Autonomous Down Link Power Control Schemes for Heterogeneous Cellular Networks

Yan, Kai 5100309398

Abstract— **The 3GPP LTE-Advanced has been deploying heterogenous networks(HetNet) as a cost effective way to meet with the unrelenting demand for wireless resources. HetNet is a mixture of macrocells,remote radio heads, relays and low power cells such as femtocells and picocells,which improves spatial spectrum reuse and enhances indoor coverage. However, the new network format comes along with new interference related challenges. In this article, I briefly introduce the concept of HetNet and also describe the major interference challenges in such architecture. Later,I will introduce some autonomous down link power control schemes towards the interference challenges, which is considered as the primary inter-cell interference cancelation(ICIC) strategy.**

I. Introduction

With more than one million wireless subscribers today in the world and predictions for this number being tripled over the next five years, the wireless industry is confronted with unprecedented challenges in satisfying the exponential growing demand for ubiquitous wireless coverage and larger data rates. In order to support this galloping demand for data traffic, Third Generation Partnership Project (3GPP) Long Term Evolution(LTE) Release 10 is currently under standardization.

In order to enhance the performance of the overall network, LTE-Advanced proposes the use of advanced technologies like carrier aggregation(CA), multi-input multi-output(MIMO) systems and coordinated multipoint(CoMP)transmission and reception.[1] However, all these advanced technologies do not allow significant enhancements as they are reaching theoretical limits. Such techniques may not always work well either, especially under low signal-to-interference-plus-noise ratio(SINR) conditions, where received powers are low due to attenuation. In order to overcome these issues and provide a significant network performance leap, heterogeneous networks (HetNets) have been introduced in the LTE-Advanced standarization.

A HetNet is a network consisting of infrastructure points with various wireless access technologies, each of them having different capabilities, constraints, and operating functionalities. Specifically, in LTE-Advanced, multi-tier network roll-outs, involving RRHs, picocells, femtocells, as well as relay stations underlaying the existing macrocellular layout are envisaged. These low-power overlaid base stations (BSs) can be either operator deployed or user deployed, and may coexist in the same geographical area, potentially sharing the same spectrum. Deploying such small cells aims at offloading the macrocells, improving indoor coverage and cell-edge user performance, and boosting spectral efficiency per area unit via spatial reuse. They can be deployed with relatively low network overhead, and have high potential for reducing the energy consumption of future wireless networks. Also, this new palette of low-power miniature BSs requires little or no upfront planning and lease costs, therefore drastically reducing the operational and capital expenditures (OPEX, CAPEX) of networks [2]. There are some details of the different elements of HetNet listed in figure 1.

Types of nodes	Transmit power	Coverage	Backhaul
Macrocell	46 dBm	Few km	S1 interface
Picocell	23–30 dBm	< 300 m	X2 interface
Femtocell	< 23 dBm	< 50 m	Internet IP
Relay	30 dBm	300 m	Wireless
RRH	46 dBm	Few km	Fiber

figure 1. Specification of different elements in HetNet

II. Interference Challenges

While system capacity within macrocells greatly increased through frequency reuse, spatial reuse is reduced at the same time. As subchannels used in one cell are banned in the neighbouring ones, the inter-cell interference effect is amplified with the number of cells grows within a certain area.In this section, the principle interference scenarios in HetNet are reviewed, followed by some discussion of inter-cell interference cancellation techniques. Since femtocells pose a significant challenge to the proper operation of a HetNet due to their unplanned deployment and intercell interference characteristics, the rest of this article is focus on macrocell interactions with femtocells and picocells. The interference problem in HetNets is especially challenging due to the following reasons:[6]

Unplanned Deployment

Low-power nodes such as femtocells are typically deployed in an ad hoc manner by users. They can even be moved or switched on/off at any time. Hence, traditional network planning and optimization becomes inefficient because operators do not control neither the number nor the location of these cells. This motivates the need for new decentralized interference avoidance schemes that operate independently in each cell, utilizing only local information, whereas achieving an efficient solution for the entire network.

CSG Access

The fact that some cells may operate in CSG mode, in which cell access is restricted and nonsubscribers are thus not always connected to the nearest BS, originates significant cross-tier interference components[3]. Figure 2 depicts a challenging scenario for ICIC, in which different nonsubscribers walk near houses hosting a CSG femtocell. In the uplink (UL), the nonsubscriber in Fig. 2a transmits at high power to compensate for the path losses to its far serving macrocell, jamming the UL of the nearby CSG femtocell(s). In the downlink (DL), a CSG femtocell interferes with the DL reception of the nonsubscriber in Fig. 2b connected to the far macrocell. Hence, this DL macrocell user equipment(MUE) becomes a victim.

Power Difference Between Nodes

Picocells and relays usually operate in open access mode, meaning that all users of a given operator can access them. Open access helps minimize DL interference as end users always connect to the strongest cell, thus avoiding the CSG interference issue. However, in HetNets, being attached to the cell that provides the strongest DL received signal strength (RSS) may not be the best strategy since users tend to connect to macrocells, not to the cells at the shortest path loss distance. This is due to the large difference in transmission power between macrocells and low-power nodes. In that way, traffic load will be unevenly distributed, thus overloading macrocells.

Moreover, due to this server selection procedure in the DL, users connected to macrocells will severely interfere with all low-power nodes located in their vicinity in the UL. Figure 2c illustrates how a user connected to a macrocell that provides the best DL RSS jams a nearby picocell UL. Note that due to lower path loss, this MUE would transmit with much less UL power if it was associated with the picocell.

Range Expanded Users

To address the problems arising due to the power difference between the nodes in HetNets, new cell selection methods that allow user association with cells that provide a weaker DL pilot signal quality are necessary. An approach under investigation is that of range expansion[4], in which an offset is added to the picocells (or relays) RSS in order to increase its DL coverage footprint (Fig. 2d). Even though range expansion significantly mitigates cross-tier interference in the UL, this comes at the expense of reducing the DL signal quality of those users in the expanded region. Such users may suffer from DL SINRs below 0 dB since they are connected to cells that do not provide the best DL RSS (Fig. 2d).

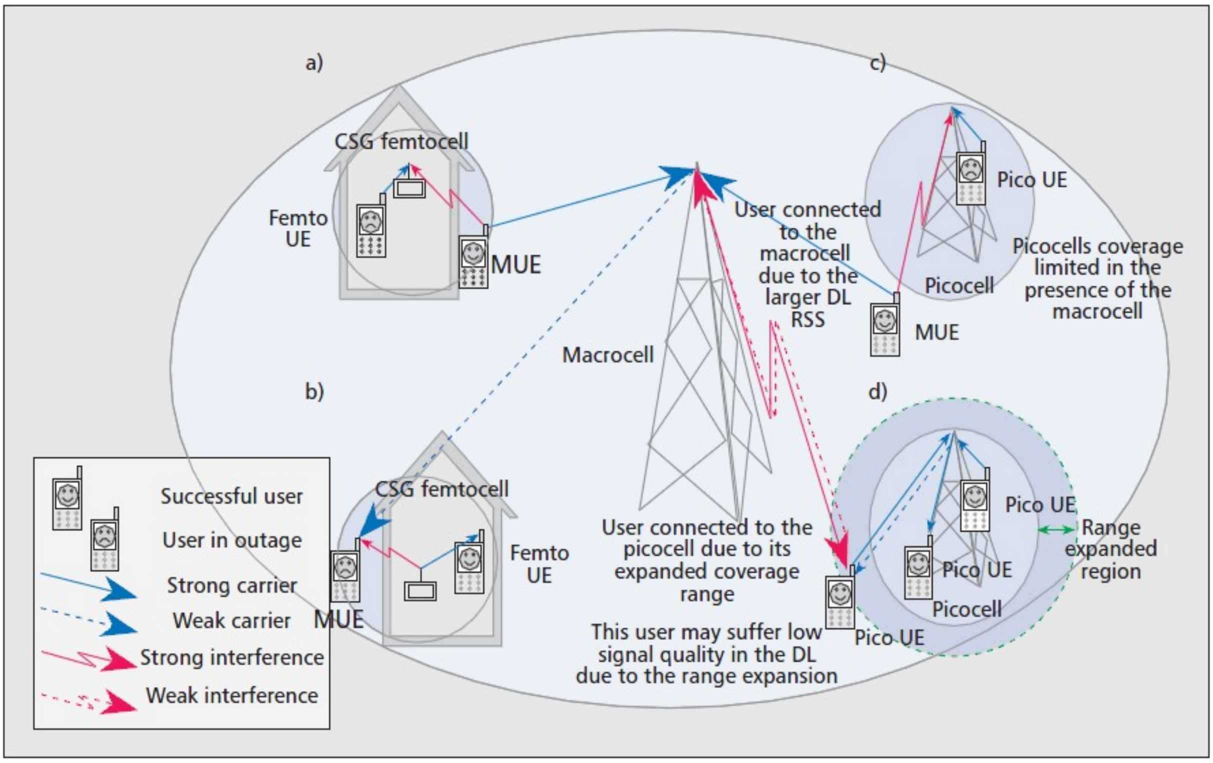

figure2. Dominant DL and UL cross-tier interference scenarios in HetNets :
a) macrocell user jamming the UL of a femtocell; b) femtocell jamming the DL of a macro user;
c) macrocell user jamming the UL of a nearby picocell; d) range-expanded picocell.

III. Power Control Techniques

Since a femtocell user having bad connectivity with the related FeNB can still handover to MeNB, from this point of view, the protection for MUE should be given higher priority. In this section, inter-cell interference coordination techniques specified in LTE standardization will be discussed to significantly improve the performance of victim MUEs.

Only CSG Access interference is discuss here. Since there is no direct X2/S1 interface between macrocell and femtocell, the real-time macro-femto coordination does not exist. Two autonomous PC schemes have been officially recommended in 3GPP. One of these two schemes requires the usage of two non-meaningful experimental parameters which need to be determined by running exhaustive network optimization; this might be infeasible in practice. The other scheme is more feasible because it only requires one femtocell's self-measured parameter and one largescale propagation parameter between femto and victim MUE. Here are some details of four more specific classification about the second scheme.

Let P_{max} and P_{min} denote the maximum and minimum home eNB transmit powers, respectively, P_M denote the received power from the strongest co-channel macro eNB at a home eNB; α and β denote two scalar power control variables. Then different DL power control approaches at femtocells can be listed as follows (all values are in dBm) [5]:

1.Strongest macro eNB received power at a home eNB:

The femtocell transmission power can be written as P_{tx} = max (min($\alpha P_M + \beta$, P_{max}), P_{min}).

2.Path loss between a home eNB and MUE:

The home eNB transmission power can be set as P_{tx} = med(P_M+ P_{ofst}, P_{max}, P_{min}), where the power offset is defined by P_{ofst} = med(P_{ipl}, $P_{ofstCmax}$, $P_{ofstCmin}$), with P_{ipl} denoting a power offset value that captures the indoor path loss and the penetration loss between home eNB and the nearest MUE, and $P_{ofst-max}$ and $P_{ofst-min}$ denote the maximum and minimum values of P_{ofst}, respectively.

3.Objective SINR of HUE:

In this approach, the received SINRs of home eNB users (HUEs) are restricted to a target value and transmit power at a femtocell is reduced appropriately to achieve this target SINR using the following expression:

$$P_{tx} = max(P_{min}, min(PL + P_{rec,HUE}, P_{max}))$$

where $P_{rec,HUE}$ = 10 log_{10} ($10^{I/10}$+ $10^{N0/10}$) + $SINR_{tar}$, I is the interference detected by the served UE, N0 is the background noise power, $SINR_{tar}$ is the target SINR for the HUE, and PL is the path loss estimate between the home eNB and the HUE.

4.Objective SINR of MUE:

The goal of this approach is to guarantee a minimum SINR at the MUEs, and the home eNB transmit power is given by P_{tx} = max (min(αP_{SINR} + β, P_{max}), P_{min}), where P_{SINR} is the SINR of the MUE considering only the nearest femtocell interference.

IV. Simulation

Figure 3 illustrate the SINR of a pedestrian user when passing by the front door of two different houses hosting a femtocell. It can be seen that when no action is taken at the femtocells, the SINR of the pedestrian user significantly falls, thus resulting in user outage. On the other hand, when power control action is taken, the MUE SINR recovers and outages vanish.

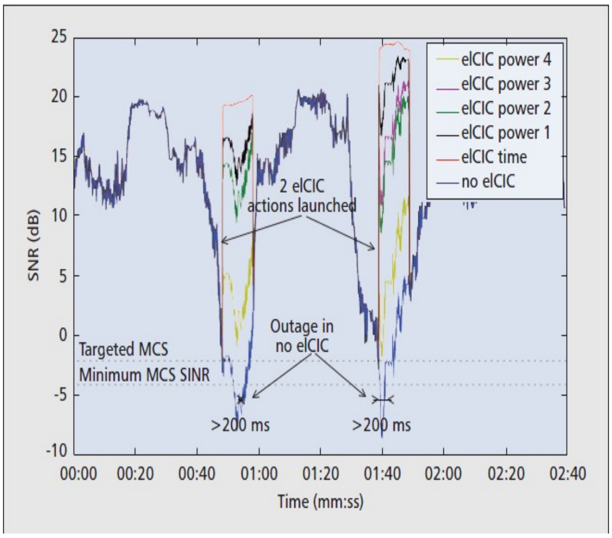

Figure 3. SINR vs. time of a victim MUE when passing close to two houses hosting a CSG femtocell.

V. Conclusion

HetNets have the potential to greatly boost the system capacity by means of frequency reuse. This article has discussed the advantages as well as interference challenges of HetNet. Specific power control schemes are analysed in this article for the avoidance of inter-cell interference to which should be paid particular attention in a HetNet. And effects of the schemes are evaluated through realistic system-level simulations.

References

References

[1] M. Dottling, W. Mohr, and A. Osseiran, Radio Technologies and Concepts for IMT-Advanced, Wiley, Dec. 2009.

[2] V. Chandrasekhar, J. G. Andrews, and A. Gatherer, Femtocell Networks: A Survey, IEEE Commun. Mag., vol. 46, no. 9, Sept. 2008, pp. 59C67.

[3] D. Lpez-Prez et al., OFDMA Femtocells: A Roadmap on Interference Avoidance, IEEE Commun. Mag., vol. 47, no. 9, Sept. 2009, pp. 41C48.

[4] NTT DOCOMO, R1-103264, Performance of eICIC with Control Channel Coverage Limitation, 3GPP Std., Montreal, Canada, May 2010.

[5] R1-104968, Summary of the Description of Candidate eICIC Solutions, 3GPP Std., Madrid, Spain, Aug. 2010.

[6] Lopez-Perez,D.;Guvenc,I.;de la Roche,G.; Kountouris,M.;Quek,T.Q.S.;Jie Zhang,"Enhanced Intercell Interference Coordination Challenges in Heterougeneous Networks,"IEEE Commun. Mag., vol. 18, no. 3, 2011, pp. 22-30.