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Advances in inter-cell interference coordination for realization of robust heterogeneous networks in lte-a systems

Bala Alhaji Salihu [1,2], Zubair Suleiman[2] Mala U. Mustapha Bakura[1,]

[1]*School of Information and Communication, Beijing University of Posts and Telecomm.100876, China*
[2]*Communication Engineering Department, Federal University of Technology, Minna, Nigeria*

ABSTRACT: *LTE-is one of the technologies of choice for 4G mobile communication so far, it has been deployed by 248 operators in 87 countries worldwide* (Chao, 2012). *Heterogeneous Network (HetNet) is the candidate for next generation mobile communication because of its robustness. However inter-cell interference is deterrent factor for achieving effective HetNet deployment. In this paper we give overview of the causes of this interference and described some research advances underway to tackle the challenge and also provide insight for further research areas for achieving effective inter-cell interference coordination in HetNet LTE-A for next generation network.*

Keywords: *Heterogeneous Network, LTE-Advanced, Inter-Cell Interference Coordination, Resource Block, E-UTRAN Node B (eNB).*

I. INTRODUCTION

To address the current exponential growth in demand for data traffic, cellular operators are aggressively overlaying smaller low power nodes (LPNs) (like Picocells, femtocells and relay nodes on top of existing macro cell E-UTRAN Node B (eNB) base stations (BSs) as an infrastructure leverage to existing macrocell eNBs. Heterogeneous Networks (HetNet) help transfer users on to LPNs, thereby enabling higher QoS to users with otherwise low reception. Because of the low transmission powers of LPNs and their relative closeness to the users, more users can now be packed within the same area. Consequently, HetNet provide "cell splitting gain" relative to macro-only networks (Lars, Lindbom; Robert, Love; Sandeep, Krishnamurthy; Chunhai, Yao; Nobuhiko, Miki; Vikram, Chanddrasekhar, 2011). By 2015, 4 major regions (Sub-Saharan Africa, Southeast Asia, South Asia, and the Middle East) and 40 countries (including India, Indonesia, and Nigeria) will have more people with mobile network access than with access to electricity at home (Cisco, 2011). Thus, this forecast is now the focus of many researchers to provide network to serve the upsurge traffic expected. Figure 1.shows a traffic projection by **Huawei** in the span of 6 years from 2008 through 2014.

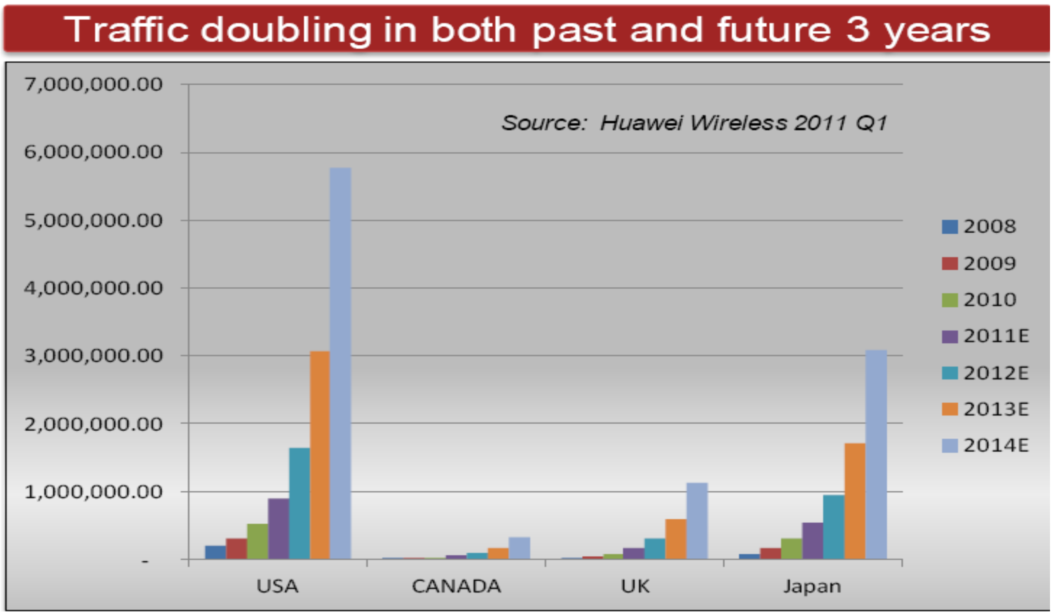

Figure 1: MBB traffic growth (HUAWEI, 2011)

HetNet deployment refers to a network of eNBs of different transmit powers i.e. different cell sizes distributed in a non-uniform manner throughout the served area (BERGSTROM, 2010). Efficient support for HetNet deployment is one of the key objectives of LTE-A (3GPP, 2009).

In HetNet LTE-A which explores **Orthogonal Frequency Division Multiple Access** (OFDMA) in the downlink and **Single Carrier Frequency Division Multiple Access** (SC-FDMA) in the uplink, new challenges of inter-cell interference management arise when the frequency reuse 1 is to be achieved according to 3Gpp LTE-A release 10 specifications. The spectrum efficiency obtained with frequency reuse 1 is the price and cause for the inter-cell interference. 3GPP-LTE-A has devoted significant standardization effort towards devising inter-cell interference coordination (ICIC) schemes for minimizing interference, culminating in the so-called "enhanced" ICIC in LTE-Advanced. Hence, ICIC techniques are becoming more relevant in system designs to provide reliable services to user equipments (UEs) e.g smart phone, netbook computers and PDAs etc with more concern about the cell-edge users usually located at cell boundaries and overlapped areas. The interferences arise as result of sharing network resource.

With reference to 3GPP standards, this article makes a HetNet LTE-A resource overview and reviews recent research trend on ICIC in HetNet with emphasis on key features of physical layer and radio interface architecture of E-UTRAN and higlights challenges ahead for effective ICIC.

The remainder of this work is thus arrainged; section 2 gives an overview of the LTE-A network architecture, section 3 discusses the radio interface and the various services rendered at the physical layer. Section 4 gives a detail about the frame structure and the dynamics involved in both uplink and downlink. Section 5 discusses interference scenarios in HetNet, interference mitigation schemes, an in-depth analysis of ICIC is made in section 6. Section 7 mentions the research challenges and section 8 concludes the article.

II. LTE-A NETWORK ARCHITECTURE

Wireless communication have evolved from 'second generation' (2G) of early 1990s, which first introduce digital cellular technology, through the third generation (3G) systems with their higher speed data networks to the much anticipated fourth generation (4G) technology being developed today. This evolutionary trend is illustrated in fig 2. Which shows that fewer standards are being proposed in 4G than in previous generations with only two 4G candidates being actively developed today: 3GPP LTE-A and 802.16m, which is an evolution of WiMAX standard known as mobile WiMAX (Agilent, 2010)?

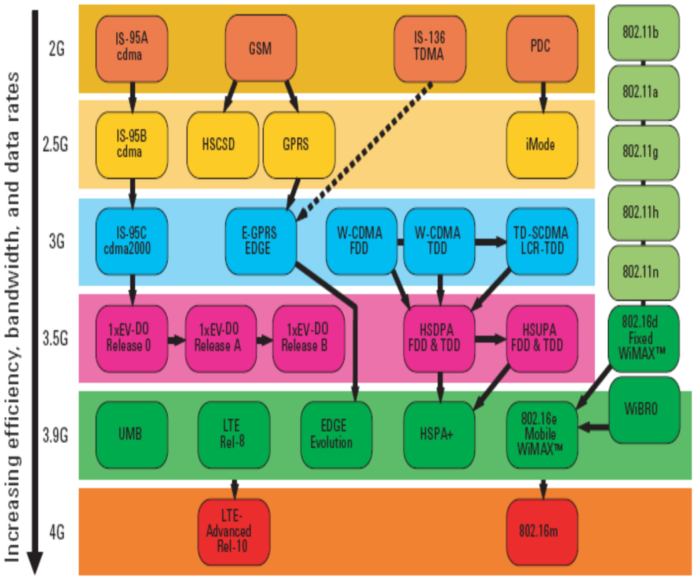

Figure 2: Wireless evolution from 1999-2010 (Agilent, 2010)

The LTE-A consist of cell sites E-UTRAN eNBs as illustrated in Figure 3. For normal user traffic (as opposed to broadcast), there is no centralized controller in E-UTRAN; hence the E-UTRAN architecture is said to be flat. The eNBs are normally interconnected with each other by means of an interface known as "X2" and to the Evolved Packet Core (EPC) by means of the S1 interface more specifically, to the Mobility Management Entity (MME) by means of the S1-MME interface and to the S-GW by means of the S1-U interface.

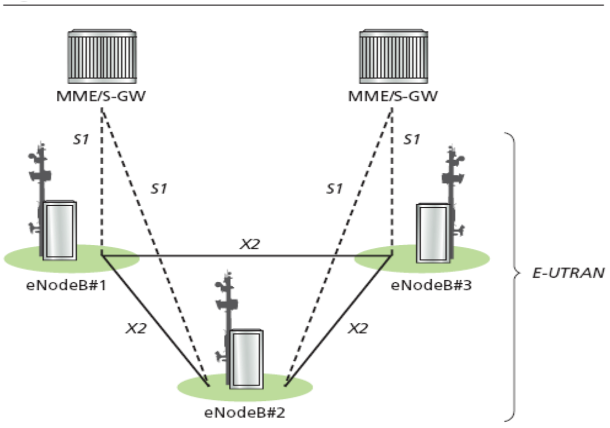

Figure 3: overall E-UTRAN architecture

The protocols that run between the eNBs and the UEs are known as the "AS protocols." The E-UTRAN is responsible for all radio-related functions, which can be summarized in the following as (Alcatel, 2009):

- **Radio resource management (RRM)** – This covers all functions related to the radio bearers, such as radio bearer control, radio admission control, radio mobility control, scheduling and dynamic allocation of resources to UEs in both uplink and downlink.
- **Header Compression –** This helps to ensure efficient use of the radio interface by compressing the IP packet headers that could otherwise represent a significant overhead, especially for small packets such as VoIP.
- **Security –** All data sent over the radio interface are encrypted.
- **Connectivity to the EPC** – This consists of the signaling toward MME and the bearer path toward the S-GW.

All of these functions are implemented within the eNBs, each of which can be accountable for coordinating multiple cells. Unlike some of the previous second- and third-generation (2G and 3G) technologies, LTE integrates the radio controller function into the eNBs. This allows lump collaboration between the different protocol layers of the radio access network (RAN), thus reducing latency and improving efficiency. Such distributed control mechanism eliminates the need for a high-availability, processing-intensive single node controller, which in turn has the potential to reduce costs and avoid "single points of failure." Furthermore, as LTE-A does not support soft handover there is no need for a centralized data-combining function in the network. Figure 4 shows the E-UTRA radio interface protocol architecture around the physical layer (Layer 1). The physical layer interfaces the Medium Access Control (MAC) sub-layer of Layer 2 and the Radio Resource Control (RRC) Layer of Layer 3. The circles between different layer/sub-layers indicate Service Access Points (SAPs).

III. RADIO INTERFACE (Physical Layer)

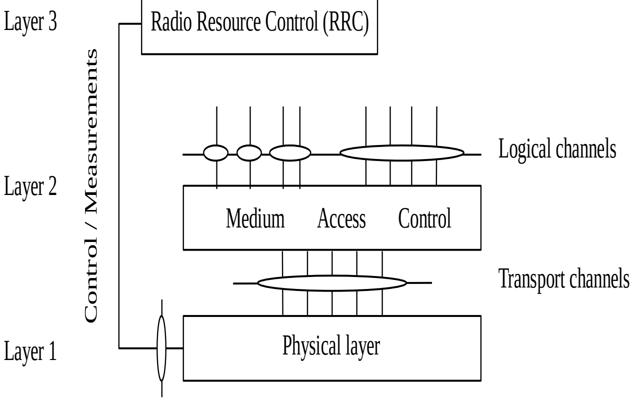

Figure 4: Radio interface protocol architecture around the physical layer

The physical layer offers a transport channel to MAC. The transport channel is characterized by how the information is transferred over the radio interface. MAC offers different logical channels to the Radio Link Control (RLC) sub-layer of Layer 2. A logical channel is characterized by the type of information transferred (3GPP TS , 2010).

Physical layer provides data transport services to the higher layers with the help of transport channel via the MAC sub-layer. It is defined in a bandwidth agnostic way i.e. allowing it to adapt to various spectrum allocations. The main functions of physical layer are summarized in (Hussain, 2009) and references therein.

IV. LTE-A FRAME STRUCTURE

In 3GPP-LTE specification, the subframe is the basic unit of transmission. The size of various fields in the time domain is expressed as a number of time units $T_s = 1/(15000 \times 2048)$ seconds. Downlink (DL) and Uplink (UL) transmissions are organized into radio frames with $T_f = 307200 \times T_s = 10\,\text{ms}$ duration. Two radio frame structures are supported (3GPP TS 36.211) Type 1, applicable to FDD and Type 2, applicable to TDD.
The total number of subcarriers depends on the overall transmission bandwidth of the system. The LTE defined parameters for system bandwidth from 1.25MHz as shown in table 1.

Table 1:Available Downlink Bandwidth is Divided into RBs

Bandwidth (MHz)	**1.25**	**2.5**	**5.0**	**10.0**	**15.0**	**20.0**
Subcarrier bandwidth	**15**					
RB bandwidth	**180**					
Number of available RBs	**6**	**12**	**25**	**50**	**75**	**100**

A physical resource block (RB) is defined as consisting of 12 consecutive subcarriers for one slot (0.5ms) in duration. An RB is the smallest element of resource allocation by base station scheduler. Figure: 7 depict the downlink resource for LTE.

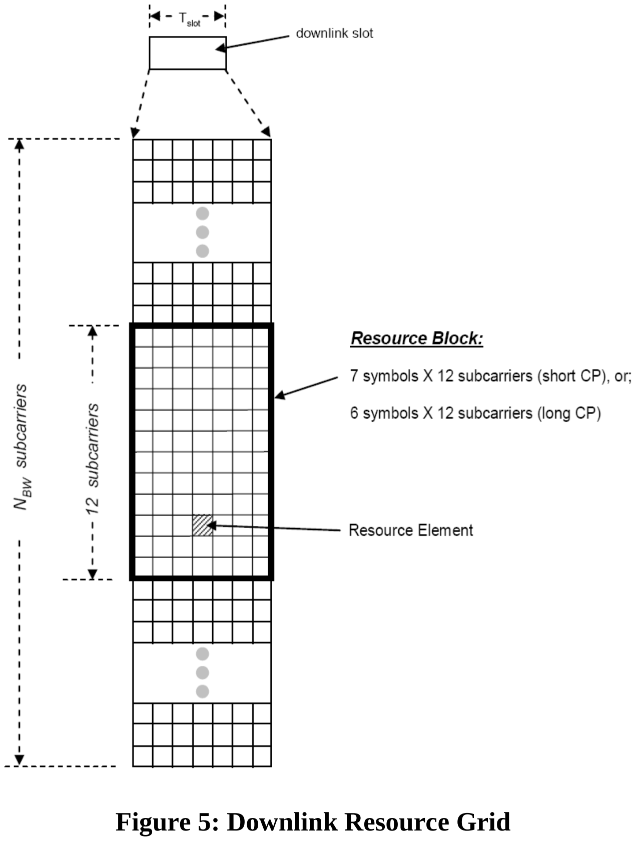

Figure 5: Downlink Resource Grid

The transmitted downlink signal consists of N_{wb} subcarriers for duration of $N_{symbols}$. It can be represented by resource grid. Each box within the grid represents a single subcarrier for one symbol period and a.k.a resource element.

The multiple access in LTE use OFDMA in the downlink (DL) and SC-FDMA in the uplink (UL) both with a cyclic prefix. The resource allocation in the frequency domain takes place with a resolution of 180Hz RB in both UL and DL. The UL user specific allocation is continuous; it enables single carrier transmission while

DL RBs are spectrum independent. LTE enable spectrum flexibility where the transmission bandwidth can be selected between 1.4 to 20MHz depending on the available spectrum. The spectrum flexibility makes LTE downward compatible with earlier generation technology and thus, eases inter-networking.

V. HETEROGENEOUS NETWORK (HetNet)

For HetNet to give robust data rate, total coverage has to be ensured and high performance LPNs have to be deployed at dense UE areas where the signal from Macro eNBs is weak. Fig 8 is depicts a typical HetNet deployment.

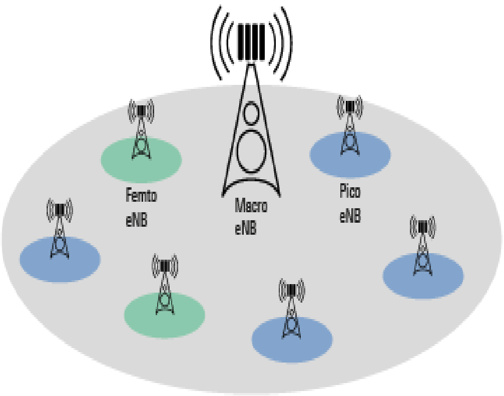

Figure 6: Heterogeneous Network Deployment

- **Macro eNB** is the top level node. The UEs should be able to reach a macro base station from anywhere within the service area. The transmit power is typically around 43dBm. The macro eNBs are connected to each other with a dedicated back haul connection.
- **Relay eNB (RN)** is a low power (23-30 dBm) eNB with an over-the-air back haul connection to the serving macro eNB.
- **Pico eNB** is a low power eNB which has a dedicated back haul connection. The transmit power is usually around 23-30 dBm. The nodes are deployed by the operator.
- **Femto eNB, or Home eNB (HeNB**), as they also are called, are LPNs that the users can buy and deploy where they need. Femto eNBs are connected to the rest of the network through the Internet. Since the users, instead of the operators, deploy HeNBs, effective planning is not possible for the HeNBs. The HeNBs can operate in two modes; open access or Closed Subscriber Group (CSG). When operating in open access, any UE can connect to the node while in the CSG mode only authorized UEs can connect. The owner of a HeNB can for example grant access to family and friends.

5.1 INTERFERENCE SCENARIOS IN HETEROGENEOUS NETWORKS

HetNet deployment has pros and cons. Although it provides a solution to problem of coverage by the addition of LPNs to cover areas where the macro eNBs signal cannot reach or the areas receiving weak signal. It is also advantageous to add LPNs in UE dense areas to cater for bursty traffic. However, these benefits are not without cost; interference is created. Different interference scenario may arise either in DL or UL as described in the following;

- In downlink; LNPs and macro eNBs normally use the same frequency (frequency reuse 1). Because of this, a macro UE close to LNP may receive a stronger signal from the LPN than from it service BSs which result in low SINR and vice versa for LPN UEs closer to macro BS. These are termed macro-LPNs and LPNs-macro interference respectively.
- In uplink; the LPNs experiences interference from macro UEs, the farther a UE gets from serving eNB the higher power it transmit in order to reach the eNB. This effect becomes more significant when the LPNs are located at the eNB cell-edge. Also, when LPNs is close to macro eNB the signals for the UEs in the LPN cell can reach the macro eNB and whence generate interference.

eNBs in a HetNet setting could also said to be in any of the following three scenarios:

- **Coverage-limited environment:** The cells are spaced very far apart from each other. Examples are rural and highway cells. Typically the signal levels near the cell edges are already very low; as a result, the out-of-cell interference levels are also very low.
- **Interference-limited environment:** The cells are packed very close to each other. Examples are dense suburban, urban or dense urban with small cells. Typically the cell-edge composite signal level is very high, but the out-of-cell interference level is also very high. As a result, the cell-edge SINR is still poor.

- **Environments somewhere between interference-limited and coverage-limited:** The cells are neither very close nor very far from each other. Examples are most light suburban cells.

5.2 INTERFERENCE MITIGATION SCHEMES

The earlier techniques popularly used to counter interference in wireless networks are considered deficient or inappropriate to combat interference cases in LTE. Examples of such techniques include; frequency hopping, spatial multiplexing and beam forming to mention a few. It is in this regards that 3GPP responded to the challenge by providing the scheme called *inter-cell interference coordination* -ICIC through standards specifications as from release 8 through 10. Techniques like higher order MIMO, coordinated multi-point (CoMP) transmission and reception, carrier aggregation (CA) and almost blank subframe (ABS) are all mechanisms provided to implement ICIC and to also assist in curbing the interference challenges in LTE-A network deployment. Either frequency domain or time line and power control is/are being explore for implementation of these techniques. Some viable frequency domain approaches includes fractional frequency reuse and adaptive beam forming.

From the link perspective, the Downlink analysis is easily represented analytically because the relative position of UE to other interfering BSs can easily be determined from the network topology which eases the probabilistic computation of SINR based on the channel fading conditions for the desired signal and interfering signals. Analyses of Uplink require not only the position of the UE under consideration but also the position of all other interfering UEs and the ones with potential to interfere. Both the positions and spatial velocity of interfering terminals and the potential interferers will be random variables thereby compounding the computational complexities.

LTE offers the capability to provide a flexible dynamic inter-base station approach to interference coordination through the use of inter- base station signaling including the use of UL reactive Overload Indicator (OI) and proactive High Interference Indicator (HII) that provide the bit map of interference condition on a per RB basis. DL ICIC is supported through the use of relative narrowband transmit power (RNTP) signal. This signal can take a value of 0 or 1 and is sent to multiple base stations serving adjacent cells for each RB. Specifically, this value is set to 0 if the ratio between the transmit of the DL signal allocated to the RB and average transmit power of the system frequency band is guaranteed to be under a certain threshold and to 1 otherwise (Dai & Hiroyuki, 2012).The RNTP message is signaled using a bitmap wherein each RNTP bit value indicate whether the corresponding RB is limited by a transmit power threshold or not. Upon receipt of RNTP message, the recipient eNBs can take into account this information while determining their scheduling decision for subsequent subframes. One of such example may be that the recipient eNB (e.g macro eNB) is transmitting above a certain power limit.

ICIC is a scheme design to curtail inter-cell interference and improve throughput at cell edges in multi-cell/ multi-station radio networks for HetNet in LTE-A. The technique specifies interface between base stations (the X2 interface) for exchanging interference –coordination information. Because of significant and importance of ICIC technology for gaining spectra efficiency and its adoption for next generation networks (3GPP LTE and beyond) the research pursuit in achieving the optimal use of this technology has being receiving keen attention from both industry and academia. Conversely, until today, there is no standardized algorithm for perfect operation of ICIC for all scenarios as mentioned in the previous section, thus the modality/mechanism of ICIC is still open for researchers and network operators.

VI. SOME HEADWAY FOR ICIC UNDERWAY IN HetNet

The basic concept of ICIC is to restrict/manage the usage of resources (power, frequency or time) such that the SINR experience by the edge UEs increases and their achievable throughput (either for the system per cell) improves. The scheme starts with ascertaining the available resources in each cell and thereafter, device a way to allocate them to UEs such that inter-cell interference remains low with less effect on the entire communication system.

Though universal mechanism of operation for ICIC is underway, nonetheless, there is a meeting line for general operation of ICIC and the main goal remain same for network community. So far, release 8, 8/9 and 10 by 3GPP LTE standardization group has being the optimum guide for building ICIC modules either in software or hardware fashion. Feasible ICIC schemes mechanism includes a pro-active scheme that can operate with or without inter-cell communication.

Adaptive multi-cell power control technique is another ICIC method being employed to increase the uplink throughput of multi-cell (MIMO) cellular systems. However, it remains hypothetic still awaiting logical input from researchers whether such schemes will be feasible and economical in real systems (Gabor, Chrysostomos, Andras, Norbert, Arne, & Muller, 2009).The paper worked out a scheme that uses frequency domain *start indices* defined according to reuse pattern. The detail algorithm is described therein.

ICIC Technique based on users ratio and Multi-Level frequency allocation is proposed by (FAN, Chen, & ZHANG, 2007). In this scheme, part of frequency is made available for the cell-adge UEs while whole spectrum of the frequency is available at the cell center with reduced transmission power. The UEs in the edge arena share the resource block within their vicinity by adjusting the traffic load of their own. Concurrently, the users at the cell center with reduced power can borrow available resource from neighboring cells with fewer loads. The flaw in this proposal is the possible increase in signaling and its ambiguity by borrowing the resource of neighboring cell. Handling sudden increase of traffic either at borrower/lender end could be impossible or cause further degradation in spectra efficiency.

In (Jinho & Seungwon, 2011) the authors considered using CoMP with minimal backhaul transmission amongst eNBs this they achieved by limiting the channel state information (CSI) to only exchange of information to identify the group of cell-edge UEs. Each eNB transmit signals to it dedicated UEs in a group over the multiple subcarriers that are shared by other eNBs in the Coordination. In addition the paper also explore lattice-reduction (LR)-based MIMO detectors to perform joint detection (multiuser detection) over interference channels to obtain diversity gain. The comparison of the received signal r_k between the conventional approach for downlink transmission and the proposed multiuser detection revealed that for conventional approach with L subcarriers the receive signal at user k is

$$r_k = \sqrt{\frac{1}{L}} h_k s_k + n_k \tag{0.1}$$

Where h_k denotes the $Lx1$ channel gain vector from base station k to user k over dedicated channel, s_k and n_k are data symbol to user k and the background noise respectively. Whereas in multiuser detection with assumption that Q base stations concurrently transmit signals to K users for a subcarriers greater than L the received signal is given by

$$r_k = \sqrt{\frac{1}{M}} H_k s + n_k \tag{0.2}$$

Where H_k is the summation of $Mx1$ channel gain vector from eNBs q to user k. s is the same as in (1.1) but cumulative. With unique assumption that numbers of eNBs in the network is the same with number of users (cell-edge users) this assumption gave rise to relation between L and M as:

$$M - LK \tag{0.3}$$

It shows from (1.3) that the proposed multiuser detection can only outperform the conventional schemes if the signals are uncoded. For coded signals the two approached makes no difference in term of performance metric. In the same line ML detection by the users involves difficult computation, thus, to avert this computation overhead a linear detector is used to help in suppressing the interfering signals from the other eNBs.

The simulation results for the proposed Multichannel sharing and joint detection for cell-edge users in downlink proved the flexibility of the approach as compared to conventional approach and also achieved marginal performance increase. However, the assumption (Number of user = number of BSs) is analytically satisfactory but not scalable since upsurge in the number of users at the cell-edges could lead to defeat of the targeted goal.

The novel mobile radio research (Volker & Eiko, 2011) makes an attempt to use carrier aggregation (CA) and Time Domain Multiplexing (TDM) to tackle ICI for HetNet deployment. The two kind of ICI scenarios identified in the paper (though alike) are micro-pico (MeNB-PeNB) and micro-femto (MeNB-FeNB). Thus, the same solution was proffered for both cases. In proposed principle, available spectrum is divided into *primary component carrier* and *secondary component carrier* (PCC and SCC) such that the PCC is the cell that is meant to mitigate interference by providing control information through PDCCH, PCFICH and PHICH channels in a given subframe. Whilst by means of cross-carrier scheduling, each network layer can still schedule UEs on other SCC.

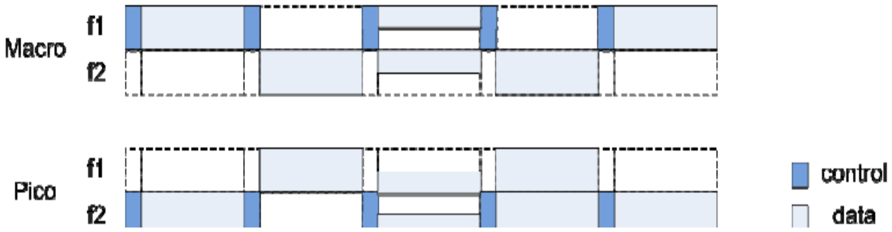

Figure 7: Illustration of Carrier aggregation based ICIC

For Time Domain Multiplexing ICIC: periodic muting is been applied to transmissions from eNBs that are inflicting severe interference onto others for a whole subframe so as to allow the suppressed eNBs to serve their UEs with the subframe. The muted subframes referred are known as absolute blank subframe (ABS). The muting still grant transmission of important information like primary and secondary synchronization signals (*PSS* and *SSS)*, physical broad cast channel (PBCH) etc to avert radio link failure. The interference with these important signals is however minimized.

The simulation results based only on static UEs shows that with CA and/or Time-base ICIC are/is capable of improving the user throughput for some specific configurations.

The work of (Li, 2011) for an effective ICIC scheme for Het-Net considered treating the challenge of interference in power domain particularly in Het-Net in LTE-A scenario where network deployment involving Macro eNBs and LPNs creates overlap (forming interference zone IZ) for UEs. The mechanism proposed for sensing this interference before impacting on the UEs is embedded in the LPN which is meant to sense the sub-carrier usage information about the UEs served by the Macro eNBs within IZ as depicted in fig 10.

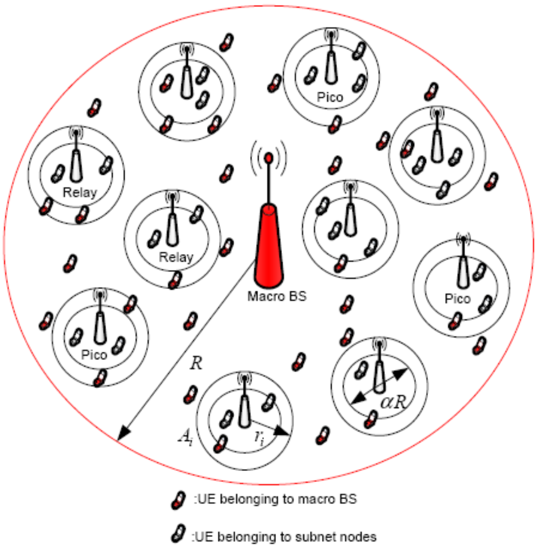

Figure 8: Mixed Macro BS and LPNs deployment with user distribution (Li, 2011)

The scheme also take care of overhead power consumption for sensing at the side of LPNs by programming the Macro eNBs to give a power reward to the LPNs as long as the LPNs continue to perform the sensing task. This proposed scheme is promising but the ability of Macro eNB's UEs to respond to sensing probe and as well maintain effective communication interface with its serving cells is not highlighted. In the same line, the process mechanism/framework for the LPNs must be enhanced if the scheme is to make a meaningful contribution. Uneven distribution of the UEs can also be a challenge.

In (Antonios, Christos, Vasileios, Konstantinos, & Andreas, 2011) the paper considered interference in femto-Macro and vice versa. He tries to make interference judgment through SINR reduction and throughput measurement in term of spectra efficiency for eNBs.

The drawback is that the proposed framework cannot be generalized because of the distance chosen for simulation is relatively small compare to what is obtainable in the field. The speed and handoff hysteresis could deter the primary assumption of the simulation. The assumption for the simulation is also far from requirements of 3GPP LTE-A specification.

VII. RESEARCH CHALLENGES

To achieve the use of wider bandwidth, multiple spectrum band and spectrum sharing as speculated for upcoming LTE-A HetNet deployment, more challenges will have to be tackled in terms of both hardware design and protocol stacks to cope with the high signaling, resource management and error control mechanism among others. The highlights in (Lan, David, & Reyes, 2010) give insight of these challenges.

Almost all the works on inter-cell interference are based on computer simulation and trail networks; little attention has been given to effects of control channels in computer simulation and trial networks except for the work of (Volker & Eiko, 2011) discussed earlier. Hence, a well standardized mechanism for protection of control channels is indispensable to attain full interference coordination for HetNet. This is because the control channels are less flexible compared to data channels and the function and viability of data channels solely depend on control channels.

VIII. CONCLUSION

This work have discussed ICIC in HetNet in interference-limited environments. It highlighted the physical resource available for sharing in HetNet and how access to these resources results in competitions among eNBs thereby giving rise to interference. It also described the various schemes proposed by both academia and operators to curb interference and increase throughput. However, research towards realization of effective ICIC for HetNet LTE-A is still underway. It finally pointed out some of the challenges ahead for HetNet deployment and in particular the protection of the control channels.

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