166]. Application aware scheme perform better in QoS aspect as it is independent of 5G physical infrastructure however, its performance is indifferent to tiers and priority of UE's applications which can have diverse QoS requirements.

9.2 Spectrum matching theory-based scheme

Multiple decision-making agents are used to find stable matching for resource allocation of available spectrum, the optimal match of transmitter and transmission alignment is done by every agent through various actions to reach optimal solution [167, 168]. Agents have the list of matches preferred by matching process (i.e., request, rejection and confirmation bases on preference profile) and a mutually beneficial outcome which will be selected.

9.3 Priority-based spectrum access scheme

Traffic and tier-based priority for spectrum access is discussed when a priority is given to traffic based on the UEs QoS requirements, whereas tier's priority help the UEs to access spectrum at various tier levels [12, 169]. In tier-based priority, dead zone is created by microcell to manage interference level for downlink MUEs where high priority MUEs carry more spectrum than low priority MUEs. This approach also suggests use of joint cell association and power control (JCAPC) to achieve high throughput, traffic load balancing, high signal to interference ratio (SIR), etc., in multi-RATs system. In another approach, reuse of frequency spectrum is proposed where high reuse type is assigned to the users with stronger SINR and low reuse type for the users at cell-edge [170], OFDMA is also used which involves tight synchronization of orthogonal frequency throughout the cell which mitigates the intercell interference.

9.4 Spectrum sharing schemes

Spectrum sharing approach suggest improvement in fairness and throughput for WiMAX and WiFi users [171], an index is calculated and attached to the system which iteratively check the capacity of system with every user connection until system is optimized. In another approach operators decides if they want to share the spectrum or not based on the favors use by receivers, where a repeated game is also involved to reach Nash Equilibrium [172]. Same set of action is taken in every stage of the game which can be played multiple times and its outcomes help in formation of iterative algorithm [167]. The design of the algorithm creates many challenges if the optimal resource allocation is not found, as low complexity cannot be then assured for cross-tier algorithm execution. Many other technical problems of this scheme such as routing and spectrum assignment (RSA), spectrum defragmentation, architectural efficiency, reconfigurable optical add/drop multiplexer (ROADM) and efficient spectrum transmission techniques, still need further investigation [173].

9.5 Spectrum auctioning theory based scheme

Spectrum auctioning is proposed where agents (transmitters) are involved in bidding process by increasing the cost of acquiring the spectrum through information exchanges where the resource will be finally allocated to the highest bidder (highest cost with transmitter) [167]. In an approach the valuation of spectrum bidder is fixed until the next stage of repeated game start [174], in this game the players may select their action based on the previous sequence of payoffs and current payoff. Although the complete information is mostly unavailable, therefore cooperation can be difficult. Cooperation requires exchange of favors over many stages in time, any operator can calculate utility gain on the basis of favors got vs favors given, gain can be reduced due to interference present or granted favors not being used [172]. However, achieving optimal solution in multi-tier architectural 5G with massive number of BSs and UEs is unlikely even in repeated game scenario. Mobile broadband systems can share the spectrum broadly in two manners, distributed and centralized [175]. The Centralized entity does not share the spectrum directly with systems, whereas distributed system interacts with each other more freely, in distributed systems interferer can coordinate for better performance. Distributed sharing of spectrum is done using channel selection which can be dynamic frequency selection (DFS) or dynamic channel selection (DCS) by spectrum sensing where system can select frequency on the basis of features or energy detection [176]. In centralized sharing scheme, geo location database (GLDB) technique is suggested where location of resource is available for accessing [177], another approach is spectrum broking where sharing negotiation is done horizontally, and short-term spectrum is granted to central entity exclusively [178]. Multiple operators can engage in sharing the spectrum for a time period by using multicarrier waveform technique [179], spectrum can be continuous or scattered with primary, secondary and license rights. Filtered bank based multi-carrier (FBMC) waveforms can be used which allows adaptability in waveform by using sub-carrier spacing and prototype filters with frame structure on the basis of propagation environment and traffic [180]. Spectrum manager is first functional unit which is used to calculate many important spectrum parameters. More BSs can become part of one operator which uses the manager for spectrum sharing among them. Second unit helps in transmission waveform adaptation and signal structuring, third unit does the scheduling of resources for UEs. FBMC can help this approach to achieve high spectral efficiency compare to OFDM or RC-OFDM, due to lower side lobes. It allows low fragment size of spectrum to provide better flexibility in allocation of resource, wider applicability and less infrastructure restrictions condition such as faster synchronization between inter-operators, better RAN sharing and faster signaling among operators.

9.6 Dynamic spectrum access (DSA) based schemes

Cognitive radio (CR) system is used for dynamic spectrum access (DSA) schemes, CR utility senses the environment electromagnetically to dynamically change and adapt parameters of radio operations [181]. CR utility's main functions are sensing, managing, sharing and mobilizing the spectrum according to primary and secondary user's QoS requirement without interference. Mobile cognitive radio networks (MCRN) is proposed which captures various network operations such as allocation of bandwidth, accessibility of channel, routing of data, spectrum management, transmission power and energy management, etc. [182]. MCRN can be effective technique to manage cross-tier interference and resource allocation. DSA can be deployed using exclusive or opportunistic CR approach such as exclusive spectrum access where spectrum bands are exclusively allocated to a mobile network for managing the interference efficiently, however, it suffers from low utilization of spectrum [172]. In this approach it is assumed that operator knows the real time RAN states of other operators which can help in agreement of fair spectrum sharing. In reality operators are hesitant in sharing the real state information with competitor because of monetary benefits which leads to auctioning of spectrum strategies. CR management-base uses software defined radio (SDR) technique to improve spectrum utilization of RF spectrum [183]. The CR base station receivers sense, monitor and allocate the unused spectrum and provide feedback to UEs (transmitters). Interference free CR network ensure that any secondary CR user will borrow the licensed spectrum only when the primary users are not using the same, where in interference tolerant CR network primary user shares some licensed spectrum resource ensuring a fixed drop threshold [184]. Software defined communication processors are used to control, configure and reuse hardware/software of various layer (i.e., Layer1 to Layer 3) to optimize the overall CR network performance [185].

9.6.1 Application of MIMO-OFDM techniques

More antennas at transceiver end implies higher degree of freedom in data transmission where time and frequency dimension are present. In OFDM system MIMO is regarded as very good spectrum efficiency approach where bandwidth can be divided into many orthogonal sub-carriers, these sub carriers are narrower which can avoid the inter symbol and inter carrier interference that improve the data rates [161]. In OFDMA every user is assigned with frequency carrier which is efficient for multi-path fading, bandwidth scalability and spectral efficiency, therefore combination of MIMO-OFDM technique with CR network can provide a way to handle spectrum scarcity in 5G systems.

The next few sections discuss about energy efficient management and existing schemes.

10 Energy-efficient management (EEM) schemes

Energy efficiency of modern communication system is a global concern whereas information and communication technology (ICT) is responsible for 2% of total emission of carbon globally, which is only growing every year due to increase in number of devices [186]. For 5G technology and beyond energy efficiency (EE) will remain one of the main objectives during design and implementation of new protocols and devices [187], BSs are responsible for 70% of the total energy consumption by operator cellular network [188]. Network architecture, transmission of radio, backhauling can be improved in terms of EE by using many suggested approaches [189]. Few of the key open challenges are mentioned [190] as follows: QoS requirements diversity and EE gain based on need balancing, size of cell design and EE impact on QoS performance in HetNets. Different kinds of relays and cooperations need more investigation in 5G systems, the energy consumption models are mostly simple for various BSs types and interference, frequent hand-offs need further addressing. Backhaul energy consumption is another big issue which needs efficient solutions [132, 191]. Radio BS (RBS), backhaul network and radio network controller (RNC) are the major energy consumption factors in overall cellular communication network [192], and all of them have fix and dynamic energy consumption part which are dependent and independent of traffic respectively. Table 7 lists, energy efficient management schemes in 5G with QoS requirement.

10.1 Energy harvesting techniques

RF energy harvesting networks (RF-EHNs) is an efficient technique for energy management. Information gateways, energy source and network nodes are main components of RF-EHNs. BSs, relays and routers generally are information gateways, RF transmitter are energy source and UEs are considered as nodes in the network [7, 9]. The idea behind harvesting RF energy technique is to provide controllable and constant RF energy which is harvested through wind, solar and vibration energy sources. Energy transfer depends upon distance and due to propagation loss, it decays with the distance. However, use of multi-antenna, beamforming, spatial multiplexing, efficient transfer of RF energy and simultaneous wireless information and power transfer (SWIPT) can help in improving the decay with distance [201, 202]. Multi-hop RF-EHNs using cooperation and attenuation can also improve the reliability, for physical and MAC layer policies of relay operations and allocation of power can improve the network performance gain and for network layer, selection of relays can improve network performance gain. RF-powered CRN is also suggested where secondary users can harvest the RF energy from primary users when they are idle, secondary users should opportunistically identify the spectrum holes and occupy the spectrum for RF energy harvesting. Energy cooperation is introduced where portion of energy from one user to another harvesting user take place, this can improve and optimize the overall system energy management even with losses due to transfer. Multi-user network is also used with transferable capabilities like multiple access, two-way relay channel. Data and energy queues are created and linked with both the source and destination, when data flow from source, energy queue is depleted and same amount of energy is increases at destination energy queue, policies of energy management uses Lagrangian formulation and Karush-Kuhn-Tucker (KKT) optimality technique to maximize the throughput of the system [11]. In another approach a hybrid access point (H-AP) is created which operates in FDC mode in downlink (DL) with few distributed users and receives information from both user's downlink as well as uplink (UL) using TDMA. Wireless energy transfer (WET) and wireless information transfer (WIT) are linked with H-AP in DL and users in UL respectively [203]. Power allocations are aimed to maximize user's linked data rates and optimized energy harvesting simultaneously. RF energy harvesting can improve the communication sustainability and lifetime through harvesting and by using better scheduling, interference can

Table 7 EEM in 5G with QoS requirement

Scheme	Massive number of devices	Huge traffic	Diverse use cases
Cross layer based [193–196]	Yes	Yes	Yes
DPS [187, 197, 198]	Yes	Yes	Yes
Energy harvest based [7, 9, 11]	Yes	Yes	Yes
Indoor communication based [139–142]	Yes	Yes	No
Cooperative [150, 199, 200]	Yes	Yes	No

be turn into usable energy. An economic energy market can be created by combining radio resource management with RF harvesting, also better gain in diversity is possible using beamformed antenna. However, RF energy harvesting suffers with few problems such as synchronization and coordination of energy sources, carriers and frequencies, management of the service providers demands, also exposure of highly intense RF can damage living tissues [204].

10.2 Dynamic power saving (DPS) techniques

Power saving protocol such as discontinuous transmission (DTX) and discontinuous reception (DRX) are introduced by LTE, they are used by mobile end devices for saving power. DTX and DRX momentarily switch the devices into power saver mode while remain connected to the network [187]. However, few connections can be of 'always traffic loaded' category in 5G which may suffer from these protocols. In another approach dynamic management of bandwidth is suggested for energy saving [197], which focuses on the dimensioning of BS for varying demand and transmission peak data rate. The resource blocks used for every LTE sub frame can be increased according to power consumption of average traffic, that means more RBs for more traffic load. Nodes with multi-standards which can work in multi-mode fashion help in energy saving as they can share functionality and components together [205].

10.3 Relay and cooperative communications based scheme

Relay nodes can be used for creating multiple connections between source and destination, with many links different path fading, diversity gain, spectral efficiency combinations are possible which can help in reduction of data transmission and energy consumption [199, 200]. There are typically two phases in relay, broadcasting and multiple access, in first source node broadcast the data for relay and destination over air and then relay and source transmit the data in multi-access phase which depends upon the protocol used. Amplify-and-forward (AF) and detect-and-forward (DF) scheme of transmission can be used in this scheme. Few more techniques are also used such as relay transmission, OFDMA, MIMO, information-theoretic analysis, signaling and energy efficient resource allocation for energy saving. However, in this approach many techniques which are effective for 4G may not be applicable for the 5G system. A dynamic cooperative approach for transmission by the nodes is proposed where selected nodes form a set of cooperation for transmission based on the existing information of the network [150]. This approach increases the average cell throughput and reduce the consumption of energy as well, but cooperation increases the complexity of system with massive number of devices and multi-tier 5G system.

10.4 Energy-efficiency based cross-layer design scheme

Every layer of protocol stack depends on other layers, therefore cross-layer communication strategies can reduce the energy consumption. Better resource allocation and dynamically adaptive transmission based on environment, traffic and service can be important in designing the cross-layer scheme [190, 193]. Adaptive modulation and coding (AMC) for different transmission resources can be used for link adaptation and MAC aspects in multi-user environment with hybrid multi-access technique to improve energy efficiency [194]. A foraging scheme is developed which mimics solitaire behavior while carrying the energy resource in natural ecological system, this scheme targets MAC and physical layers for green energy radio network [206]. A combination of cooperative communication in D2D through mmWave and long-range LTE system is proposed, where clusters of UEs and BSs are put on sleep systematically while managing intercell interference and resource allocation [207]. In another approach ultra-dense small cell and mmWave communication is used while analyzing backhaul network energy efficiency in 5G, two different architectures are used to model traffic for backhaul, the outcome indicates distributed solutions are better compared to centralized solutions for overall spectral efficiency [132].

10.5 The use of indoor communication technologies

Light-emitting diodes (LEDs) are now used worldwide in commercial application as well indoor communication to reduce energy consumption [208] and for greener network [188, 209]. Visible light communication (VLC) technology with mmWave can be used in 5G wireless communication for better EE, VLC uses off-the-shelf LEDs for solid-state lighting (SSL) to signal transmitter with p-intrinsic-n (PIN) photo-diodes and avalanche photodiodes as receiver [159, 210]. The energy consumption of one bulb in VLC system is comparable to RF-based transmission of equal data density for analysis, however, VLC system is more sensitive towards weather, also information is carried by light intensity (power) which need to positive and real-value signal. A full-fledged optical wireless (FSO) network can be created using lighting infrastructure, that can be used for outdoor propagation while considering realistic loss. VLC technique and mmWave can significantly increase the data rates and energy efficiency in indoor environment [182]. However, VLC and mmWave uses high frequency which cannot penetrate solid materials and can be scattered or absorbed by rain, gases and foliage, therefore not suitable for long distance outdoor environment.

Hybrid resource management is discussed in the next few sections with their existing schemes.

11 Hybrid resource management (HRM) schemes

Implementation complexity is one of the major challenges of HRM approaches due to increase in massage overheads for satisfying various QoS requirements [39], however, technologies such as massive MIMO, UDNs, FDC, mmWave backhauling, energy harvesting can help 5G to handle these challenges [39].

11.1 Joint scheduling and massive MIMOs techniques

Massive MIMOs leads to a scenario where number of BSs antennae are larger than mobile users, this will lead to better support as simultaneous transmit depends upon the number of antennae [211]. However, there is trade-off for QoS performance as EEM and SEM compete with each other, joint scheduling and strategic massive MIMOs can be combined to achieve maximum system sum rate where a bad antenna is removed in every iteration and new are added in orthogonal fashion. User scheduling and two step beam forming is used in multi-user scenario with massive MIMO for selecting semi-orthogonal users using CQI and post user optimal selection with zero forcing beam forming (ZFBF) using CSI through user's feedback [212]. In ZFBF approach the performance of rate sum increases with the number of users and feedback overhead remain lower than random beam forming. In another approach massive MIMO is used with various bandwidth sizes and scheduling algorithm, where system capacity improved without additional infrastructure in LTE downlink network environment [161]. The QoS performance increases with massive MIMO but complexity of the decoding process is high [213, 214]. The noise, path fading effect, system energy and spectral efficiency can be handled efficiently by using joint scheduling and massive MIMO, but EEM and SEM trade-off need further attention [183, 209].

11.2 Integrated spectrum and energy harvesting techniques

Spectrum harvesting with ARQ retransmission and probing (SHARP) method is proposed, where secondary users (SUs) listen to feedback from primary user ARQ and probing for information about channel and interference, to use energy and spectrum for harvesting [125]. In another approach secondary service provider (SSP) is introduced for harvesting and accessing the spectrum of SUs using CR ability of infrastructure, SU cooperate with CR routers of network and use harvested bands which increase reusability of available spectrum and capacity [215]. Another architecture for 5G system with CR module for energy harvesting is proposed where CR devices have spectrum sensing and energy harvesting at the same time [157]. They convert the ambient energy into electrical energy and sense the availability of licensed channel for access simultaneously. Distributed sensing is used in D2D network for licensed spectrum harvesting where energy can be ambient RF energy however, the conversion of energy from ambient source may not be sufficient and requires supplementary energy sources to satisfy entire cell demands. A fusion center can be used which sends the sensing signal for cooperation among CR devices, then devices send the sensing information consist of moment and location to fusion center for energy harvesting decision. Typically, BS can be a fusion center for one cell and decides about scheduling of cooperating CR radios. However, decentralize cooperative fusion centers can be used for reduction in energy consumption in heterogeneous 5G system.

11.3 Joint cell association and power control (JCAPC) based

Resource aware cell association technique is used for JCAPC where traffic load is balanced with SIR maximization and interference minimization together in multitier 5G system [12]. Coordination among inter nodes for cell-association, scheduling and interference is proposed in small cell with backhaul consideration [216]. In another scheme sleeping cell-users in downlink transmission is proposed while considering user performance, BS association, channel conditions, traffic load and active BSs [159]. User association techniques are also devised for sleeping user connection with BSs with maximum mean channel access probability (MMAP) which depends upon traffic and scheduling at BSs. Channel access aware (CAA) scheme for user association is proposed for better resource allocation and interference management which can also achieve high spectral efficiency and traffic load balancing for down-link at BSs. This scheme uses traffic information from various BSs and CQI [217]. Interference mitigation is done using almost blank sub frame (ABS) based coordination in macro cell and small cell tiers. Prioritized power control can be combined with cell association to achieve any HRM objective also deciding the objective is very critical [169].

11.4 C-RANs and H-CRANs based

Low capital and operating cost with high data transmission rate in HetNets are the main advantages of cloud radio access networks (C-RANs) [218, 219]. Radio resource heads (RRHs) act as relay for signal compression and forwarding from UEs to destination base band unit (BBU) pool using fronthaul connections. High power nodes (HPNs) are used for the coverage of multiple HetNets which can guarantee seamless coverage with backward compatibility in C-RANs [220]. Heterogeneous C-RANs is also proposed for mitigation of inter and cross tier interference with cooperative gain. H-CRANs can improve spectral and energy efficiency using different scenarios such as coordinated multi-point transmission, cloud based cooperative RRM, self-organizing network (SON) and high scale cooperative antennae [221].

11.5 Joint SDR and SDN based scheme

Resource optimization and spectrum utilization can be achieved using software defined radio (SDR) with software defined network (SDN) [222]. SDR presence at MAC and physical layers help UEs to scan various band and access different RATs using one interface [190]. SDN presence from MAC to upper layers help switches and routers to use any automatic monitoring function, as it provides decoupling of data and control planes of network architecture using programmable modules. This decoupling provides high degree of freedom with simpler programmable network environment [223]. SDR and SDN combination can achieve better energy utilization, security and optimization, however the SDN standardization and adoption issues are still open.

11.6 Bio-inspired techniques

Bio-inspired energy and channel (BEACH) management method is introduced for better channel utilization and energy efficiency in wireless multi-radio network [219]. It uses optimal behavior of living organisms for modeling and mimicking various scenarios present in different cellular communication environment including energy and frequency channel scenarios related to transceiver's radio interfaces in wireless environment [206]. Energy-aware throughout (EAT) maximization is the main objective of an optimal algorithm used in the scheme, which increases the lifetime of network and data rates. The algorithm uses bio-behaviors which are suitable to optimize the network resource allocation which in time improve the spectrum and energy efficiency of RAN systems [195, 224]. Foraging theory-based bio-inspired MAC protocol architecture is developed that connect nodes using channel contention or negotiation. Optimal network resource allocation using foraging and non-foraging targets stable network, then transfer the payload traffic considering optimal network and gain for every packet [20]. Symbiotic heterogeneous coexistence ARchitecturE (SHARE) is proposed for collaboration between heterogeneous CRN and TV white space (TVWS) where direct coordination is difficult due to MAC/PHY design compatibility and standards [225]. Symbiotic relationship mimicking between these heterogeneous system resembles organisms in ecological system, and indirect coordination is used to share resources using mediator in heterogeneous CRN, also weighted fair schemes are used for spectrum resource allocation.

Radio resource management is discussed in last few sections in detail, next section discusses about the architecture and design of 5G, its implementation and key components with respect to RRM and RAN slicing.

12 5G wireless network design

12.1 Understanding mm-wave wireless channel

Emerging mm-wave wireless channel has various challenges but absence of standard for channel modeling is the foremost issue. Other technical aspects, such as various kinds of multi-access, new architectural designs, novel air interface methods, etc., will require detailed investigation as well [15, 21]. The scrutiny of mm-wave frequencies on the ground of biological safety is also a significant concern [226].

12.1.1 Propagation loss

The basic free space path loss equation suggests that with the use of higher frequencies the losses will also grow, however, it depends upon the intervening antennas as well, the use of isotropic antennas in future 5G network requires further investigation [227]. The path loss magnitude in free space with same aperture area of antennae show similarity in both long and short wavelength, but capability of casting narrow beams is higher in mm-wave links [228–230]. The interference due to directional transmission by narrow-beam is lower and capability of spatial multiplexing is higher. The performance of mm-wave links is expected to be high, however, factors such as link margin of radio, node distance, diversity of multi path will remain key in propagation loss.

12.1.2 Penetration and LOS communication

The behavior of propagation signal can be analyzed only after considering the environment (i.e., indoor and outdoor) which will include foliage, structures and humans also analysis of reflection, penetration and scattering with mm-wave every environment is essential [231]. The penetration resistance by outdoor building materials such as glasses, doors, elevators, drywalls is high when mm-waves are used [189]. Even indoor structures such as white boards, mesh and clutter glass has high impact on the multi path components, path loss and attenuation of mm-waves [232]. The impact of human body is also significant on mm-waves as it creates major obstruction as well as shadowing effect, however, use of larger antenna can help in mitigating the shadowing effect by human body [233]. Serving different coverage sites may require isolation of indoor and outdoor environment by different nodes, which will help in energy conservation, relaxation in traffic overhead and better resource allocation [209]. Feedback mechanisms, better user selection technique and clustering can help in significantly reducing the overheads in small cell environment [234]. The application of line of signt (LOS) with massive number antennas in small cell environment is promising for mm-wave technology, however, many challenges still need deeper investigation for LOS as well non-line of sight (NLOS) propagation.

12.1.3 Multipath and NLOS

Multi path effect is created due to reception of signal by antenna through various paths [235], power delay profiles (PDP) can help in analyzing multi path effects for mm-wave environment. NLOS problem is also integral part of multi path effects as finding LOS links are not always possible in outdoor environment [236, 237]. Rain focused measurement such as attenuation, short term signal level, vegetation attenuation and wide band power delay profiles are compared with dry weather environment for multi path effects analysis [238], pointing angles for various multi path components can also help in improving the links. Corners, edges, humans can mostly cause shadowing instead of attenuation and reflection coefficients can suggest possible signal levels presence in shadowing area [239]. Wider width beam antennas have high accuracy for received signal estimation whereas shorter width beam antennas have spatial directivity advantages, therefore best combination of width can help the antennas to achieve high SNR as well as low delay spread [16]. High power consumption, high latency and low data rate are major challenges for NLOS path communication which requires equalizer, multi path statistics can help in equalizer design and modulation scheme selection.

12.1.4 Doppler effects

The shift value of incoming waves can be different due to mobility of carrier or receiver which result in Doppler spread [227, 229], time selective fading which is induced by the Doppler can be handled using sizing of packet technique and suitable coding over the channel [240]. The Doppler spread can be further reduced by narrow transmission beam with low angular spread produced by the mm-waves signal.

12.1.5 Creating and controlling the beam

Beam forming algorithm for mm-wave is crucial for energy management and transmission in desired direction. Antenna and sub arrays configuration with beam forming weight control the beam. Digital, analog or RF front end can be used for beam forming [241]. Directive beams are created using the beam forming weight, applied on analog or digital signal [242]. The coefficients are multiplied with each radio frequency (RF) chain, after or before fast Fourier transformation (FFT) over modulated signal during digital beam forming, whereas, coefficients are applied to RF signal after modification in time domain during analog beam forming. Hybrid beam forming has phase shifter and sharp beams of analog domain, as well as flexibility of digital domain. RF components efficiency in mm-wave frequencies is mostly poor, therefore power amplifiers are used and operated at their maximum level. Phase shifter are used for array control, use of narrow beam is also suggested for broader beams and data control channels. Splitting of the antenna array into logical multiple sub array is proposed for broader beams [243]. New algorithm for beam forming is suggested to maximize the cell sum-rate in virtual network with interference minimization [244].

12.1.6 Antenna training protocols

Training protocol for beam forming is crucial to find the best direction pair for beams [245], beam with steer capability can be used for handsets and base stations for backhauling coordination and RF communication. Angular spread of multi path, signal pilot of narrow band and pointing direction of antenna can be used to determine directions efficiently [240]. Singular value decomposition (SVD) based pre-coding scheme for transmission and reception is proposed, which trains coefficients of antenna in iterative manner in multi steps, the computational complexity of the scheme is low when large number of antennas are used with low RF chains [246]. A unique signature is assigned to each beam angle in beam coding training method, which helps in faster best angle estimation for pairs, this method proved robust in NLOS propagation environment as well [247]. In satellite communication antennae tracking technique is applied for direction determination, tracking system can help the axis to move in small steps to obtain high gain in received signal, nevertheless, the performance of scheme depends upon SNR and step size [248].

12.1.7 Angle of arrival estimations

Angle of arrival (AOA) vary with time and its knowledge is crucial in outdoor environment, in a proposed work every transmitter gets distributed AOA with combination of azimuth angle for each links between receivers. Base station (BS) transmitter must point towards receiver direction and steering of beam should be at 60 degree for lower path loss and delay. In blockage situation device need an alternate path based on the signal strength of beam pairs, alternate path finding technique is proposed using the value of AOA that uses cancellation of successive AOAs for selecting the best one, which results in better performance and low errors in estimation [249]. Directional self-pursuing protocol (DSP) is also used for achieving high conservation of energy and bandwidth with low redundancy, on demand discovery of route and directional antenna are considered as DSP special cases, which improves reliability and efficiency of broadcast communication in wireless environment [250].

12.2 Sectorized antenna

In MIMO enabled mm-wave system, obtaining information from every antenna element is difficult and RF beam forming requirements for overcoming poor links limit the system, use of narrow beam by transceiver can be helpful in this scenario, as data transmission happen only between best transceiver beam pairs [251]. A fixed pattern in antenna direction can be achieved by sectorization of antennas, an arc-like sector is created using multiple antennas and these arcs provide significant gain in a limited azimuths range [252], overlapping sectors are also created from range of nodes transmitting in the same direction [250]. Jointly covered range for transmission is more efficient than omni-directional transmission, where the requirement of hardware is also less. Reuse of frequency and spectrum capacity can be improved by using spatial division multiple access (SDMA) and beam combining protocol with TDMA or FDMA [240].

12.3 Massive MIMO system

Massive multiple input and multiple output (MIMO) system improve the energy and spectral efficiency significantly, as each antenna position itself for direct transmission to receiver, also the spatial multiplexing provides huge increase in BS capacity [253, 254]. Effective scheduling and modulation techniques are critical for massive MIMO environment, also TDD is preferred over FDD due to low complexity implementation. Traditionally 2D configuration of grid for the deployment of antennas is suggested for massive MIMO, however 3D configuration can also be used with further investigation [255]. Low power and budget components are preferred for building massive MIMO and huge amount of overheads are generated due to channel state information of BS with massive MIMO, which affects the overall system performance. New design of massive MIMO is proposed by integration of antenna array and electromagnetic lens to reduce the spatial interference and to improve the energy focus [256]. Small cell with reduced antenna array size and less electronic circuit combined with mm-wave transmission is a better candidate for deployment of massive MIMO. Residual self-interference can also be managed by exploiting temporal and spatial massive MIMO freedom [257].

12.4 Full duplex radio technology

By using same frequency channel for both transmission and reception simultaneously (i.e., full-duplex (FD)) double spectral efficiency can be achieved, however, path loss, internal interference and fading degrade the efficiency of FD communication [258]. The recent advances in beam forming and RF technology can help the FD transmission, also with massive MIMO technique, better mitigation of internal interference of spatial domain is possible [7, 109, 259]. Low latency, double capacity and improved feedback with physical layer security can be achieved by using FD, it also removes the hidden node issue present in the contention-based network. Self-interference (SI) due to simultaneous uplink and downlink resource block (RB) scheduling is the main challenge of FD, active and passive cancellation technique is typically used for handling the SI issue [260]. Directional antennas, cross-polarization and absorptive shielding is used to isolate the transceiver in passive cancellation, whereas node's transmit signal information is used to cancel interference in active cancellation technique. Massive MIMO, beam forming, small cell, centralization of architecture can help in efficient FD realization, whereas intelligent scheduling, better power control and rate selection can lead to high gain in capacity through FD communication.

In the next sections we discuss the architectural shift needed for 5G, and slicing implementation schemes.

13 Architectural paradigm shift for 5G and slicing implementation

Bandwidth limitation with very low latency demands, forced the movement of network from BS centric to device centric architecture which requires a paradigm shift. The demand of deploying smaller cell is increasing, user centric designs are preferred as users are now participants as well which relay, store, deliver content and perform computation in the network. In hyper dense 5G environment, micro, pico and femto cells are preferred for deployment [261]. The traditional air interface will no longer be the part of future network due to co-channel interference whereas sectorized directional antennas can be chosen over omnidirectional antennas. SDMA and energy efficient design of antenna are critical, and the separation of control plane from user plane can help interoperability aspect of different network working seamlessly.

13.1 Radio network evolution

In 5G higher frequency channels are used and their outdoor signal penetration is very limited [15], and layout of nodes which is site specific are preferred as subways, offices and malls need high data rate in ultra dense deployment [189]. LOS is always be chosen over NLOS communication however, diffracted, reflected and scattered signals need more attention in LOS communication during blockage [240]. 5G is inclusive technology therefore integration with legacy network (i.e., 3G, 4G) will be challenging [262]. Coverage extension and significant gain can be achieved using larger beam forming which can also improve cell edge link quality and interference management, also it can provide low cost solution and lower latency when used with mm-wave enabled BS grids [241]. A modem with dual-mode capability is proposed which can switch from 4G to mm-wave communication and vice-versa, in one case it can exclusively work with 5G systems and in another case control information can be transmitted using 4G network whereas data transmission can use 5G mm-wave communication. Better link quality and spectrum overlap for BS grids can be possible using narrow beam concept [229]. In Fig. 6 HetNets is shown where different types of small cells coexist with relays and macrocell.

13.2 Advanced air interface

Use of large array for small antennas to enhance directional electromagnetic waves is essential for mm-wave communication, which also need phase and amplitude control to cancel out unwanted directional waves and directional air interface can fulfill this requirement [263]. SDMA can be used for achieving highly directional beam with adaptive beam forming [229], it also improves the reusability of frequency in transceiver for beam forming [264], but high-power requirement and mixing of signal components can limit the advantages. Hybrid beam forming approach with analog and digital combination using optimal weight assignment can help in improving the overall efficiency of beam forming. BS sectorization can limit the hardware requirements and improve performance of beam forming but requires better data transmission and synchronization technique [265]. Larger deployment of BS and LOS communication requirements can be reduced by segregating uplink and downlink communication [266].

13.3 Next generation smart antenna

SDMA capabilities can be fully realized using smart antennas which uses multi-beam array of antennas, it can reduce the interference with improvement in coverage area and low power consumption, for both BS and mobile devices [267]. The narrow beam antennas can transfer more energy at higher frequency while using same old aperture size [242]. Different beams can use the same channel with smart antenna system, which can reduce the co-channel interference significantly. Directional antennas require complex operative process which increases the cost of implementation however, low complexity antennas can also increase the capacity gain with proper implementation [268]. The complexity, cost and optimal gain are critical factors for designing smart antenna system for 5G environment. Design of antenna sub array can be planer, circular and segmented, and selection of antenna sub array according to requirements can significantly improve scan range, directivity and coverage [269]. Horn antennas are used for high output power BS due to their higher gain over every other antenna [270], whereas simple patch antennas are used for mobile devices because of their low power, size and space requirements.

13.4 Agility and resilience by splitting of plane-SDN

5G system requires inherent flexibility and swiftness in the network that can be achieved using SDN, which decouples the control and data planes. The resources of control plane remain unaffected with the increase in capacity of user plane [270, 271]. The software components are used for decoupling the data and control plane by managing the control plane, which also reduce the hardware dependency [222, 272]. Open interfaces are used for data and control plane interactions as well as configuration switching. Network remodeling can be done by using SDN over OSI layers for automated administration, SDN controller

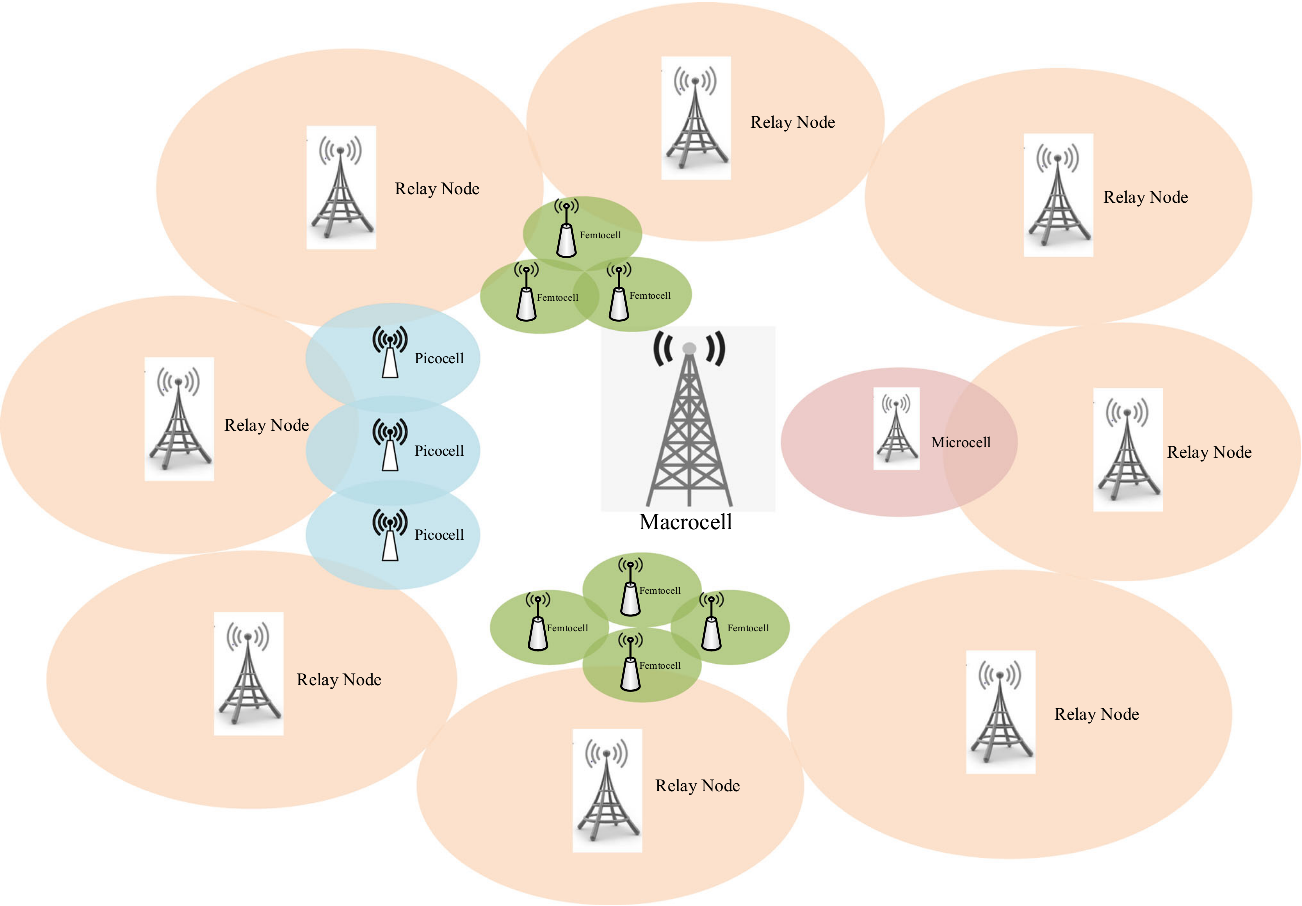


Fig. 6 HetNets architecture

can remove redundancy in interfaces by monitoring policy assignment to the routers. Self-organizing network (SON) solution can also be developed using SDN with RAN. RAN can be optimized by control plane coordination using SON solution without affecting the data plane [273]. SON solution can help the network to achieve high gain with better cooperation in data plane, coordinated multi point (CoMP) transmission can be used to facilitate better cooperative transmission of data with fine time scale requirements.

13.5 Centralized architecture-cloud RAN

CAPital EXpenditure (CAPEX) and OPerating EXpenditure (OPEX) with interference among cells are major architectural limitations of wireless communication. However, cloud radio access network (C-RAN) can improve the coverage, mobility, energy efficiency and architectural design with reduction in operational and deployment cost of network [274]. The resources of baseband are pooled at BBU, and various BBUs from different remote sites are centralized at C-RAN virtual BBU pool, which results in resource saving, multiplexing gain and less energy consuming operations. It also improves cost-efficiency, scalability, time consumption and integration with services. Radio resource heads (RRHs) have the direct connection with the BBU pool where every RRH has transceiver, modem, filter, amplifiers and digital signal processor [275]. Users are connected with the RRH directly that simplifies the overall architecture and make it more flexible, efficient and affordable [271]. Powerful computing ability of cloud can be used for handling complex processes of control mechanisms [222]. Backward compatibility and cost efficiency can be achieved in hyper dense environment using infrastructure sharing [200]. RF front end can be shifted to BBUs which enables shared cloud radio-based transmission, where analog RF can be used as well by many operators and services without causing high interference. SDN can also be used for merging cloud application seamlessly by using programmable interfaces, a virtual network can be created using SDN where Cloud will act as backbone [276]. Heterogeneous backhauling with integration of broadband access network and wireless backhaul can be an effective solution for expensive small cell backhaul network, therefore standardization of interface can be important for designing backhaul network with RAN [277]. RAN as service is proposed for dynamic adaptation of nodes for routing which can increase the flexibility in centralized RAN. Compress and forward strategy for relaying is proposed for transmitting compressed received signal to the central processor for optimization of system in uplink C-RAN. Quantized noise level of compression is considered as key in designing backhaul [278].

13.6 Heterogeneous approach-HetNets

Combination of small cells with lower transmission power and macro cells typically create the HetNets, with small cell deployment the capacity of the network increases and coverage holes also get covered [4, 279, 280]. Use of pico, femto and macro cells together improve the frequency reuse due to overlaps [19]. Coordinated operation in HetNets leads to better interference management, reverse TDD protocol can also be used in 5G system HetNets to further reduce the interference [3]. Signal structure consisting coding, channel, resource allocation, modulation can be used as well by the advanced transceiver for better interference management [18]. Improvement of coverage and capacity of HetNets can be achieved by smart coupling between different RATs [281]. Two tier heterogeneous network architecture is proposed to improve overall performance of network, where low power small cell access (SCAs) and massive MIMO BS co-location techniques are used which ensure better coverage, cooperation and capacity for lower mobility users. However, unreliability of wireless backhaul infrastructure in SCAs is main limitation of two-tier heterogeneous network. Cloud based platform is suggested for better management, operation, optimization and deployment of HetNets, it can also improve the seamless connectivity aspect of HetNets as well by better location management and hand-off. Figure 7 describes the 5G system network slicing architecture where three crucial slices namely enhanced mobile broadband (eMBB), internet of things (IoT) and ultra reliable low latency communications (uRLLC) is shown. NFV and SDN vertical is also shown with their core and edge cloud components.

13.7 RAN slicing in 5G system

Radio access network slicing requires division of spectrum into set of channels with various kinds of bandwidths where time and frequency of every channel can be transformed into RBs for dynamic radio resource allocation. Radio access bearers (RABs) are the data transmission service providers between UEs and the core network, different kind of QoS attributes are linked with the RABs such as minimum bit rate, retention and allocation priority, QoS class, etc., [282]. Different kind of traffic demands can be satisfied using various RRM schemes with better deployment and exploration of available RAN resources. Required RRM functionalities for RAN slicing are:

13.7.1 RAN slicing and inter-cell interference coordination

Inter-cell interference mitigation is essential whenever same carrier is used, inter-cell interference coordination (ICIC) creates certain limitation for various RBs use, by restricting cell transmission power to certain RBs and stopping the data transmission to some RBs [283]. ICIC generally decides which set of RBs are allowed for using available carrier and what is the maximum power of transmission is allotted for every RB.

The carrier assigned to cell will be shared by the tenants, where spatial distribution of traffic is considered during spectrum planning. In this RAN slicing different RBs are assigned to every tenant in every carrier throughout the cell. This approach will remove the cell interference while transmission by achieving the traffic and radio-electrical isolation among slices [284]. After RBs assignment to the tenants, they can use ICIC strategies for establishment of RBs set to every carrier for managing inter-cell interference which exists within the tenant's RAN slice. The isolation between slices enables the implementation of various ICIC policies, packet scheduling and admission control algorithms for every slice. This approach follows the ’RAN slicing at spectrum planning’ principle with better granularity due to RBs slicing instead of carriers.

13.7.2 RAN slicing and packet scheduling

Packet scheduling (PS) make decisions regarding the assignment of carrier to cell and how available RBs can be used for data transfer of existing RABs. A transmission time interval is attached to scheduling process as maximum operation time duration must be low due to its ultra-low latency support. PS select the physical layer attributes for RB transmission use which are antenna mapping, coding, modulation scheme [282]. These selections decide how many numbers of bits from every RB can possibly be served in one TTI, therefore bit rate of delivery for every RAB can be controlled.

In this approach the slicing of RAN is done at every cell level through RBs distribution among tenants, number of RBs used is limited for every tenant which ensures isolation of traffic in each cell. However, inter cell interference can occur due to absence of radio-electrical isolation [285]. Tenant specific algorithm for PS can improve the capacity, many existing priority criteria can also be used for serving RABs in high traffic situation for tenants.

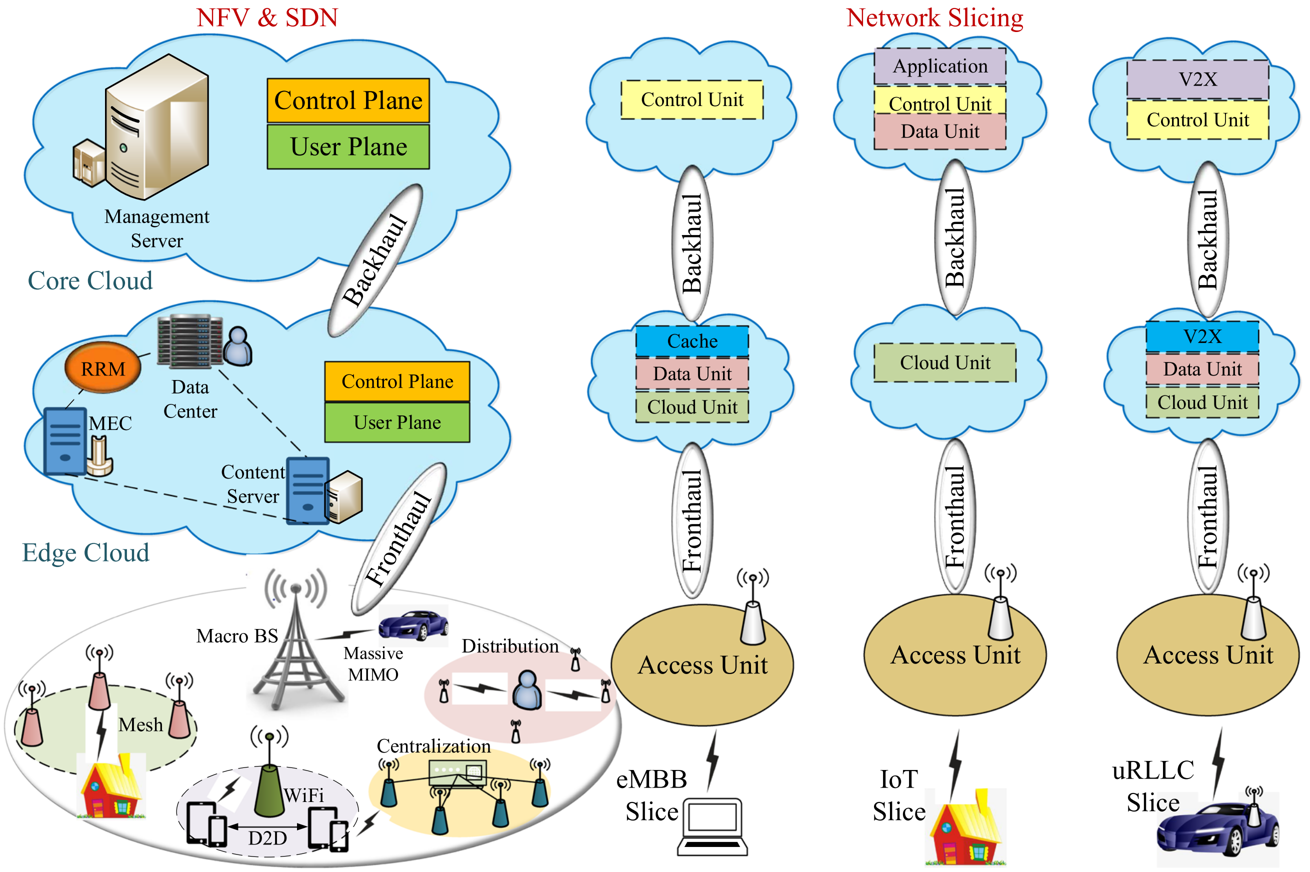


Fig. 7 5G system network slicing architecture

13.7.3 RAN slicing and admission control

The acceptance and rejection of new RAB request is decided by the admission control (AC) function, AC checks overall utilization of resources and QoS requirements of working RABs before accepting or rejecting new request and its QoS needs [286, 287]. However, the efficiency of resource utilization of any RB depends upon various techniques applied on physical layer of radio link such as coding and modulation, automatic repeat request scheme, MIMO, propagation channel condition, interference as well as RRM scheme for decision making.

The slicing is done on the basis of new RAB admission at every cell, the admission of RAB go through tenant AC which decides whether RAB should be admitted or rejected, each tenant can implement retention and allocation strategy by giving priority to certain RAB types when slice capacity limit is reached [288]. The slicing scheme accept or reject the RAB after analyzing overall resource consumption of every tenant with new RAB admission, radio-electrical isolation is not ensured in this slicing and inter-cell interference among tenants can occur. Certain level of isolation in traffic can be achieved by using AC as PS function which is common for every tenant in the cell, no tenant specific scheme exists in this approach.

In another approach new resource allocation mechanism is proposed that uses the various relationship exist with different players including network slice tenants and providers of network infrastructure [289]. An admission control mechanism is used by providers whenever a tenant request for network slice which also uses the benchmark of optimal policies. A stochastic model is proposed for network slicing in this paper where multi-queuing is used for optimal admission control which considers the patience and waiting characteristics of tenants related to network slice requests, various performance characteristics like fairness between different types of network slice and tenants are also considered [290].

13.7.4 RAN slicing at the spectrum planning level

Slicing can be done for every tenant by assigning various carriers to these tenants after arrangement of RAN spectrum resources into these carriers, the characteristics and number of assigned carriers should provide overall coverage and sufficient capacity [208]. After carrier assignment to tenants, these tenants can use spectrum planning scheme for using the spectrum throughout cell by considering the distribution of traffic and service for all UEs. Tenant specific policies can help in carrier isolation interms of traffic, radio-electrical which leads to better mechanism for allocating resources to RABs.

13.8 Network slicing based 5G system architecture

Network slicing can unify shared network and physical infrastructure to achieve different operating instances which can work independently for one network function specifically [291]. Network function virtualization (NFV) can be used for implementing network slicing with SDN technology [292]. Mobility management entity (MME), packet/service gateway (P/S-GW), policy and charging rule function (PCRF) of traditional network can be replaced by NFVs which can host functions related with physical infrastructure by using off-the-shelf servers in core network (CN) and RAN. These servers can act as pool of virtual machines (VMs) by using off-the-shelf software and hardware. Also RAN division is done into BBUs of C-RAN and radio access units. The processing unit is centralized and mostly virtual, pooling of resource is done for service slicing to achieve various QoS requirements [293]. Network slicing logical architecture has radio access plane, multiple RATs with heterogeneous network and efficient cooperation mechanism for 5G. WiFi access point and small cell deployment can also improve the demands of increasing traffic in 5G [294]. D2D communication can be used for further improvement in capacity, energy and spectrum efficiency with reduced burden on backhaul and lower delay. D2D can play an important role in slicing of network for better QoS and emergency communication in 5G system. The architecture of CN has changed into decentralized core cloud, where control and data planes are separated to reduce delay and signaling overheads with better mobility and interference management. Resource management is handled by the control plane whereas other functions and servers of RAN is shifted to edge cloud which is centralized pool with virtual functionalities. Data forwarding is primary task of edge cloud whereas baseband processing belongs to core cloud, user functions of P/S-GW are also moved to edge cloud for lower latency and backhaul load.

Platform for computing are mainly deployed at edge cloud including RRM module which can collaborate for efficient computing, massive data transmission and storage execution in real time environment. SDN can be utilized for connecting distributed VMs linked with core and edge cloud by mapping them together in 5G network. Network slicing can also be controlled using SDN centralized controller, one slice of end-to-end network has collection of specific network functions and modules for resource allocation, which can be totally isolated from other slices. A slice of enhanced mobile broadband (eMBB) has different requirement such as larger bandwidth, higher data rate services, caching method, cloud and data unit for assisting control functions to implement the eMBB services. Ultra reliable low latency communication (uRLLC) slice has extremely sensitive latency requirement with high security and reliability which can be used in vehicle-to-everything and autonomous driving. Every function should be dedicatedly instantiated on edge cloud for uRLLC slice. Various vertical functions must be placed at upper layer in IoT slice for supporting different demands of external services of tenants. Network function manager which is virtualized, used for mapping between VMs and physical functions of network. SDN controller controls the virtual network by using interface protocols to connect vertical and data layer with coordination of virtualized network function management (VNFM). Virtualized infrastructure management (VIM) is the center for allocating resources to VMs by monitoring and analyzing status of resource utilization. Orchestration and network management belongs to the core of slicing as creation, deletion and activation of network slice is done according to requirements of services [295].

In another approach [296] a business network model is proposed where network slice manager determines various prices of network chunks to give an overall network information view. The slicing mechanism depends upon the auctions which are economic based where overall objective is network revenue maximization by making smart selling decision of network chunks. Resource efficiency and profit maximization through network slicing is proposed in this work [297] where coexistence of multiple network slices is explored with modeling of resource pricing. Resource efficiency maximization is done using slice provider problem formulation and profit of slice customers is optimized through slice customer problem formulation. An online genetic strategy optimizer is used for slicing in another approach to optimize the long term utility of network [298]. Here slicing strategies are encoded into binary sequences and these sequences are used for genetic optimization, which enable efficient inter-slice resource management by using mobile network operator decisions and requests from tenants. A network slicing game framework is proposed where every slice reacts with other slice behavior and settings [299]. This framework depends upon the network shares which enable the customization of resource allocation according to users, a minimum rate requirement of users is also consider which has significant impact on game results and equilibrium. An auction based scheme is proposed to allocate network resource in SDN based multi-tenant environment [300]. FlowVisor is considered for auction execution for network resources, it is a non-cooperative game setup for controllers to bid and obtain network resources with attached costs according to their interests. A learning procedure is also included for convergence towards equilibrium in distributed manner. A data analytic tool DeepCog is introduced in another approach which uses the deep neural network for training by using a loss function to forecast the resource orchestration and management in 5G network slice [301].

A soft slicing framework is proposed [302], which support time varying load traffic. Resource block pre-allocation is done to multiple available gNodeB at network level which ensures satisfaction of QoS requirements, also dynamic scheduling is considered for RB sharing among gNodeBs. A new framework is proposed to cater with diverse slice requirements through 5G RAN slicing [303]. These slicing requirements include throughput, latency, resource usage, etc., which are presented as number of resources per deadline interval. These slices are scheduled using Earliest Deadline First principle for efficient performance with changing traffic dynamics.

13.8.1 Mobility management

SDN decouples the control and user plane at gateway in CN environment, control signaling can be reduced using intelligent control functions even in large distributed nodes network however, ultra high density of network and devices with higher mobility has management challenges when network-slicing is done. Better mobility management schemes are needed for network sliced 5G system to work with seamless mobility, continuity, scalability and quality of user experience [304]. Various network slicing has different requirements and characteristics in mobility, reliability and latency terms. Mobility management requires two main procedures namely location registration and handover management [305].

13.8.2 Location registration

Once mobile device registers itself with the network, it periodically reports its location information to the network. Subscriber servers in 5G environment can be distributed at edge cloud for reducing registration delay and backhaul loads due to proximity with the end devices [21, 306]. Heterogeneous multi-RATs can be aggregated to achieve seamless mobility and accessibility. Coordination of multi-RATs is required for location sharing information of connected devices.

13.8.3 Handover management

In network sliced 5G system, service-oriented management for mobility is used through flexible mechanism of handover and adaptive threshold of handover. Software defined wireless network (SDWN) is included in RAN for mobility management. Hierarchical deployment of control plane is done closer to edge cloud for faster handover decision making with one essential controller for every slice of network [307]. Cooperation among controllers is also required in hierarchical control plane scenario in SDWN [21, 308]. Core cloud support the user's communication from one slice with other terminals during handover, whereas data transmission through edge cloud and access unit to user starts from the core cloud. Physical elements of network are virtualized and replaced by the logical core and edge cloud servers where unified interface protocols can be used for more flexibility [309]. SDN controllers are deployed at edge and core cloud which enable access planes to perform the hangovers cooperatively in highly complex scenarios [310].

14 Conclusion

The architectural shift that is needed to move towards 5G and beyond is transforming the future network into hyper dense HetNets, and to satisfy the features and QoS requirement of 5G wireless network radio resource management schemes will remain extremely critical. The problem of resource management is multi-dimensional and has multiple challenges such as interference management, resource utilization, QoS requirement, fairness and energy management, therefore the solutions should be adaptive to change according to the user's and network demands.

This paper presents the key challenges of resource management and how this is a combination of multiple problem which are directly or indirectly connected with each other, various RRM schemes are also presented, ranges from traditional to advanced. The solutions for this ambitious and complex problem require intelligent and robust approaches which can be hybrid of more than one scheme.

In this review 5G environment and architecture is also discussed in the radio resource perspective and how the environment directly impacts the radio resource allocation and management. The management of energy is critical and essential part of resource management and this paper present various existing approaches to manage the energy efficiently in various environment.

The environmental transformation from LTE to 5G requires change in various infrastructural and system level. The environment of 5G will be inclusive in nature and

LTE/LTE-A infrastructure will remain integral part of upcoming evolution. However, deployment of network must change, where small cells will play key the role and its impact on designing RRM solutions will be significant in hyper dense heterogeneous 5G environment. This paper indicates the RRM schemes are essentially including the small cell environment in their approach however, designing a fair, energy and resource efficient solution with interference mitigation in hyperdense environment is very challenging issue. The QoS requirements of users are also getting increasingly demanding and efficient RRM schemes must consider these aspects as well. The implementation of 5G RAN is also presented with its various essential components and RRM as part of it.

Finally, it can be concluded that the future of RRM depends upon the deployment environment and this area of research will remain interesting and challenging as the features and requirements will remain highly demanding for 5G and beyond.

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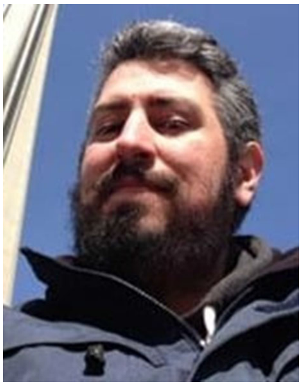
Tafseer Akhtar received his Master of Technology (Cyber Security) degree from Department of Computer Engineering at National Institute of Technology of Kurukshetra, India in 2017. He is Early Stage Researcher and Marie Curie Fellow in the Department of Electrical & Computer Engineering, University of Patras, Greece. His research interests include but are not limited to 5G Small Cell Networks, Radio Resource Management, Game Theory, Distributed Learning, Network Coded Cooperation and Network Security. He is a student member of the IEEE.



Christos Tselios received his Diploma degree from the Electrical and Electronic Engineering Department, University of Patras (2009). He has been a research fellow at Ericsson EUROLABS in Aachen, Germany and the Cassiopeia $-$ Department of Computer Science in Aalborg University, Denmark in 2011. His research interests include but are not limited to 5G Networks (Mobile Edge Computing and Fog Computing Architectures), Network Security, Internet-of-Things protocols, and Machine-to-

Machine communication. He is the author of several research papers in international journals, conferences and edited books and has also participated in several European (both FP7 and H2020) and national (GSRT) projects related to the ICT domain.

Ilias Politis received his B.Sc. in Electronic Engineering from Queen Marry College London, UK in 2000, his M.Sc. in Mobile and Personal Communications from King's College London, UK in 2001 and his Ph.D. in Multimedia Communications from the University of Patras Greece in 2009. Currently he is a Senior Researcher at the Wireless Telecommunications Lab. of the Electrical and Computer Engineering at the University of Patras, Greece and Senior Researcher at the Hellenic Open University, Greece. Dr. Politis has been actively involved in all phases of H2020-MSCA-SECRET, H2020-MSCA-SONNET, H2020-RIA-EMYNOS, FP7-ICT-ROMEO, FP7-SEC-SALUS and FP7-ICT-FUTON projects, as well as, several national funded research projects, while research interests include future generation networks, next generation multimedia networking and emergency communications. He is a member of the IEEE.