Journal of Advanced Civil Engineering, Architecture, and Urban Planning
ISSN 3065-1425
Volume 11 Issue 3
July – September 2023
Impact Factor: 6.15
Enquiry: contact@continentalpub.online
Published by Continental Publication | https://continentalpub.online/index.php/jaceaup

TACKLING RF INTERFERENCE CHALLENGES: A SURVEY OF ICIC SCHEMES FOR OFDM DOWNLINK IN CELLULAR NETWORKS

[1]Ahmed Mahmoud Abdel-Halim and [2]Mohamed Ahmed El-Desouky
[1,2]Communication Engineering Department, Al-Azhar University, Cairo, Egypt

Abstract: *The evolution of wireless systems towards next-generation standards is poised to revolutionize Intelligent Transportation Systems (ITS) with a multitude of applications ranging from broadband digital communications to real-time video security. Among the proposed techniques for enhancing wireless communication, Orthogonal Frequency Division Multiplexing (OFDM) stands out for its ability to transmit data efficiently over challenging channels while maintaining high data rates and low complexity. Next-generation cellular systems hold the promise of achieving substantially higher cell throughput and enhanced spectral efficiency compared to existing technologies like GSM, EDGE, and High Speed Packet Access R.7 (HSPA+). This paper explores the potential of next-generation wireless systems in facilitating advanced applications for ITS, highlighting the role of OFDM and advancements in cellular technologies.*

Keywords: *Next-generation wireless systems, Intelligent Transportation Systems (ITS), Orthogonal Frequency Division Multiplexing (OFDM), Cellular systems, Spectral efficiency*

1. Introduction

The next generation wireless systems are proposed for Intelligent Transportation System (ITS) and the applications of proposed ITS are intended to use for wideband digital communications such as: broadband wireless internet access digital television, audio broadcasting, and video conferencing, realtime video security, communication for high speed trains,.. etc. One of the techniques which are proposed for next generation wireless communication system is OFDM, which is used to transmit data over extremely hostile channel at a comparable low complexity with high data rates. Next generation cellular systems promise significantly higher cell throughput and improved spectral efficiency as compared to existing systems such as GSM, EDGE, and High Speed Packet Access R.7 (HSPA+). For example, system performance requirements for the 3GPP, LTE of UMTS and LTE-A target significant improvements in cell edge spectral efficiency and peak transmission rates that can reach, respectively, 0.04-0.06 bps/Hz/cell, 100 Mbps and beyond [1,2].

In order to achieve these targets, dense frequency reuse of the scarce radio spectrum allocated to the system is needed. Efficient use of radio spectrum is also important from a cost of service point of view, where the number of served users is an important factor. However, as the frequency reuse increases, so does the interference caused by other users using the same channels.

Therefore, interference becomes a decisive factor that limits the system capacity, and hence, the suppression of such interference becomes of a particular importance to the design of next generations cellular networks.

2. Problem Statement

As a result of several research papers have been published, there is no existence to a comprehensive survey that investigates to the wide range of ICIC avoidance schemes. Moreover, there have been several confusions between the various ICI schemes; either in their naming conventions or their operational principles due to the large number of published work in this area. For example: some published work uses the notion of "Partial Frequency Reuse (PFR)" [3] while others use "Fractional Frequency Reuse with full isolation (FFR-FI)" to refer to the same scheme [4]. Also some published work refers to the well known "Reuse-3" scheme as "Hard frequency reuse" [4], the notion of "Soft Frequency Reuse (SFR)" was originally proposed in [5] with a particular definition, whereas in [6] a different scheme was introduced with the same name of "Software Frequency Reuse (SFR)".

This raises the need to present a comprehensive coverage of this fast moving field. Also, wireless communications and mobile computing provides the R&D communities working in academic telecommunications and networking industries with a forum for sharing research and ideas. On the other hand, the 3G RF interference in HetNet environment as in Figure 1 and its mitigation techniques used become a hot research area now for multi-cell interference avoidance in OFDMA systems as no recent new techniques were proposed. The Small cells, Pico cells and Femto cells represent a promising solution to enhance network performance with a pervasive coverage at low cost and energy consumption. Small cells stand for small size cells that can be deployed in indoor or outdoor environments and are based on existing or emerging cellular wireless network standards (such as WiMAX, UMTS and LTE). The convergence of wireless communications and mobile computing is bringing together two areas of immense growth and innovation as it is presented in this paper.

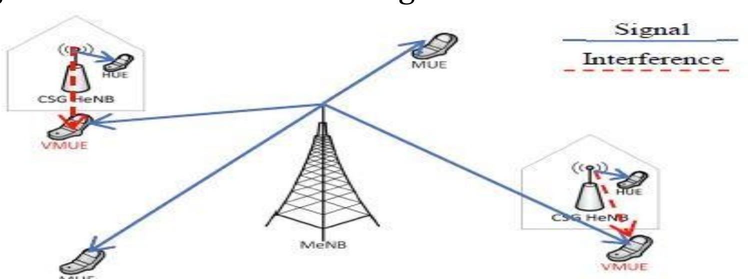


Figure 1: HetNet Environment.

3. Previous And Related Work

In this section a brief review on the main previous survey published papers related to the interference avoidance schemes. In reference [7] a performance of a Turbo coded OFDM wireless link is evaluated in the presence of Rayleigh fading for SISO, SIMO, MISO and MIMO system.

Data are encoded using turbo encoder then modulated by QPSK or 16 QAM or 64 QAM and further encoded using STBC, and the encoded data are split into "n" streams which are modulated by OFDM and simultaneously transmitted using "n" transmit antennas and the results showed the coded MIMO-OFDM has a significant difference over un-coded schemes, in ref [8], the channel allocation schemes has been classified to three categories: Fixed Channel Allocation (FCA), Dynamic channel Allocation (DCA) and Hybrid Channel allocation (HCA). TABLE 1 summarizes the three categories descriptions of channel allocation schemes.

Table 1: Summary of Channel Allocation Schemes [8].

Channel Allocation Schemes	Description
FCA	A set of nominal channels are permanently allocated to each cell for its exclusive use. Where channels can be allocated to cells either *uniformly* (equal shares) or *nonuniformly* (based on expected traffic loads) with the option of allowing cells to borrow channels from one another.
DCA	All channels are kept in a central pool and are assigned dynamically to cells when requested, and then returned back to the central pool when became idle. The main idea of DCA is to allocate a channel that minimizes the system cost provided that certain interference constraints are satisfied.
HCA	Presents a mixture between FCA and DCA where the total number of channels available is divided into *fixed* and *dynamic* sets. The *fixed* set is assigned as in the FCA schemes while the *dynamic* set is shared by all cells.

While in reference [5] the paper proposed four categories for interference avoidance schemes - based on how much it adapts the network – to Static Schemes (SS), Low Level Dynamic Schemes (LLDS), Intermediate Level Dynamic Schemes (ILDS) and High Level Dynamic Schemes (HLDS). The results showed that as the degrees of freedom increases the total throughput and 10% throughput increase. Table 2 summarizes the different categories between interference avoidance schemes.

Table 2: Summary of Interference Avoidance Schemes [9].

Interference Avoidance Scheme	Description
SS	The best values for the different parameters (power ratio allocated to each user class, number of sub-bands allocated to each user class, frequency allocated to each cell) are determined based on full traffic load scenarios and then these values are kept fixed.

LLDS	As the best values for the different parameters may not always be "best" with different traffic loads, several pre-planned sets of best values for the different traffic loads and varied distributions of users. Given that BSs can know the total number of user and there are reliable and efficient connections between BSs, a scheme can switch based on the traffic load between two or more sets of best values each optimized for a certain traffic load.
ILDS	Given the serving user's quantity in each cell and locations of users in its own cell data available to the BSs, BSs calculates the best values for the different parameters to escape the limitation of using one of the pre-planned best value sets in LLDS.
HLDS	Require the availability of the channel condition information. It works similarly to ILDS to calculate the best values for power ratio, the sub-band number and allocation of frequency but it also calculates the number of sub-channel to be allocated to each user based on its channel condition.

In reference [8], the paper presented a survey on resource allocation algorithm for downlink of multi-user OFDM system, however a single cell was assumed, thus ICI and ICIC for the downlink were not discussed.

In DCA and based on information used for channel assignment, DCA schemes can be classified either as *call-by-call* (use only current channel usage conditions) or *adaptive* (use previous as well as current channel usage conditions), while based on the type of control employed, schemes can be classified either as *centralized* (a centralized controller assigns channels to users) or d*istributed* (base stations assigns channels to users) [9,10]. Distributed DCA schemes can be either cell based (base stations use local information collected from users and the exchanged information from other base stations) or adaptive (base stations rely only on the signal strength measurements collected locally from its users). Although many claims have been made about the relative performance of each DCA scheme to one or more alternative schemes, the trade-off and their range of achievable capacity gains are still unclear, and questions remain unanswered: How does each dynamic scheme produce its gain? What are the basic trades-off? Why do some schemes work only under certain traffic patterns? Can different schemes be combined? What is the value of additional status information of the nearby cells? What is the best possible use of the bandwidth [11,12].

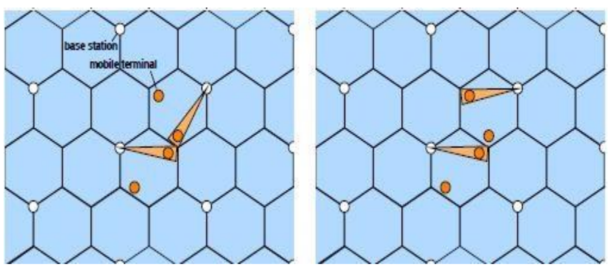
4. System Model

1. Interference Coordination (IFCO) in Spatial Domain

The channel throughput is determined based on the used Modulation and Coding Scheme (MCS) for a channel (selected based on the Channel Quality Indicator (CQI) reported from the user) which is mapped to the Transport Block Size (TBS) that can be used by using the mapping tables in reference [13]. Since different users perceive different channel qualities, a "bad" channel (due to deep fading and narrowband interference) for one user may still be favorable to other users. Thus, OFDMA exploits the multi-user diversity by avoiding assigning "bad" channels, which is an important feature in OFDMA.

In OFDMA systems, ICI is caused by the collision between resource blocks [14]. With such collision model, the overall system performance is determined by the collision probabilities and the impact of a given collision on the Signal to Interference and Noise Ratio (SINR) associated with the colliding resource blocks. ICIC mechanisms aim at reducing the collision probabilities and at mitigating the SINR degradation that such collisions may cause in order to improve the system performance and increase the overall bit rates of the cell and its cell edge users. Generally, ICIC techniques can be classified into *mitigation* and *avoidance* techniques. In interference mitigation, techniques are employed to reduce the impact of interference during the transmission or after the reception of the signal [15].

In order to achieve the goal of coordinating transmissions in neighboring cells, IFCO is a powerful tool to solve the problem of ICI in cellular networks and may control over various different resources and variables in the cellular network based on various common input parameters and controllable resources, such as Position of Mobile Terminals, Direction of Arrival (DoA), Signal Measurements and Channel Quality. The controllable resources and variables can be time, frequency, and code resources, Space Transmit power and MCS. Figure 2(a) shows a case where two transmissions in neighboring cells cause high interference on one another as it may occur in an uncoordinated system. In contrast, the transmissions are coordinated in Figure 2(b) in order to minimize interference. The coordination in the spatial domain may leverage all degrees of freedom that the installed beamforming systems allow such as placing nulls or arbitrarily shaping the radiation pattern.



(a) Uncoordinated (b) Coordinated operation

Figure 2: Illustration of IFCO in spatial domain.

2. Interference Avoidance Schemes Classifications

A wide range of techniques is presented in order to improve the throughput of the cell-edge users by reducing or suppressing the ICI. Interference mitigation techniques includes: (1) Interference randomization (where some cell-specific scrambling, interleaving, or frequency-hopping (spread spectrum)) , (2) Interference cancelation (where the interference signals are detected and subtracted from the desired received signal, or if multiple antenna system is employed, the receiver can select the best quality signal among the various received signals) [6], (3) Adaptive beamforming (where the antenna can dynamically change its radiation pattern depending on the interference levels) [4,8]. Interference avoidance schemes represent the frequency reuse planning algorithms used by the network elements to restrict or allocate certain resources (in both frequency and time domains) and power levels among users in different cells. The objective of these frequency reuse planning algorithms is to increase the SINR, and hence, allow the system to support as many users as possible. These frequency reuse planning algorithms must satisfy the power constraint in each cell by ensuring that the allocated transmission power of an Enhanced NodeB (eNB) does not exceed the maximum allowable power. A fundamental concept common to most interference avoidance schemes is to classify users in the cell based on their average SINR to a number of users' classes (also known as "cell regions"). Interference avoidance schemes then apply different reuse factors to the frequency band used by the different classes of users (i.e, to different cell regions). Figure 3 depicts the various types of interference avoidance schemes.

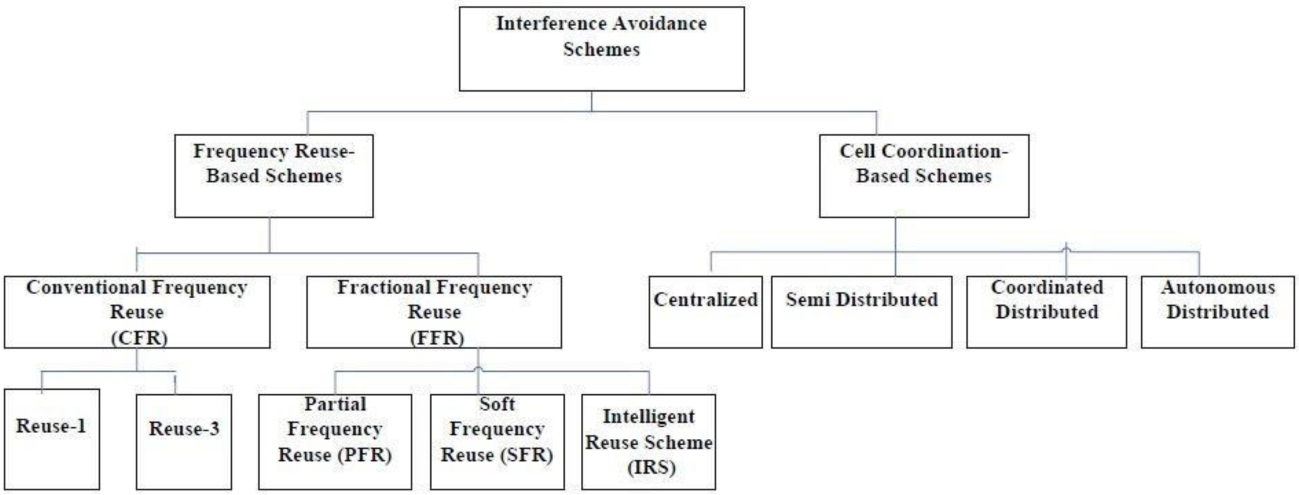


Figure 3: ICI Avoidance Schemes Classifications [5].

3. Fractional Frequency Reuse

One of the fundamental techniques to deal with the ICI problem is to control the use of frequencies over the various channels in the network. Frequency reuse-based schemes include: conventional frequency planning schemes (Reuse-1 and Reuse-3), fractional frequency reuse (FFR), partial frequency reuse (PFR), and soft frequency reuse (SFR). Despite their differences, all frequency reuse-based schemes need to specify the followings: (1) the set of channels (sub-bands) that will be used in each sector/cell, (2) the power at which each channel is operating, and (3) the region of the sector/cell in which this set of channels are used (e.g., cell-centre or cell-edge) [16,17].

Different schemes define different values and approaches for these various parameters. Accordingly, we can identify a unified structured description for any frequency reuse-based scheme. We believe that such structured description will not only simplify the expression of various schemes, but it will also reduce ambiguity in understanding some of the subtle schemes. In the following section, we introduce a new classification model that can use to explain some of the key frequencies reuse based schemes.

The assignment of mobile terminals to the different reuse partitions can be done based on various criteria. Typically, those terminals that are close to the base station experience good Signal to Interference Ratio (SIR) conditions and are therefore assigned to partitions with a small reuse factor. Vice versa, mobile terminals close to the cell edge are usually assigned to partitions with a large reuse factor. This circumstance is illustrated in Figure 4.

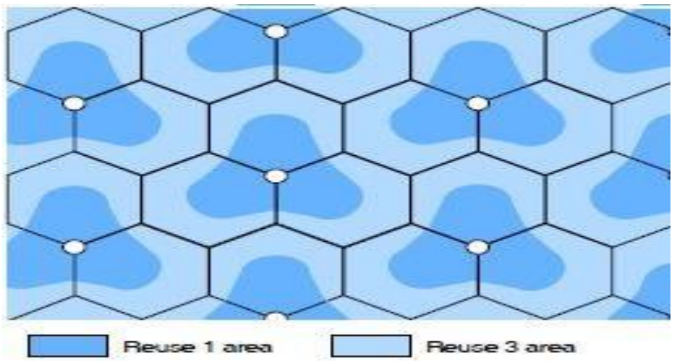


Figure 4: Illustration of Fractional Frequency Reuse with two reuse.

To avoid the shortcomings of the conventional frequency reuse schemes, the fractional frequency reuse (FFR) scheme is introduced to achieve a FRF between 1 and 3. FFR divides the whole available resources into two subsets or groups, namely, the *major* group and the *minor* group. The former is used to serve the cell-edge users, while the latter is used to cover the cell-center users [18]. Generally, the FFR scheme can be divided into three main classes as in Table 3.

Fractional Frequency Reuse	**Description**
PFR	a common frequency band is used in all sectors (i.e., with a frequency reuse-1) with equal power, while the power allocation of the remaining sub-bands is coordinated among the neighboring cells in order to create one sub-band with low inter cell interference level in each sector.
SFR	Each sector transmits in the whole frequency band. However, the sector uses full power in some frequency sub bands while reduced power is used in the rest of the frequency band.
IRS	Band allocated to different sectors expands and dilates based on the existing workloads. These schemes start with a reuse-3 like configuration at low workloads which can be changed with the increase of workloads to become PFR, SFR or even reuse-1.

Table 3: Summary of Interference Avoidance Schemes [5].

4. FFR Based on Frequency Allocation Scheme

Figure 5, represents the FFR based frequency allocation for a typical femto cell system. Total frequency is divided by four frequency sub-bands, a f is allocated for cell - center and f_B (f_{B1}, f_{B2}, f_{B3}) is allocated for three sectors in an orthogonal fashion in order to avoid the interference between macro and femto cells. For example, OFDMA in IEEE 802.16m can be considered which allocate Physical Resource Unit

(PRU) for macro and femto cell. PRU is composed of 18 subcarriers and 6 symbols, the total number of PRU of OFDMA with 10 MHz bandwidth will be 48 including Cyclic Prefix (CP).

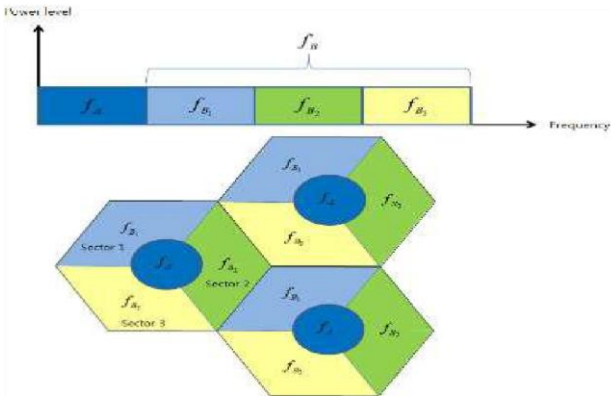


Figure 5: FFR based Frequency Allocation Scheme.

In order to evaluate the total cell throughput, the Shannon's Formula [1] is used as:

$$R = BW\log(1+SNR)_2 \quad (1)$$

Where, R is the cell throughput and BW is the bandwidth of PRU for each user and SINR for each user can be applied By:

$$SINR = \frac{P_i h_i}{\sum_{j=1}^{M} P_j h_j + n_0} \quad (2)$$

Where P_i is the received power from macro cell and femto cell, h_i is the channel gain of MS received from macro cell and femto cell, Pj is the interference power from macro cell or femto cell which use a same PRU and hj is the channel gain of MS received from macro cell and femto cell which use a same PRU and n_0 is the Additive White Gaussian Noise (AWGN) for each user. A conventional interference cancellation scheme between macro and femto and the throughput increased based on FFR environment. Femto BS is allocates different frequency bandwidth according to existence macro MS around the femto BS, and the femto BS is interfered other femto BS. SINR performance has been decreased than dynamic FFR, but 90% of MS throughput has been increased [19-21].

5. LTE Commercialization Trend

Wireless mobile communications are continuously evolving to respond to increasing needs of quality of service, data rates and diversity of the offered services. Meeting the ever expanding requirements; require innovations in architectures, protocols, spectrum sharing techniques, and interoperability between HetNet networks. This is reflected throughout the research by strongly focusing on new trends, developments, emerging technologies and new industrial standards, providing leading edge coverage of the opportunities and challenges driving the research and development of mobile communication systems.

1. Universal Mobile Access (UMA) Femto Cells

Mobile operators have been searching for licensed indoor coverage solutions since the beginning of wireless networks. Unfortunately, the bulk of this opportunity (i.e. residential environments) has been beyond the addressable market for cost and operational reasons. To be successful, a residential licensed access point (i.e. femto cell) solution must include low cost femto cells, a reasonable approach for managing RF interference, and a standard, scalable, IP-based approach for core network integration.

Femto cells are important because mobile operators need to seize residential minutes from fixed providers, and respond to emerging VoIP and WiFi offerings. Figure 6, shows the services provided to operator and subscribers. For operator, benefits will be: (1) Reduce churn with high quality 3G coverage, (2) Avoid capital expense by off loading the macro 3G network, on the other hand, subscriber benefits will be: (1) High performance 3G and (2) coverage at home.

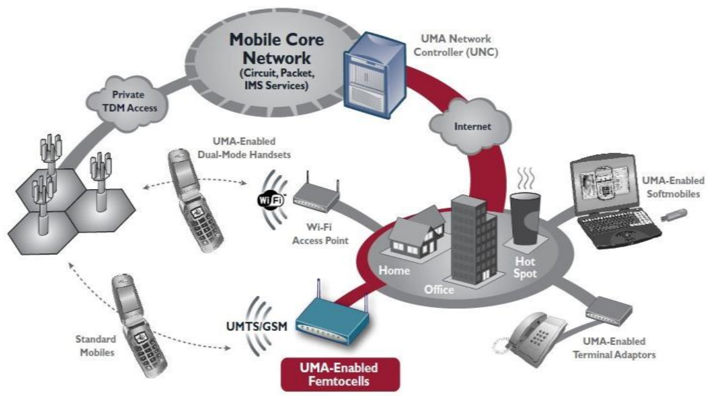


Figure 6: UMA the 3GPP standard for convergence provides high performance mobile coverage at home [22].

Recent developments from silicon and femto cell access point vendors promise to address the cost and interference issues over the next several years; a solution for core network integration has remained a challenge, as UMA provides standard, secure, scalable and cost effective IP-based access into core mobile service networks, it is now being leveraged to address this challenge. LTE technology is a basic mobile communication standard presented in late 2009 by ITU-T. Nowadays, 4^{th} Generation of Mobile communication systems are launched known as LTE-A. The main targets of LTE system are to support high data transfer, low latency, increased bandwidth (capacity), and improve Quality of Service (QoS). However these benefits face a lot of challenges. Among these challenges are high path loss and greater signal attenuation due to higher frequencies, transmit power controls, and the problem of interfering signals from neighbor cells (ICI).

ICI results from the motion of user from cell center to cell edge resulting in power reduction of the signal transmitted from the cell center while interference signals from neighbor cells is increased. ICI randomization, cancellation, and coordination/avoidance are three general approaches for ICI mitigation approaches. Frequency reuse is one of the most commonly used interference coordination technique, where the whole frequency band is divided into several sub-bands and wisely allocated to a specific area so as to improve signal status at cell edge. Frequency reuse is a common approach to increase data rate of point to multipoint systems [23].

2. From LTE-A To 4G Future

In reference [28], LTE and LTE-A have undeniably provided a major step forward in mobile communication capability, enabling mobile service provisioning to approach for the first time that

available from fixed-line connections. However, market demands typically do not evolve simply in discrete steps; therefore, the future evolution of LTE-A will be a story of continuous enhancement, on one hand, taking advantage of the advancing capabilities of technology, while on the other aiming to keep pace with the expectations and needs of the end users.
The likely directions of this continuing enhancement are discussed, and some areas where further technical advancement will be required are identified. In particular, potential measures to enhance the efficiency of spectrum utilization by joint multi-cell optimization, dynamic adaptation of the network to traffic characteristics and load levels, and support for new applications are highlighted. The limited availability of suitable radio spectrum will increasingly impact the future evolution of LTEA. This is already evident in the carrier aggregation features provided by LTE-A, and it is inevitable that the range of band combinations that have to be supported will continue to increase. Techniques to enhance dynamic load management between carriers according to traffic demand will also become an increasingly valuable tool for ensuring full and efficient use of scarce spectrum resources. Such dynamic techniques are likely in due course to evolve in the direction of cognitive radio solutions, with increasing utilization of spectrum sharing and white space detection as spectrum becomes ever more crowded [24].

4. 3G RF Interference Mitigation Techniques - Self Optimization Network (SON) and WCDMA HetNets

In mobile radio networks with several operators covering the same geographic area, interferences between the frequency channels of the model used in 3G to evaluate the interference between operators is relined so that the simulation results reflect the parameters used for path to reduce the interference between the operators by radiation pattern design of the antennas at the base stations [25]. The following are proposed techniques can be used to mitigate it.

1. Automatic Carrier Selection

In this technique, a frequency list is provided by supervision system named by SCMS, the small cell selects the appropriate frequency for operation during auto-configuration, i.e., once every 24 hrs, that has least interference using Network Listen Measurements (NLM). A suitable hysteresis is added to prevent toggling between carriers and applicable to non-group deployments only. This proposed technique is mainly suitable for the home segment, which removes the need for manual provisioning of carrier frequency and has better coverage and capacity due to the selection of less interfered channel.

2. Up link (UL) Interference Management

The worst case of UL interference occurs when a small cell mobile handset (UE) comes close to the border of the neighboring small cell / macro cell and there is also another UE on the border with both UEs transmitting at high uplink data rates. Aim of this feature is to control small cell UE maximum, UL transmitted Power based on; estimated pathloss between small cell UE and its neighboring Small Cell/Macro cell based upon UE CPICH protocol measurements and the neighbor's CPICH transmit power. UL UE maximum transmitted power is updated through Radio Resource Control (RRC) signaling protocol. The mechanism is activated only when following events occur; UL Received Total Wideband Power (RTWP) - checking the uplink interference - is above a threshold of uplink enhanced dedicated channel (E-DCH) or high UL data rate is configured on the small cell UE. An Operation &

Maintenance defined maximum level of interference that the small cell UE can create into a neighbor cell is implemented. This technique is suitable for all segments and any carrier deployment scenario [26].

3. Continuous Coverage Self-Optimization Based on Admission

In closed access mode, too many Location Area Update (LAU) and Routing Area Update (RAU) attempts from public UEs will trigger a reduction in the pilot power, SON technique to adapt the coverage of the closed access mode Shared Carrier (SC) based on how often non registered UEs are trying to camp on femto or rate at which registered users are performing outgoing handovers. This technique is particularly useful for a SC placed in a sub-optimal location, e.g., next to a window, the technique algorithm runs continuously and can adapt to local traffic variations [27].

One of the proposed features of this technique is it configurable thresholds for camping rate and handover rate can be targeted and is applicable mainly to home and enterprise segments in shared carrier deployments to minimize impact of downlink RF leakage on non-registered/public users and to minimize signaling resulting from frequents camping requests from non-registered users.

4. Outdoor Metro Cell Deployments Challenges

Deployment of small cells in realistic environments poses significant challenges. It is crucial to address these challenges for enabling large scale adoption of small cells in the future. The myriad of challenges include co-existence schemes with neighboring cells (including small and macro cells), interference management mechanisms (to ensure continuity of service over neighboring small and macro cells), self organizing and self management issues (crucial for efficient deployment of small cells) and optimal network architectures (related to the host radio access technology).

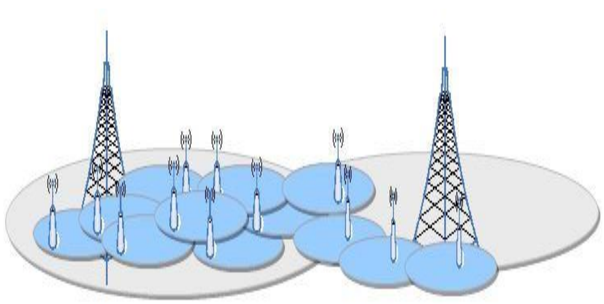


Figure 7: Metro Deployment Zones [28].

Metro Cells can provide additional data capacity in areas of high traffic density in dense urban outdoor areas as macro RF signal levels are generally very high in operator areas deployment of interfaces based outdoor metro cells under an existing interface based macro layer is challenging. Based on simulations and field experience macro cell coverage area can be divided into three zones (red, yellow and green) in terms of suitability for deploying outdoor metro cells on shared carrier, metro cells can be deployed in the Green and Yellow zones, but deployment guidelines need to be followed in order to get good trade-off between performance improvement and interference impacts [29]. Implementation of traffic segmentation is recommended in the Yellow zone in order to maintain Key Performance Indicators (KPIs). Similarly, multiple metro cells deployed in close proximity and configured in a group can offload more users and improve business case in comparison to isolated metro cell deployments Hierarchal Cell Structure (HCS) high mobility detection feature can be implemented on the macro to minimize camping of fast moving idle mode UEs on metro cells Exclusion zone – interference is significant, small cell off load potential is low due to reduced small cell size Intermediate zone – interference is still significant, but benefits of small cell offload starts to come into play Safe zone – effect of interference is not significant, benefits of small cell offload is maximized [30].

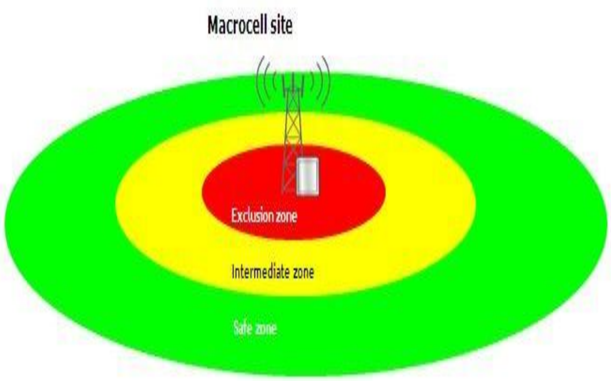


Figure 8: Metro Deployment Zones [31].

5. Conclusion

ICIC schemes can be viewed as a scheduling strategy used to limit the inter cell interference such that cell-edge users in different cells preferably are scheduled on complementary parts of the spectrum when needed. The common theme of ICIC avoidance schemes is to apply restrictions to the usage of downlink resources such time/frequency and/or transmit power resources. Coordination of restrictions will provide an opportunity to limit the interference generation in the area of the cellular network.

Accordingly, SINR can be improved at the receivers in the coverage area, which will provide potential for increased (cell-edge) data-rates over the coverage area or increased coverage for given data-rates. FR schemes are an interference management techniques well suited to OFDMA-based cellular networks. In this paper, a summary of the different interference avoidance techniques is presented. The study showed that FFR with reuse four has the smallest interference hence better edge spectral effiency than SFR with different power ratios. For SFR it is better to use power ratios between 2, 4 as they achieve reasonable inner radii than other power ratios. The study showed that there is tradeoff aspect between capacity and coverage related to SFR and FFR respectively, LTE-A reflected throughout the research by strongly focusing on new trends, developments, emerging technologies and new industrial standards. 3G RF interference mitigation techniques for SON, HetNets providing leading edge coverage of the opportunities and challenges driving the research and development of mobile communication systems.

6. Future Work

An evaluation framework and a benchmark are needed to allow researchers to develop and evaluate their ICIC schemes in a sound manner. Such an effort will provide researchers with data sets for unified realistic scenarios that define common realistic conditions, such as: cells layout, number of channels, propagation data, and traffic intensity. Recently, with the emergence of the cloud-computing technology and other technologies related to wireless infrastructure including software radio technology and remote radio head technology, Wireless Network Cloud (WNC) with Base Station Pooling (BSP) is becoming an interesting alternative network architecture where all eNBs computational resources (enabled by Software Radio) are pooled in a central location and connected via fiber to simple radiofront ends (Remote Radio heads) mounted on remote cell-towers. On the current advances and solutions as well as challenges and key research directions - linked to the deployment of small cells covers the link adaptation methods in LTE/LTE-A and present strategies for simulating and designing receivers to implement these methods.

References

E-UTRA and E-UTRAN Overall description: Stage 2 (Relase 8), 3GPP Technical Specification TS 36.300 V8.70, Dec. 2008. Avaliable: http://www.3gpp.org, July 2012.

Requirements for Further Advancements for E-UTRA (LTE-Advanced) (Relase 8), 3GPP Technical Specification TS 36.913 V8.0.0. Available (July 2012): http://www.3gpp.org, June 2008.

M. Rahman and H. Yanikomeroglu, *"Enhancing cell-edge performance: a downlink dynamic interference avoidance scheme with inter-cell coordination,"* IEEE Trans. Wireless Commun., vol. 9, no. 4, 2010, pp. 1414-1425.

R. Kwan and C. Leung, *"A Survey of Scheduling and Interference Mitigation in LTE,"* Journal of Electrical and Computer Engineering Electrical and Computer Engineering, 2010, vol. 2010.

S. Zhang, *"Inter-cell interference coordination in indoor LTE systems,"* Masters Thesis, Royal Institute of Technology, Sweden, 2011.

F. Khan, LTE for 4G Mobile Broadband: Air Interface Technologies and Performance: Cambridge University Press, 2009.

Kamruzzaman, M.M. *"Performance of Turbo coded wireless link for SISO-OFDM,SIMO-OFDM, MISO-OFDM and MIMO-OFDM system,"* in Key Lab of Information Coding & Transmission, South west Jia Tong University, Chengdu, Sichuan, China, Dec. 2011, pp. 185 – 190, 22-24.

S. Sadr, A. Anpalagan and K. Raahemifar, *"Radio Resource Allocation Algorithms for the Downlink of Multiuser OFDM Communication Systems,"* IEEE Commun. Surveys & Tutorials, vol. 11, no. 3, Third Quarter 2009, pp. 92-106.

Okada, K. Kubota, F.,*"On dynamic channel assignment in cellular mobile radio systems,"* Circuits and Systems, IEEE International Symposium on 11-14 Jun 1991, vol. 2, pp 938 – 941.

Beck, R., Panzer, H.,*"Strategies for handover and dynamic channel allocation in micro-cellular mobile radio systems,"* Vehicular Technology Conference, IEEE 39th , 1-3 May 1989, vol.1, pp 178 – 184.

I. Katzela and M. Naghshineh, *"Channel assignment schemes for cellular mobile telecommunication systems: a comprehensive survey,"* IEEE Personal Commun., vol. 3, no. 3, 1996, pp. 10-31.

Hassan, N.U.L., *Assaad, M., "Optimal Fractional Frequency Reuse (FFR) and resource allocation in multiuser OFDMA system,"* Information and Communication Technologies, 2009. ICICT '09. International Conference on 15-16 Aug. 2009, pp. 88 – 92.

Tekinay, S. Jabbari, *"Handover and channel Assignment In Mobile Cellular Networks,"* Communications Magazine, IEEE vol. 29, Issue 11, , Nov. 1991, pp 42-46.

3GPP TS 36.213 V10.5.0, *"E-UTRA Physical layer procedures,"* 3rd Generation Partnership Project, 2012. Available (July 2012):http://www.3gpp.org/ftp/Specs/archive/36 series/36.213/36213a50.zip.

G. Li and H. Liu, *"Downlink Radio Resource Allocation for Multi-Cell OFDMA System,"* IEEE Trans. Wireless Communications, vol. 5, no. 12, 2006, pp. 3451-3459.

Hashima, S., Elnoubi, S.,"Analysis of frequency reuse cellular systems using worst case Signal to Interference ratio," in Telecommunications (ConTEL), 2013 12th International Conference on June 2013, pp. 185-190.

Abeta, S., "Toward LTE Commercial Launch and Future Plan for LTE Enhancements (LTEAdvanced)," Communication Systems (ICCS), 2010 IEEE International Conference on 17-19 Nov. 2010, pp 146 – 150.

G. Fodor, Ch. Koutsimanis, and W. Mller, *"Intercell Interference Coordination in OFDMA Networks and in the 3GPP Long Term Evolution System,"* Journal of Communications, vol. 4, no. 7, 2009, pp. 445-453.

3GPP R1-060291, *"OFDMA Downlink inter-cell interference mitigation,"* Nokia, 2006. Available (July 2012):http://www.3gpp.org/ftp/tsgran/WG1 RL1/TSGR1 44/Docs/R1-060291.zip.

3GPP R1-050764, "Inter-cell Interference Handling for E-UTRA," Ericsson, 2005. Available (July2012):http://www.3gpp.org/ftp/tsg ran/WG1 RL1/TSGR1 42/Docs/R1-050764.zip.

J. G. Kim, "Adaptive Allocation for Usable Frequency in FFR Based Femtocell Network Environment," in Ubiquitous and Future Networks (ICUFN), 2013 Fifth International Conference on July 2013, pp. 770 – 775, 2013.

Baker, M., "From LTE-advanced to the future," IEEE Communications Magazine, vol. 50 , Issue 2 , pp. 116 – 120, February 2012.

S.Das, H. Viswanathan, "Dynamic load balancing through coordinated scheduling in packet data systems," in Proc. IEEE INFOCOM 2003, vol. 1, pp. 786-796, 2003.

T. Bonald, S. Borst, "Inter-Cell Scheduling in Wireless Data Networks," in Proc. 11th European Wireless Conference 2005 , pp. 1-7, 2005.

E. Yaacoub and Z. Dawy,"A Survey on Uplink ResourceAllocation in OFDMA Wireless Network," IEEE Commun. Surveys & Tutorials, vol. 14, no. 2, pp. 322-337, Second Quarter 2012.

E. Haro, S. Ruiz, D. Gonzalez, M. Garcia-Lozano, and J. Olmos, "Comparison of Different Distributed Scheduling Strategies for Static/Dynamic LTE Scenarios," Technical University of Wien, 2009.

Wen Li, Z.Ma, S.Shen, *"Feasibility Study of Relay In 3GPP LTE-Advanced From Coexistence Prespective,"* Communication Technology and Application (ICCTA 2011), IET International Conference on 14-16 Oct. 2011, pp 357 – 361, 2011.

Gozalvez, J., *"First LTE-Advanced Commercial Network Deployed [Mobile Radio],"* Vehicular Technology Magazine IEEE Vol 8, Issue 1, pp 10-17, March 2013.

J.G. Kim, W.G.Bae, *"Adaptive allocation for usable frequency in FFR based femtocell network environment,"* Ubiquitous and Future Networks (ICUFN), 2013 Fifth International Conference on 2-5, pp. 770-775, July 2013.

K.Tae Kim, S.K. Oh, *"An Incremental Frequency Reuse Scheme for an OFDMA Cellular System and Its Performance,"* Vehicular Technology Conference, 2008. VTC Spring 2008 IEEE, 11-14 May, pp 1504 – 1508, 2008.

D. Gonzalez, M. Garcia-Lozano, *"Static Inter- Cell Interference Coordination Techniques for LTE Networks: A Fair Performance Assessment,"* In Proc. the 3rd international conference on Multiple access communications (MACOM'10), pp.211-222, 2010.