Performance Analysis of Interference Averaging for Link Adaptation in LTE/LTE-A Downlink

Yuanjie Wang*, Xiaoyi Wang†, Deshan Miao†, Zhenhui Tan*
*School of Electronic and Information Engineering, Beijing Jiaotong University, Beijing, China
†Nokia Siemens Networks, Beijing, China
*12111008@bjtu.edu.cn

***Abstract*—In LTE/LTE-A system, Link Adaptation (LA) is a crucial procedure. One key factor is to have precious interference estimation considered in the LA, since the accuracy of interference estimation has a significant impact on the Channel Quality Indicator (CQI). In this paper we pay our attention to the CQI mismatch problem in Link Adaptation procedure, which is mainly caused by rapid fluctuation of inter-cell interference depending heavily on traffic load. Obvious performance loss has been observed in system level simulation due to this problem, thus we propose an interference averaging scheme for CQI calculation by considering not only the instantaneous interference level, but also the interference level in the past when UEs doing CQI calculation. Based on intensive system level simulations, it can be observed that the proposed scheme can improve the system performance both for average throughput and cell-edge throughput.**

Keywords-LTE/LTE-A; Link Adaptation; CQI-mismatch; Throughput; Interference Averaging

I. INTRODUCTION

The upcoming massive deployment of the 3GPP UTRAN Long Term Evolution (LTE) cellular system is speeding up the standardization procedure of LTE-Advanced (LTE-A), which is accepted by ITU-R as the 4G standard in the real sense [1]. LTE-A is expected to provide 1Gbps and 100Mbps data rate in local area and wide area, respectively. Such a big challenge boosts many advanced technologies such as Carrier Aggregation (CA), Coordinated Multipoint (CoMP), etc, which can extremely improve the system performance. Meanwhile, there are still lots of ongoing efforts targeting at the underlying PHY layer, trying to fully explore the potential optimization.

In the PHY layer, Link Adaptation (LA) is a key process to select proper Modulation Coding Scheme (MCS), so its accuracy will directly influence the throughput performance [2]. LA is based on Channel Quality Information (CQI) report which is usually in the form of quantized Signal to Interference and Noise Ratio (SINR). However, an intrinsic problem of link adaptation is the inaccuracy of CQI especially in some interference limited scenarios. The main reason is the CQI report delay and fast variation of interference, in another word, the interference level a scheduled UE suffers, at its scheduling time when the serving Base Station (BS) chooses MCS for it, will become quite different to that at the time of UE measurement. That has been identified as one of the most important factor limiting the LTE/LTE-A performance.

Some papers have already noticed this problem, and proposed several solutions on it. Given that the fluctuation of interference mainly depends on the resource allocation decisions of neighbouring base stations, bonding to dynamic entry and departure of users within their coverage, some papers deal with this through Inter-cell Interference Coordination (ICIC) [3]. In [4], the authors adopt a prominent strategy called Fractional Frequency Reuse (FFR). FFR is essentially a static frequency reuse strategy, where neighbouring cells don't share the same fractional spectrum for cell-edge users to avoid severe interference and thus of course can maintain the link adaptation accuracy efficiently. However, this kind of strategies sacrifices the Spectrum Efficiency (SE), thus are not very economical and practical in the spectrum shortage nowadays. There are also dynamic strategies discussed in paper [5–8], however this kind of schemes needs signaling between BSs, thus requires high-speed backhaul infrastructure. The common ground of these above-mentioned schemes is that they all avoid the influence of interference fluctuation by means of resource scheduling.

Other options trying to cope with this problem by directly focusing on interference itself are presented in paper [9] and [10]. In [9], the authors propose an interference randomization scheme, making the subcarriers allocated to a certain user randomly distributed in the whole time-frequency grid after a random permutation, resulting in only limited interference from a strong interferer to this user. It has been showed that interference randomization can outperform ICIC in the case of high load while to be inferior in the case of low load. In [10], it proposes a scheme based on interference prediction assuming reasonably accurate multi-cell channel estimation and fast backhauls between BSs. By using the predictable interference, LA accuracy can be improved; however, the system complexity increases a lot, too.

In this paper, we investigate an approach called interference averaging to mitigate the fluctuation of

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interference, thus leading to more accurate link adaptation. This approach is simple and effective without requirement of coordination between BSs and fast backhauls. We hope it may give a hand to the engineering practice.

The rest of this paper is organized as follows: In Section II we describe our system model while In Section III we describe the actual interference averaging scheme in detail. Simulation results are showed in Section IV and finally, some remarks are concluded in Section V.

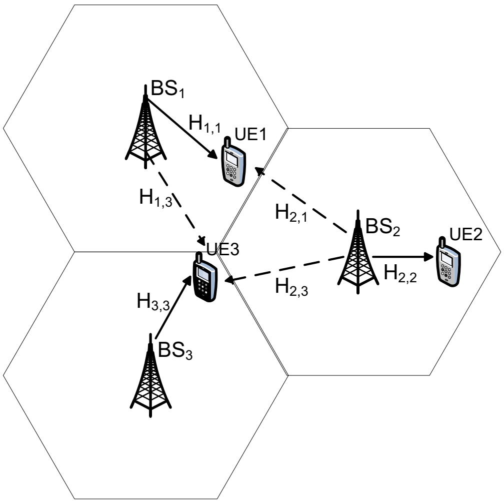

Fig. 1. Homogeneous Macro Network

II. SYSTEM MODEL

A. Basic Model

We consider a closed loop MIMO system with N homogeneous macro BSs as illustrated in Fig. 1. Each UE is only served by one BS simultaneously and equipped with N_R receiving antennas. Each BS has N_T transmitting antennas, thus the maximum number of streams is $N_s = \max\{N_T, N_R\}$. Assuming $BS_{b'}$ is transmitting signals to UE_m on subcarrier k in subframe n, then the received signal of UE_m at stream s' can be written as (1), where $P_{b,m}$ is the average received power per subcarrier of UE_m from BS_b ; assuming $H^{k,n}_{m,b} \in C^{N_R \times N_T}$ is the fast fading frequency-selective channel matrix between UE_m and BS_b on subcarrier k, in subframe n; $\vec{\omega}^{k,n}_{b,s} \in C^{N_T \times 1}$ is the precoding vector of stream s at BS_b; $x^{k,n}_{b,s}$ is the signal scalar transmitted by BS_b on stream s ; $N^{k,n}_m \sim CN(0,\sigma^2)$ is the i.i.d. Additive White Gaussian Noise (AWGN). The first term is the desired signal of UE_m on stream s', subcarrier k while the second term describes the Inter-Stream Interference (ISI) of UE_m and the third term stands for the Inter-Cell Interference (ICI) that UE_m suffers from other cells. It is worth noting here that the ICI may change dramatically in different subframes because of the time-varying channel between UE_m and its interfering base stations.

$$\begin{aligned} \vec{y}^{k,n}_{m,s'} &= \sqrt{P_{b',m}} H^{k,n}_{m,b'} \vec{w}^{n}_{b',s'} x^{k,n}_{b',s'} + \sum_{s \neq s'} \sqrt{P_{b',m}} H^{k,n}_{m,b'} \vec{w}^{n}_{b',s} x^{k,n}_{b',s} \\ &+ \sum_{b \neq b'} \sum_{s} \sqrt{P_{b,m}} H^{k,n}_{m,b} \vec{w}^{k,n}_{b,s} x^{k,n}_{b,s} + N^{k,n}_m \end{aligned} \tag{1}$$

Before calculating the SINR that UE_m will experience on stream s', we need to see the receiver model below. For simplicity, we ignore the superscript (k,n) in (1), and then we can get:

$$\hat{x}_{b',s'} = \vec{u}^{*}_{m,s'} \vec{y}_{m,s'} \tag{2}$$

where $\vec{u}^{*}_{m,s'}$ is the receiver equalization vector, $\hat{x}_{b',s'}$ is the estimation of transmitting signal. Here we consider an MMSE receiver to be used and then we can get $\vec{u}^{*}_{m,s'}$ from the following equations (3) to (5):

$$H_e = H_{m,b'}[\vec{w}_{b',s_1}, \vec{w}_{b',s_2}, \ldots, \vec{w}_{b',s_L}] \tag{3}$$

$$Z = H_e^{*}(H_e H_e^{*} + R_m)^{-1} \tag{4}$$

$$\vec{u}_{m,s'} = Z(s',:)^{*} \tag{5}$$

where $Z(s',:)^{*}$ represents the $s'th$ row of matrix Z . Thus, the SINR on stream s' can be calculated as below:

$$SINR_{m,s'} = \frac{\vec{u}^{*}_{m,s'} H_{m,b'} \vec{w}_{b',s'} \vec{w}^{*}_{b',s'} H^{*}_{m,b'} \vec{u}_{m,s'}}{\vec{u}^{*}_{m,s'} R_m \vec{u}_{m,s'}} \tag{6}$$

where

$$\begin{aligned} R_m &= I\sigma + \sum_{s \neq s'} H_{m,b'} \vec{w}_{b',s} \vec{w}^{*}_{b',s} H^{*}_{m,b'} \\ &+ \sum_{b \neq b'} \sum_{s} H_{m,b} \vec{w}_{b,s} \vec{w}^{*}_{b,s} H^{*}_{m,b} \end{aligned} \tag{7}$$

R_m is the total interference covariance matrix, including noise covariance matrix, inter-stream interference covariance matrix and inter-cell interference covariance matrix. Then CQI for a resource block n can be defined as arithmetic average of SINRs measured on its subcarriers. Suppose the CQI is calculated in subframe n, but due to the CQI delay and report period configuration, it cannot be used until subframe $n+d$. So, even the channel variation with time can be assumed neglectable when low speed UE is considered, however, because of the dynamic variation of traffic together with precoding vectors used in neighbouring cells, R_m can still vary a lot during time interval d, resulting in CQI mismatch.

The precoding vector used by UE_m's serving base station $BS_{b'}$ is usually based on recommendation of $UE's$ feedback, although it can be replaced by the BS with another one, for simplicity, here we assume the BS always follows the $UE's$ recommendation.

B. OLLA

Here we give a brief introduction of the famous Outer Loop Link Adaptation (OLLA) module which already been used in LTE/LTE-A system. It will be shown that our Interference Averaging scheme has efficient performance both with and without OLLA in Section IV.

OLLA is a general approach to mitigate the Link Adaptation errors whose main function is to compensate the long-term CQI mismatch and thus keep the BLER of the initial transmission below an acquired target threshold. In this regard, we use an OLLA approach similar to the one in [11]. Specifically, before making any Link Adaptation decisions, the BS should adjust the CQI received from a certain UE for resource block n by an offset Δ_{OLLA}, as presented in equation (8):

$$CQI(n) = CQI_{Rx}(n) - \Delta_{OLLA}[dB] \quad (8)$$

where $CQI_{Rx}(n)$ is the CQI fed back for resource block number n from that UE. What should be noted here is that the OLLA algorithm is UE-specific, which means different values of Δ_{OLLA} should be used depending on the UE index. However, the offset Δ_{OLLA} does not depend on the resource block index. Δ_{OLLA} should be identified as the following rules, if a first transmission is successful, then Δ_{OLLA} should be decreased by δ_{down}, whereas if the first transmission fails, then Δ_{OLLA} should be increased by δ_{up}. The two offsets δ_{up} and δ_{down} have relation to the target BLER threshold according to equation (9).

$$\delta_{down}|_{dB} = \frac{\delta_{up} \cdot BLER_{target}}{1 - BLER_{target}}|_{dB} \quad (9)$$

It is effective for OLLA to reduce the long-term CQI mismatch, but OLLA can't mitigate the error caused by dynamic ICI in short time scale, for example, time scale of several TTIs.

III. INTERFERENCE AVERAGING SCHEME

Here we introduce our interference averaging scheme which will be shown in the next section to bring performance gain. To diminish the influence of fast fluctuation of interference, we relate current instantaneous interference with previous measured interference by using a forgetting factor α which is a systemconfigurable parameter, as in (10):

$$I = \alpha I_{new} + (1-\alpha) I_{prev} \quad (10)$$

where I_{new} is the new instantaneous interference measured by the UE at current subframe, I_{prev} is the previous interference used for CQI calculation at the last measurement time.

As for simulation, the interference terms in (10) can be substituted by corresponding interference covariance to calculate SINRs according to (6) and (7). This is reasonable because the interference covariance matrix equivalently measures the contribution of total interference, including both inter-stream interference and inter-cell interference. The detailed procedure of the scheme for simulation is presented in Fig. 2.

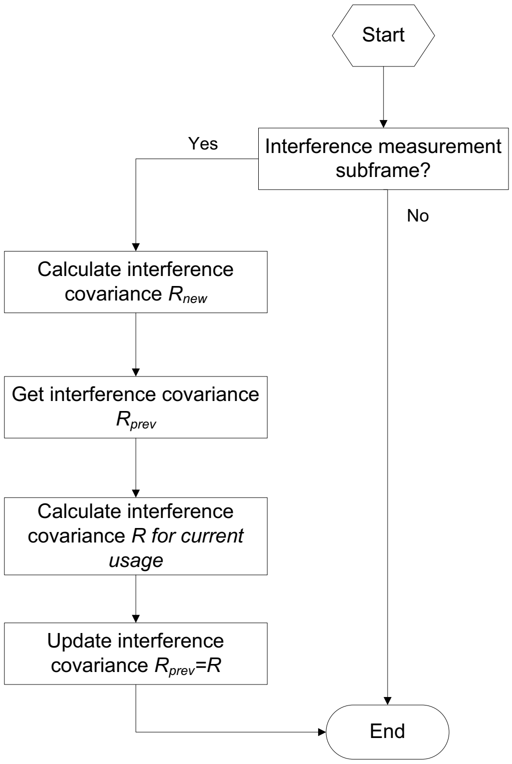

Fig.2. Procedure of proposed scheme

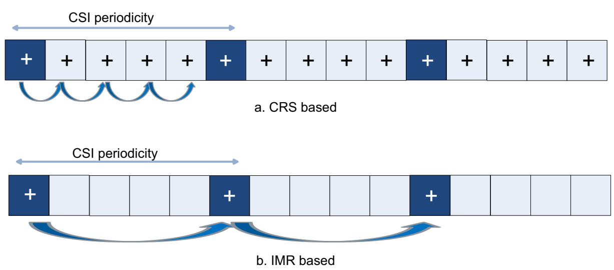

Fig.3. Association pattern of interference measurement subframes

When take reality into account, there are two ways to implement this interference averaging scheme, one is based on Cell specific Reference Signals (CRS), and the other one is based on Interference Measurement Resource (IMR).

A. CRS Based

The CRS-based interference averaging scheme is particularly suited for backwards compatibility, i.e. used by earlier-release UEs (before Release 10), as shown in Fig. 3 (a).

Since CRS is presented at every TTI, if interference averaging is used, then interference in every subframe is associated with the interference in subframes before through the interference forgetting factor.

B. IMR Based

IMR is newly introduced for interference measurement in Release 10. It is a set of resource elements on which the serving base stations is totally muted, thus all the signals that UEs receive on it are interference together with noise. It is rather convenient for the Release 10 UEs to proceed with interference measurement and CQI feedback. IMR is usually configured to be periodic. When interference averaging is used, the association pattern of the interference measurement subframes is shown in Fig. 3 (b).

IV. SIMULATION RESULTS

We analyze the proposed interference averaging scheme by intensely system level simulations. For ease of calibration, we use 3GPP macro case 1 cellular network, which consists of 7 sites with 3 sectors per site. Wrap-around model is used to avoid the boundary effects. The 3GPP spatial channel model (SCM) in Urban Macro deployment is used to evaluate the system performance. Transmission mode 8 is chosen for its oriented interference characteristic. Both full-buffer and FTP traffic model are evaluated. When in full-buffer cases, there are 10 uniformly distributed UEs in each cell and all of them are assumed to be active, whereas in FTP traffic cases, Poisson arrival UEs with FTP traffic model is assumed. We adopt the Effect Exponential SINR Mapping (EESM) model to realize the link-to-system mapping. As for the scheduler, frequency domain Proportional Fairness (PF) scheduling algorithm is used. The KPIs of system performance are set to be Average Spectrum Efficiency and Cell-edge Spectrum Efficiency. The main system parameters are listed in Table. I.

TABLE II. Test case 1-4

Test case	configuration
1	OLLA off, CRS based, full buffer
2	OLLA off, IMR based, full buffer
3	OLLA off, CRS based, FTP traffic
4	OLLA off, IMR based, FTP traffic

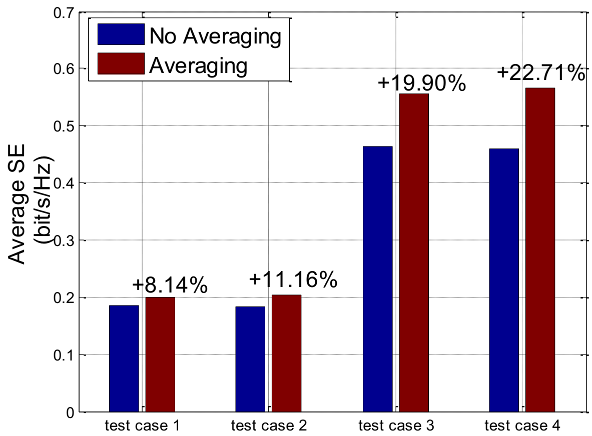

Fig.4. Average SE performance for different test cases

TABLE II. SIMULATION PARAMETERS

Parameter	**Value**
Simulation scenario	3 GPP case 1, 7 sites, 3 sectors per site
Duplex mode	FDD downlink
Carrier frequency	2 GHz
System bandwidth	10MHz
Num of subcarriers	600
Wrap-around model	yes
UE Num per cell	10
Channel model	3 GPP SCM Urban Macro
Indoor/out door UEs	80% indoor, 20% outdoor
Transmission mode	TM 8
Traffic model	Full buffer; FTP type 1, 300Kb
Cell selection	RSRP; no handover margin
Link to system mapping	EESM
Noise figure	9 dB
HARQ	8 Parallel processes
Receiver type	Ideal MMSE
Scheduler type	PF
BS configuration	4 Tx, 0.5λ separation, cross polarization
BS power	40 W
UE configuration	2 Rx, cross polarization
CQI period	10 ms
CQI delay	5 ms
Feedback mode	Subband PMI/CQI
Num of RBs per subband	3
UE speed	3 km/h
OLLA step up size	OFF; 0.5 dB
OLLA target BLER	10%

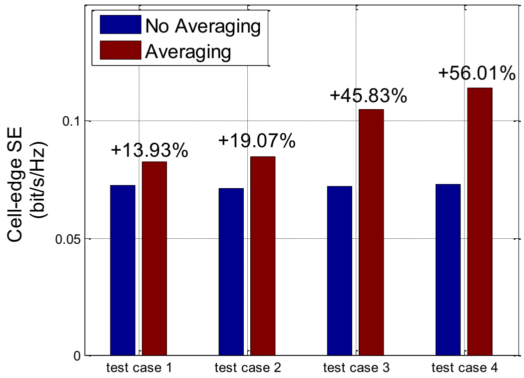

Fig.5. Cell-edge SE performance for different test cases

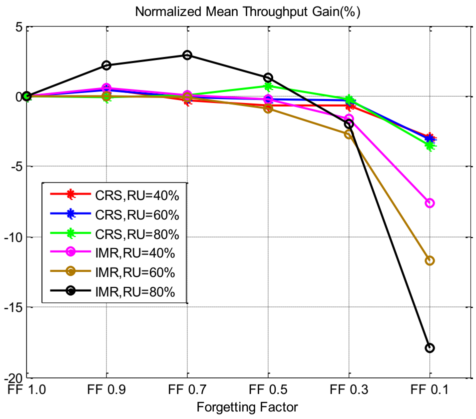

Fig.6. Normalized Mean Throughput Gain

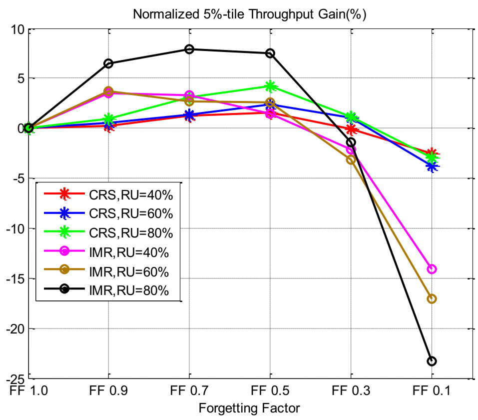

Fig.7. Normalized 5%-tile Throughput Gain

In order to illustrate plain performance of the proposed interference averaging scheme, we turn off OLLA for test case 1-4. Specific configurations for test case 1-4 are listed in Table. II. Fig. 4 and Fig. 5 show the Average Spectrum Efficiency (SE) and Cell-edge Spectrum Efficiency, respectively. From Fig. 4 and Fig. 5, it can be seen that without OLLA, doing interference averaging can bring significant gains for both full buffer and FTP traffic model, based on both CRS and IMR. It can also be observed that, compared to full buffer traffic cases, higher gains are obtained for FTP traffic cases. The main reason is that the interference fluctuation in network bonds to traffic intensively, thus dynamic entry-and-departure of users in FTP cases causes interference level changes rapidly, which is more beneficial for interference averaging. We can also observe that doing interference averaging brings higher gain for cell-edge user performance than average user performance. This is reasonable for cell edge users always suffer much more serious interference than cell center users, especially when transmission mode 8 is used.

Fig. 6 and Fig. 7 show the performance of interference averaging working with OLLA, where the OLLA step size is set as $0.5dB$. Different forgetting factors are used for both CRS and IMR based schemes under different FTP traffic load. Remember that forgetting factor 0 means no interference averaging. The traffic load is characterized by Resource Utilization (RU), which is defined as the average ratio of allocated PRBs to total PRBs. It can be seen that when OLLA is on, the performance gain of interference averaging is diminished; however, it can still obtain steady gain when FTP load is high. This is because that when load is low, OLLA can efficiently handle the fluctuation of interference, instead, using interference averaging may harm the convergence of OLLA, whereas when high load case, OLLA alone can't perfectly handle the intensive interference variation, thus using interference averaging can enhance the systemperformance.

V. CONCLUSION

In this paper, we evaluate an interference averaging scheme to handle the CQI mismatch problem caused by rapid interference fluctuation in Link Adaptation process. By intensely system simulation in a 3GPP macro case 1 scenario with transmission mode 8, it has shown that the proposed interference averaging scheme can obtain significant gains for both full buffer cases and FTP traffic cases when there is no OLLA function. When working together with OLLA, we also see from the simulation results that, with proper selection of the interference forgetting factor, the proposed scheme can enhance the system performance steadily, especially when the traffic load in network is high.

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REFERENCES

[1] D. Astely, E. Dahlman, A. Furuskär, Y. Jading, M. Lindström, and S. Parkvall, "LTE: The evolution of mobile broadband," *IEEE Commun. Mag.*, vol. 47, no. 4, pp. 44 – 50, Apr. 2009.

[2] K. I. Pedersen, T. E. Kolding, F. Frederiksen, I. Z. Kovacs, D. Laselva, and P. E. Mogensen, "An overview of downlink radio resource manage-ment for UTRAN long-term evolution," *IEEE Commun. Mag.*, vol. 47, no. 7, pp. 86 – 93, July 2009.

[3] G. Boudreau, J. Panicker, N. Guo, R. Chang, N. Wang, and S. Vrzic, "Interference coordination and cancellation for 4G networks," *IEEE Commun. Mag.*, vol. 47, no. 4, pp. 74–81, Apr. 2009.

[4] M. Assaad, "Optimal Fractional Frequency Reuse (FFR) in Multi-cellular OFDMA System", *IEEE 68th Vehicular Technology Confer-rence, (VTC-Fall)*, vol., no., pp.1-5, Sep. 2008.

[5] D. Kimura, Y. Harada, H. Seki. "De-Centralized Dynamic ICIC using
X2 Interfaces for Downlink LTE Systems," In Proc. VTC 2011 Spring. Budapest. May 2011, pp. 1-5.

[6] H. Zhuang, Z. Luo, M. Pikhletsky, S. Dmitri, F. Khafizov, "Traffic-based dynamic spectrum management for inter-cell interference coordination in LTE networks", *in Proc. IEEE Global Communications Conference (GLOBECOM),* pp. 5062 – 5067, Dec. 3-7, 2012.

[7] Sediq, Akram Bin, Rainer Schoenen, and Zhijun Chao. "A novel distributed inter-cell interference coordination scheme based on projected subgradient and network flow optimization." *Personal Indoor and Mobile Radio Communications (PIMRC), 2011 IEEE 22nd International Symposium on*. IEEE, 2011.

[8] Wang, Jun, et al. "Load Balance based Dynamic Inter-Cell Interference Coordination for Relay Enhanced Cellular Network." *Vehicular Technology Conference (VTC Spring), 2012 IEEE 75th*. IEEE, 2012, pp. 1-5.

[9] R. Bosisio and U. Spagnolini, "Interference Coordination Vs. Interference Randomization in Multicell 3GPP LTE System," IEEE WCNC, pp. 824-829, Mar. 2008.

[10] Muller, A., and Philipp Frank. "Cooperative interference prediction for enhanced link adaptation in the 3GPP LTE uplink." *Vehicular Technology Conference (VTC 2010-Spring), 2010 IEEE 71st*. IEEE, 2010, pp. 1–5.

[11] Pedersen, Klaus I., et al. "Frequency domain scheduling for OFDMA with limited and noisy channel feedback." *Vehicular Technology Conference, 2007. VTC-2007 Fall. 2007 IEEE 66th*. IEEE, 2007, pp. 1792–1796.